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राष्ट्रीय भवन निर्माण मानक 2026
NATIONAL BUILDING CONSTRUCTION STANDARDS 2026

खण्ड 1 / VOLUME 1

मानकः पथप्रदर्शकः

भारतीय मानक ब्यूरो
BUREAU OF INDIAN STANDARDS

राष्ट्रीय भवन निर्माण मानक 2026

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National Building Code Sectional Committee, CED 46

FOREWORD

The Planning Commission, soon after the Third Five Year Plan, decided that the whole gamut of operations involved in construction, such as administrative, organizational, financial and technical aspects, be studied in depth. For this study, a Panel of Experts was appointed in 1965 by the Planning Commission and its recommendations are available in the 'Report on Economies in Construction Costs', published in 1968.

This study resulted in a recommendation that a National Building Code (NBC) be prepared to unify the building regulations throughout the country for use by government departments, municipal bodies and other construction agencies. The then Indian Standards Institution (now Bureau of Indian Standards) was entrusted by the Planning Commission with the responsibility of preparation of the National Building Code. Accordingly, Bureau of Indian Standard (then ISI) brought out first NBC in 1970. The same was subsequently revised in 1983, 2005 and 2016.

The third revision of NBC was published in 2016. This was a result of large scale changes in the building construction activities, such as change in nature of occupancies with prevalence of high rises and mixed occupancies, greater dependence and complicated nature of building services, development of new/innovative construction materials and technologies, greater need for preservation of environment and recognition of need for planned management of existing buildings and built environment, resulting in a paradigm shift in building construction scenario. A comprehensive revision was therefore brought out to address all these aspects and also reflect the changes incorporated in various standards which were considerably utilized in the 2016 revision.

Since the last revision, many things have changed, including per capita land availability, growing infrastructure requirements, socio-economic conditions, and technological advancements, to name a few. Hence, in these changing times, the requirements for development have also changed. The faster economic growth that India needs at present is possible if the ongoing reforms help the infrastructure sector to operate efficiently and compete cost-effectively by utilizing the available land optimally and reducing excessive compliance burden.

Based on the current realities, socio-economic scenario existing in the country, and the requirement of rapid urbanization and income growth, the total building stock is projected to increase exponentially in the coming years. Further, construction and infrastructure development are poised to determine the speed and scale of progress across every sector. These enable mobility, clean water, energy, and urban growth, which all directly contribute and shape economic opportunity and quality of life.

Construction, being a state subject, the contribution of the state government and local authorities are significant in infrastructure growth of the country. However, the land resources are limited. Maximum utilization of land resources is of prime importance in the current scenario. Further, India has come a long way from the time of first publication of the building code to the present day status. The requirements of standards and codes have also changed from a prescriptive regime, where the States and Local Authorities required hand holding, to now a more performance oriented outlook giving ample scope for innovation and decision making. The knowledge base in the country has also increased exponentially with exposure to the global best practices and adapting them to suit the country specific needs. Consequently, the contents of the current version, in which this publication has been renamed as the National Building Construction Standards (NBCS), have undergone substantial changes from those of the earlier NBC.

Thus in the current (fifth) version, this NBCS has been restructured substantially with a more safety and performance oriented approach rather than a prescriptive one. This includes leaving the adminstrative provisions land use requirements, like floor area ratio (FAR), development control rules (DCRs) and parking norms, which falls under the domain of local and state government, from the ambit of this NBCS. Open spaces, ground coverage, space utilization and land use related matters are primarily the state subject, and as such, these items have also not been included in this NBCS. As regards, other aspects covering construction practices, landscaping, sustainability aspects of built environment and asset and facility management, which are not directly linked to the design requirements vis-a-vis safety of the built environment have been taken out of this NBCS and will be published separately as guidelines of good practices mainly addressing management, sustainability, maintenance and practices to improve the working and efficiency of the built environment. The portions covering building materials, structural design aspects, building services and plumbing services are retained as part of this NBCS.

The fire and life safety aspect, a state subject, but due to its importance towards the safety and well-being of the occupants as well as the common public, has also been included in this NBCS.

The current version of this NBCS with the restructuring is as follows:

a) The current version consists of

Foreword

Part A	Introduction
Part B	Building Materials
Part C	Structural Design
Part D	Building Services
Part E	Plumbing Services
Part F	Fire and Life Safety

Index of Terms

b) The other Parts of NBC 2016, namely Part 7 'Construction Management, Practices and Safety'; Part 10 'Landscape Development, Signs and Outdoor Display Structures'; Part 11 'Approach to Sustainability'; and Part 12 'Asset and Facility Management', have also been taken out of this NBCS. However, these will be brought out separately as special publication in the form of handbooks of good practices.

Towards making this NBCS more comprehensive, forward-looking and easy to implement, various technical aspects have been introduced apart from updating the existing provisions. The key points that have been addressed in this version of NBCS are:

1) Innovative building materials.
2) Review of blast-resistant design of buildings.
3) Detailed review of ground improvement techniques and inclusion of combined piled-raft foundations.
4) Inclusion of design parameters of new and imported timber species.
5) Construction methodologies using various bamboo species.
6) Inclusion of earthquake resistant systems of masonry.
7) Inclusion of the structural safety aspect of tall concrete buildings.
8) Updating the provisions on structural steel based design; and inclusion of a new section on composite construction.
9) Detailed provisions on glazing systems covering therein bullet-resistant glass and blast-resistant glass.
10) Charging infrastructure for electric vehicles.
11) Inclusion of provisions relating to renewable energy sources for buildings, such as rooftop solar photovoltaic (PV) systems, building-integrated photovoltaic (BIPV) systems, and solar water heating systems.
12) Inclusion of new section on power-driven parking systems for vehicles in buildings.
13) Focus on water-efficient fixtures in buildings; bio-digesters and packaged sewage treatment plants or decentralized STPs.

Notwithstanding the above, the repeated onslaught of natural calamities such as earthquakes, cyclones, landslides, floods, faced by the country has brought home the ever-increasing need for a common guiding document to enable monitoring and implementation of sound technical provisions and comprehensive features built into such a document. This NBCS fulfills this need apart from bringing at one place comprehensive provisions relating to selection of building materials, resilient design principles, various building services and plumbing services, etc, all ensuring to follow a unified approach thereby promoting resource efficiency, environmental responsibility and long-term resilience. This NBCS also captures the global best practices and technological developments in setting a robust roadmap towards establishing a more efficient mechanism promoting ease of doing business.

As the regulation of land development and buildings is a State subject and is dealt by the States and local bodies such as urban (and rural) local bodies within their jurisdiction through building regulatory documents like building regulations, development control rules building byelaws, and fire regulations, this document is voluntary in nature and is non-binding. The implementation depends on adoption or adaptation by concerned parties or stipulations in a contract or by appropriate adoption by the concerned authorities.

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COMMITTEE COMPOSITION

National Building Code Sectional Committee, CED 46

Chairperson

Shri V. Suresh
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Kesavadasapuram, Thiruvananthapuram – 695004

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Central Public Works Department, New Delhi	Chief Engineer (CSQ) (Elect) Suptg Engr (CSQ) (Elect) (*Alternate*)
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Delhi Development Authority, New Delhi	SHRI SANJAY KUMAR KHARE SHRI NARENDER KUMAR GOEL (*Alternate*)
Directorate General Border Roads, New Delhi	REPRESENTATIVE
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Tata Consulting Engineers, Mumbai	Shri R. L. Dinesh
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The Institution of Engineers (India), Kolkata	Dr Binu Sukumar Dr A. Hemamathi (*Alternate*)

Panel for Loads, Forces and Effects, CED 46:P4

Organization	*Representative*(*s*)
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CSIR-Structural Engineering Research Centre, Chennai	Dr P. Harikrishna Dr Keerthana M. (*Alternate* I) Dr J. Prawin (*Alternate* II)
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Organization	*Representative*(*s*)
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Himachal Pradesh State Disaster Management Authority, Shimla	Representative
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Panel for Soils and Foundations, CED 46:P5

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Indian Association of Structural Engineers, New Delhi	SHRI SUSHIL K. DHAWAN DR ABHAY GUPTA (*Alternate* I) DR ANIL JOSEPH (*Alternate* II)
Indian Geotechnical Society, New Delhi	DR A. P. SINGH DR NEELIMA SATYAM (*Alternate* I) DR ADITYA SINGH (*Alternate* II)
Indian Institute of Technology Delhi, New Delhi	DR J. T. SHAHU DR BAPPADITYA MANNA (*Alternate*)
Larsen & Toubro Limited, Chennai	DR G. D. RAJU SHRI VISAKAN R. (*Alternate*)
Military Engineer Services, Engineer-in-Chief's Branch, Army HQ, New Delhi	SHRI AJAY KUMAR SINGH SHRI AMAN GARG (*Alternate*)
NTPC Ltd, New Delhi	SHRI MANI BHUSHAN SHRI DEVENDER SINGH (*Alternate*)
National Capital Region Transport Corporation, New Delhi	SHRI JITENDRA KUMAR
National Council for Cement and Building Materials, Ballabgarh	SHRI P. N. OJHA SHRI AMIT TRIVEDI (*Alternate*)
National Institute of Disaster Management, New Delhi	DR AMIR ALI KHAN
The Institution of Engineers (India), Kolkata	ER VIJAY SHANKAR DR ALOK KUMAR (*Alternate*)
In Personal Capacity (*H-105*, *Casagrand Aristo*, *No. 5*, *Noble Street*, *Alandur*, *Chennai – 600016*)	SHRI A. VIJAYARAMAN

Panel for Timber and Bamboo, CED 46:P6

Organization	*Representative*(*s*)
In Personal Capacity [*Pratap Nursery Lane*, *(Near Gurudwara Sahib)*, *Panditwari*, *Dehradun – 248007*]	SHRI K. S. PRUTHI **(*Convener*)**
Bamboo Society of India, Bengaluru	SHRI PUNATI SRIDHAR SHRI K. N. MURTHY (*Alternate*)

Organization	*Representative*(*s*)
Building Materials and Technology Promotion Council, New Delhi	DR SHAILESH KR AGRAWAL SHRI C. N. JHA (*Alternate*)
CEPT University, Ahmedabad	DR DHARA SHAH
CSIR-Central Building Research Institute, Roorkee	DR RAJESH KUMAR VERMA DR NEERAJ JAIN (*Alternate* I) SHRI PRASANTA KAR (*Alternate* II)
Central Public Works Department, New Delhi	SUPERINTENDING ENGINEER, DELHI CIRCLE-1 EXECUTIVE ENGINEER, L- DIV (*Alternate*)
Centre for Green Building Materials & Technology, Bengaluru	MS NEELAM MANJUNATH
Creative Design Consultants & Engineers Pvt Ltd, Greater Noida	SHRI AMAN DEEP
Forest Research Institute, Dehradun	SHRI RAJESH BHANDARI SHRI R. S. TOPWAL (*Alternate* I) SHRI ASHWATH HEGDE (*Alternate* II)
Forum of Scientists, Engineers and Technologists, Kolkata	SHRI RABI MUKHOPADHYAY DR PARTHASARATHI MUKHOPADHYAY (*Alternate*)
Housing and Urban Development Corporation Ltd, New Delhi	DR DEEPAK BANSAL MS POOJA NANDY (*Alternate* I) SHRIMATI NIRMAL BATRA (*Alternate* II)
Indian Association of Structural Engineers, New Delhi	DR DULAL GOLDAR DR VISALAKSHI TALAKOKULA (*Alternate*)
Indian Institute of Technology Delhi, New Delhi	DR SURESH BHALLA
ICFRE – Institute of Wood Science and Technology, Bengaluru	SHRI ANAND NANDANWAR SHRI AMITAVA SIL (*Alternate* I) DR NARASIMHAMURTHY (*Alternate* II)
Military Engineer Services, Engineer-in-Chief's Branch, Army HQ, New Delhi	SHRIMATI S. GAYATRI MUKHERJEE SHRI SHEKHAR GUPTA (*Alternate*)
Mutha Industries Pvt Ltd, Mumbai	SHRI ANIL MUTHA SHRI NEERAJ MUTHA (*Alternate* I) SHRI SUDIP CHAKRABORTY (*Alternate* II)
North East Centre for Technology Application and Reach, Shillong	SHRI KRISHNA KUMAR MS LYNGKSIAR KHONGWIR (*Alternate*)
The Institution of Engineers (India), Kolkata	SHRI MANOJ KUMAR SINGH ER KUMAR ARVIND (*Alternate*)
Windsor Wood (India) Pvt Ltd, Mumbai	SHRI PRAKASH NARMADASHANKAR SUTHAR
Wonder Grass Initiative Pvt Ltd, Nagpur	SHRI VAIBHAV KALEY
In Personal Capacity (*103/II*, *Vasant Vihar*, *P. O. New Forest*, *Dehradun – 248006*)	SHRI S. S. RAJPUT

Panel for Masonry, CED 46:P7

Organization	*Representative*(*s*)
In Personal Capacity (*131*, *Sector11D*, *Faridabad — 121006*)	SHRI V. V. ARORA (***Convener***)
Adlakha Associates Pvt Ltd, New Delhi	SHRI P. K. ADLAKHA SHRI V. K. SETHI (*Alternate*)

Organization	*Representative*(*s*)
Association of Consulting Civil Engineers (India), Bengaluru	SHRI UMESH B. RAO DR RAGHUNATH S. (*Alternate*)
Bhabha Atomic Research Centre, Trombay	SHRI K. SRINIVAS SHRI H. E. IYER (*Alternate*)
Building Materials & Technology Promotion Council, New Delhi	DR SHAILESH KR AGRAWAL SHRI PANKAJ GUPTA (*Alternate*)
CSIR-Central Building Research Institute, Roorkee	DR AJAY CHOURASIA MS HINA GUPTA GHOSH (*Alternate*)
CSIR-Structural Engineering Research Centre, Chennai	DR A. RAMACHANDRA MURTHY DR S. R. BALASUBRAMANIAN (*Alternate* I) SHRI FARVAZE AHMED A. K. (*Alternate* II)
Central Public Works Department, New Delhi	SUPERINTENDING ENGINEER & PROJECT DIRECTOR, DPC-1 EE CUM SM (CIVIL)-1 (*Alternate*)
Indian Association of Structural Engineers, New Delhi	DR DEEPAK BANSAL MS SANGEETA WIJ (*Alternate*)
Indian Institute of Science, Bengaluru	DR B. V. VENKATARAMA REDDY DR K. S. NANJUNDA RAO (*Alternate*)
Indian Institute of Technology Delhi, New Delhi	DR DIPTI RANJAN SAHOO DR SRINIVAS MOGILI (*Alternate*)
Indian Institute of Technology Guwahati, Guwahati	DR HEMANT B. KAUSHIK
Indian Institute of Technology Hyderabad, Kandi	DR KOLLURU V. L. SUBRAMANIAM
Indian Institute of Technology Madras, Chennai	DR ARUN MENON
Indian Institute of Technology Patna, Patna	DR VAIBHAV SINGHAL
Military Engineer Services, Engineer-in-Chief's Branch, Army HQ, New Delhi	SHRI SAMEER PANDEY SHRI M. V. SHANKAR (*Alternate*)
National Council for Cement and Building Materials, Ballabgarh	SHRI AMIT TRIVEDI SHRI AMIT PRAKASH (*Alternate*)
The Institution of Engineers (India), Kolkata	SHRI SATYA PRAKASH SHRI MASARRAT NOOR KHAN (*Alternate*)

Panel for Plain, Reinforced and Prestressed Concrete, CED 46:P8

Organization	*Representative*(*s*)
In Personal Capacity (*Grace Villa*, *Kadamankulam PO*, *Thiruvalla – 689583*)	SHRI JOSE KURIAN **(*Convener*)**
Association of Consulting Civil Engineers (India), Bengaluru	SHRI M. S. SUDHARSHAN
Central Public Works Department, New Delhi	CHIEF ENGINEER (CENTRAL VISTA PZ-1) SE, CPVC-5 (*Alternate*)
Creative Design Consultants & Engineers Pvt Ltd, Greater Noida	SHRI AMAN DEEP
CSIR-Central Building Research Institute, Roorkee	DR S. K. SINGH SHRI SUBASH CHANDRA BOSE GURRAM (*Alternate* I) SHRI GOVIND GAURAV (*Alternate* II)
CSIR-Central Road Research Institute, New Delhi	REPRESENTATIVE

Organization	*Representative*(*s*)
CSIR-Structural Engineering Research Centre, Chennai	DR B. H. BHARATKUMAR DR S. BHASKAR (*Alternate* I) SHRI THONDAMON V. (*Alternate* II)
Engineers India Limited, New Delhi	DR SUDIP PAUL MS RIYA DAS (*Alternate*)
Freyssinet Prestressed Concrete Company Limited, Mumbai	SHRI P. Y. MANJURE
Hindustan Construction Company Limited, Mumbai	SHRI SHAILESH THATTE
Indian Association of Structural Engineers, New Delhi	SHRI RAJEEV GOEL DR ABHAY GUPTA (*Alternate*)
Indian Concrete Institute, Chennai	SHRI A. K. JAIN SHRI K. P. ABRAHAM (*Alternate*)
Indian Institute of Technology Madras, Chennai	DR C. V. R. MURTY DR AMLAN K. SENGUPTA
Larsen & Toubro Limited, Chennai	SHRI V. SADASIVAM SHRI STHALADIPTI SAHA (*Alternate* I) SHRI J. RAJESH (*Alternate* II)
Military Engineer Services, Engineer-in-Chief's Branch, Army HQ, New Delhi	SHRI PRAMOD KUMAR SINGH SHRI NIRAJ KUMAR (*Alternate*)
Ministry of Road Transport and Highways, New Delhi	CHIEF ENGINEER, STANDARDS & RESEARCH (BRIDGES)
National Council for Cement and Building Materials, Ballabgarh	SHRI P. N. OJHA DR BRIJESH SINGH (*Alternate*)
Research, Designs and Standards Organization (Ministry of Railways), Lucknow	SHRI V. K. PANDEY SHRI SANDEEP SINGH (*Alternate*)
Tandon Consultants Pvt Ltd, New Delhi	SHRI MAHESH TANDON
The Institution of Engineers (India), Kolkata	SHRI MANOJ KUMAR SINGH DR M. A. CHAKRABARTI (*Alternate*)
VMS Consultants Private Limited, Mumbai	MS ALPA R. SHETH
In Personal Capacity (*131, Sector 11D, Faridabad – 121006*)	SHRI V. V. ARORA
In Personal Capacity (*M1F1 VGN Minerva Apartments*, *Guruswamy Road*, *Nolambur*, *Chennai – 600095*)	DR C. RAJKUMAR

Panel for Steel, CED 46:P9

Organization	*Representative*(*s*)
In Personal Capacity (*II*, *2A*, *Rani Meyyammai Towers*, *MRC Nagar*, *R A Puram*, *Chennai – 600028*)	DR V. KALYANARAMAN (***Convener***)
Association of Consulting Civil Engineers (India), Bengaluru	SHRI MANOJ KAWALKAR SHRI RAJKUMAR KACHARLA (*Alternate*)

Organization	*Representative*(*s*)
Central Public Works Department, New Delhi	CHIEF ENGINEER & ED, (LLT DELHI) ZONE EE CUM SM (CIVIL)-1 (*Alternate*)
Creative Design Consultants & Engineers Pvt Ltd, Greater Noida	SHRI AMAN DEEP
CSIR-Central Building Research Institute, Roorkee	DR AJAY CHOURASIA DR R. SIVA CHIDAMBARAM (*Alternate* I) DR CHANCHAL SONKAR (*Alternate* II)
CSIR-Structural Engineering Research Centre, Chennai	DR G. S. PALANI DR NAPA PRASAD RAO (*Alternate* I) DR M. SARVANAN (*Alternate* II)
Engineers India Limited, New Delhi	SHRIMATI PAPIA MANDAL SHRI CHANDRA SHEKHAR SHARMA (*Alternate* I) SHRI SAPTADIP SARKAR (*Alternate* II)
Indian Association of Structural Engineers, New Delhi	DR HARSHAVARDHAN SUBBARAO DR ABHAY GUPTA (*Alternate*)
Indian Institute of Technology Madras, Chennai	DR S. ARUL JAYACHANDRAN DR P. S. LAKSHMI PRIYA (*Alternate*)
Institute for Steel Development and Growth, Kolkata	SHRI PYDI LAKSHMANA RAO SHRI ARIJIT GUHA (*Alternate* I) SHRI M. M. GHOSH (*Alternate* II)
Interarch Building Products Pvt Ltd, Noida	SHRI GAUTAM SURI SHRI NAVAZ MANIKKAL (*Alternate* I) SHRI SUNIL PULIKKAL (*Alternate* II)
Jindal Steel and Power Limited, New Delhi	SHRI SANJAY NANDANWAR SHRI BIJU MAHIMA (*Alternate*)
Kirby Building Systems India Limited, New Delhi	DR PADMAJA GOKARAJU SHRI VENUMADHAVA REDDY (*Alternate*)
Larsen & Toubro Limited, Chennai	SHRI T. VENKATESH RAO
MECON Limited, Ranchi	SHRI A. KRISHNA RAO SHRI C. KRISHNAM RAJU (*Alternate*)
Military Engineer Services, Engineer-in-Chief's Branch, Army HQ, New Delhi	SHRI M. V. SHANKAR BRIG Y. K. AHUJA (*Alternate*)
PEB Manufacturers' Association, Navi Mumbai	SHRI MANISH GARG
Research, Designs and Standards Organization (Ministry of Railways), Lucknow	SHRI RAJESH KUMAR SRIVASTAVA SHRI SRIJAN TRIPATHI (*Alternate*)
Tata Steel Ltd, Jamshedpur	SHRI HARIHARAPUTHIRAN H.
The Institution of Engineers (India), Kolkata	DR S. SENTHIL SELVAN DR P. R. KANNAN RAJKUMAR (*Alternate*)

Panel for Prefabrication and Systems Buildings, CED 46:P10

Organization	*Representative*(*s*)
Larsen & Toubro Ltd, Chennai	SHRI K. SENOU (***Convener***)

Organization	*Representative*(*s*)
Adlakha Associates Pvt Ltd, New Delhi	Shri P. K. Adlakha
Anna University, Chennai	Dr K. P. Jaya
B.G. Shirke Construction Technology Pvt Ltd, Pune	Shri Yogesh P. Kajale Col Sanjay M. Adsar (*Alternate*)
Building Materials and Technology Promotion Council, New Delhi	Dr Shailesh Kumar Agrawal Shri C. N. Jha (*Alternate*)
Central Public Works Department, New Delhi	Chief Engineer cum ED, RPZ EE cum SM (civil)-1 (*Alternate*)
Creative Design Consultants & Engineers Pvt Ltd, Greater Noida	Shri Aman Deep
CSIR-Central Building Research Institute, Roorkee	Dr Ajay Chaurasia Shri Ashish Kapoor (*Alternate* I) Shri Siddharth Behera (*Alternate* II)
CSIR-Structural Engineering Research Centre, Chennai	Dr J. Prabakar Dr K. N. Lakshmi Kandhan (*Alternate* I) Shri A. M. Sarath (*Alternate* II)
Indian Institute of Technology Hyderabad, Kandi	Dr Suriya Prakash S.
Indian Institute of Technology Madras, Chennai	Dr Radhakrishna G. Pillai Dr Nikhil Bugalia (*Alternate*)
Indian Association of Structural Engineers, New Delhi	Shri Mahesh Tandon Shri Alok Bhowmick (*Alternate*)
Innovela Building Solutions, Pune	Shri Saurabh Purandare
Interarch Building Products Pvt Ltd, Noida	Shri Gautam Suri Shri Manish Kumar Garg (*Alternate*)
Kirby Building Systems India Ltd, Hyderabad	Dr Padmaja Gokaraju Shri G. Venumadhava Reddy (*Alternate*)
Larsen & Toubro Ltd, Chennai	Shri C. K. Somaraju Shri Amit Barde (*Alternate* I) Shri Aparup Biswal (*Alternate* II)
Lloyd Insulations (India) Ltd, New Delhi	Shri Ajay Singh Shri Jitendra Kumar Jain (*Alternate*)
Military Engineer Services, Engineer-in-Chief's Branch, Army HQ, New Delhi	Brig Y. K. Ahuja Col Deepak Singh (*Alternate*)
National Council for Cement and Building Materials, Ballabgarh	Shri Amit Trivedi Dr B. P. Ranga Rao (*Alternate*)
PEB Manufacturers' Association, Navi Mumbai	REPRESENTATIVE
Precast India, Pune	Shri Ajit Vasant Bhate Shri Kapilesh Bhate (*Alternate* I) Dr K. Shantharaju (*Alternate* II)
Precision Precast Solutions, Pune	Shri Dhananjay Bhosale Shri Rajendra R. Kulkarni (*Alternate*)
Tata Bluescope Steel Ltd, Pune	Shri Krishnakant Rane

Organization	*Representative*(*s*)
The Indian Institute of Architects, Mumbai	SHRI CHAMARTHI RAJENDRA RAJU SHRI KURIAN GEORGE (*Alternate* I) SHRIMATI VIBHA SHRIVASTAVA (*Alternate* II)
The Institution of Engineers (India), Kolkata	DR R. K. BHANDARI SHRI HEMANT S. VADALKAR (*Alternate*)
TRC Engineering India Pvt Ltd, Bengaluru	SHRI ARJUN MUDAMBI
In Personal Capacity (*132*, *Marigold*, *Serene County*, *Telecom Nagar*, *Gachibowli – 500032*)	SHRI M. P. NAIDU
In Personal Capacity (*303*, *Tower 4*, *Lotus Panache*, *Sector 110*, *Noida – 201304*)	SHRI J. K. PRASAD

Panel for Lighting and Natural Ventilation, CED 46:P12

Organization	*Representative*(*s*)
CEPT University, Ahmedabad	DR RAJAN RAWAL (***Convener***)
AB Initio, Thane	SHRI SHIRISH DESHPANDE
Ashok B Lall Architects, New Delhi	SHRI ASHOK B. LALL MS GIRISHA SETHI (*Alternate*)
Bureau of Energy Efficiency, Ministry of Power, New Delhi	MS PRAVATANALINI SAMAL SHRI MAYANKRAJ PRAJAPAT (*Alternate*)
Central Public Works Department, New Delhi	CHIEF ENGINEER (T&R)-II SE (T)-ELECT (*Alternate*)
CEPT University, Ahmedabad	DR YASH SHUKLA DR MINU AGARWAL (*Alternate*)
CSIR-Central Building Research Institute, Roorkee	SHRI NAGESH BABU BALAM SHRI NAVEEN NISHANT (*Alternate* I) SHRI ANUP KUMAR PRASAD (*Alternate* II)
CSIR-National Physical Laboratory, New Delhi	DR PARAG SHARMA SHRI V. K. JAISWAL (*Alternate*)
Directorate General Factory Advice Service and Labour Institutes, Mumbai	SHRI VIPUL MISHRA SHRI SOURISH DATTA CHOUDHURY (*Alternate*)
Edspring Technologies, Noida	SHRI ANKUR KHANDELWAL
Indian Institute of Technology Delhi, New Delhi	DR DIBAKAR RAKSHIT
Indian Institute of Technology Madras, Chennai	DR BENNY RAPHAEL DR SHANMUGARAJ S. (*Alternate*)
Indian Institute of Technology Roorkee, Roorkee	DR E. RAJASEKAR
Indian Society for Lighting Engineers, New Delhi	DR PRAKASH BARJATIA DR GIRJA SHANKAR (*Alternate* I) DR S. M. ALI (*Alternate* II)
Kaleidoscope, Noida	SHRI AMOR KOOL
Larsen & Toubro Ltd (Sustainability Group), Chennai	DR S. RAJKUMAR
Military Engineer Services, Engineer-in-Chief's Branch, Army HQ, New Delhi	SHRI V. K. TIWARI SHRI H. K. GUPTA (*Alternate*)

Organization	*Representative*(*s*)
Ministry of New and Renewable Energy, New Delhi	DR A. K. TRIPATHI SHRI H. C. BORAH (*Alternate*)
School of Planning and Architecture, New Delhi	DR V. K. PAUL DR ANIL DEWAN (*Alternate*)
Signify Innovations India Ltd, Hyderabad	SHRI NITISH POONIA SHRI SHRIKANT DATTATREYA PHANSE (*Alternate* I) MS MEGHA SONI (*Alternate* II)
Space Design Consultants, New Delhi	DR VINOD KUMAR GUPTA
The Indian Institute of Architects, Mumbai	SHRI GYANENDRA SINGH SHEKHAWAT MS RANEE VEDAMUTHU (*Alternate* I) SHRIMATI LEENA NIMBALKAR (*Alternate* II)
The Institution of Engineers (India), Kolkata	SHRI RAM NIWAS RAJPOOT
In Personal Capacity (*QRG Towers*, *2D*, *Sec - 126*, *Expressway Noida – 201304*)	SHRIMATI SUDHESHNA MUKHOPADHYAY

Panel for Electrical Installations, CED 46:P13

Organization	*Representative*(*s*)
In Personal Capacity (*C-20*, *Sector 47*, *Noida – 201301*)	SHRI N. NAGARAJAN **(*Convener*)**
Aeon Consultants, New Delhi	SHRI PUNEET GUPTA SHRI PRAVESH KUMAR PUNDIR (*Alternate*)
Bureau of Energy Efficiency, New Delhi	MS PRAVATANALINI SAMAL SHRI PANKAJ SHARMA (*Alternate*)
Cape Electric Pvt Ltd, Kanchipuram	SHRI S. GOPA KUMAR SHRI NANDU GOPAN (*Alternate*)
Central Electricity Authority, New Delhi	SHRI R. K. VERMA SHRI A. K. RAJPUT (*Alternate*)
Central Public Works Department, New Delhi	CHIEF ENGINEER CSQ (ELECT) SUPERINTENDING ENGINEER (ELECT), CSQ(E) (*Alternate*)
Chief Electrical Inspectorate, Govt of Tamil Nadu, Chennai	SHRI P. PALANI SHRI V. RAMAKRISHNAN (*Alternate*)
DEHN India Pvt Ltd, Gurugram	SHRI SAMIR SHANKAR SHRI MANU MUKUNDAN (*Alternate*)
Delhi Metro Rail Corporation, New Delhi	SHRI DEEPAK KUMAR GUPTA SHRI RAJEEV SAXENA (*Alternate*)
Energy Efficiency Services Limited, New Delhi	SHRI ASHISH SHARMA
Engineers India Ltd, New Delhi	SHRI HARISH KUMAR (*Alternate*)
Forum of Construction Utility Services, Bengaluru	SHRI MAXIM NORBET PINTO
International Copper Alliance, Mumbai	SHRI AMOL KALSEKAR SHRI MANAS KUNDU (*Alternate*)

Organization	*Representative*(*s*)
Larsen & Toubro Ltd, Chennai	SHRI D. MAHESWARAN SHRI K. K. JEMBU KAILAS (*Alternate*)
Maple Engineering Design Services, Bengaluru	SHRI B. S. ASWATHNARAYAN SHRI PRASANNA KUMAR (*Alternate*)
Military Engineer Services, Engineer-in-Chief's Branch, Army HQ, New Delhi	SHRI VIMAL KUMAR TIWARI SHRI ARVIND KUMAR (*Alternate*)
Ministry of New and Renewable Energy, New Delhi	SHRI H. R. KHAN SHRI G. UPADHYAY (*Alternate*)
National Federation of Engineers for Electrical Safety, Chennai	SHRI S. APPAVOO SHRI ABHISHEK SINGH (*Alternate*)
OBO Bettermann, Chennai	DR K. JANAKI RAMAN SHRI ARUL PRAKASH (*Alternate*)
Proion Consultants Private Limited, New Delhi	SHRIMATI SHRUTI GOEL
Public Works Department (Electrical Division), Govt of Maharashtra, Mumbai	SHRI HEMANT SALI
Schneider Electric India Pvt Ltd, Gurugram	SHRI C. S. KORE SHRI DEBDAS GOSWAMI (*Alternate*)
Siemens Ltd, Chennai	SHRI VIJAY WANWE
Solar Energy Corporation of India, New Delhi	SHRI C. K. SINGH
Tata Motors Ltd, Mumbai	SHRI SENTHILNATHAN THANGAVELU
The Institution of Engineers (India), Kolkata	DR G. MADHUSUDANAN DR S. SENTHILKUMAR (*Alternate*)
In Personal Capacity (*Cedar 102, SJR Park Vista Aptts, Haralur Road, Ambalipura, Bengaluru – 560012*)	SHRI J. N. BHAVANI PRASAD
In Personal Capacity (*J-403*, *Second Floor*, *New Rajinder Nagar*, *New Delhi – 110060*)	SHRI CHAITANYA KUMAR VARMA

Panel for Air Conditioning, Heating and Mechanical Ventilation, CED 46:P14

Organization	*Representative*(*s*)
Indian Society of Heating, Refrigerating and Air Conditioning Engineers, New Delhi	SHRI ASHISH RAKHEJA **(*Convener*)**
AEON Integrated Building Design Consultants LLP, Noida	SHRI SAURABH GOYEL SHRI ANURAG JOSHI (*Alternate*)
ASHRAE India Chapter, New Delhi	SHRI INDRAJIT BHATTACHARYA
Blowtech Air Devices Pvt Ltd, Noida	SHRI SUSHIL K. CHOUDHURY
Blue Star Limited, Chennai	SHRI B. THIAGARAJAN SHRI SRINIVAS REDDY (*Alternate*)
Bureau of Energy Efficiency, New Delhi	SHRI SAURABH DIDDI SHRI PANKAJ SHARMA (*Alternate*)

Organization	*Representative*(*s*)
Caire Consult, Greater Noida	SHRI ANKIT JAIN
Camfil India Pvt Ltd, Gurugram	SHRI ANIL CHOPRA
Carrier Air-conditioning and Refrigeration Ltd, Gurugram	SHRI BIMAL TANDON
CSIR-Central Building Research Institute, Roorkee	DR SHORAB JAIN DR TABISH ALAM (*Alternate* I) DR CHANDAN SWAROOP MEENA (*Alternate* II)
Central Public Works Department, New Delhi	CHIEF ENGINEER, CSQ (ELECT) SE (ELECT) CSQ (E) (*Alternate*)
CEPT University, Ahmedabad	DR RAJAN RAWAL DR YASH SHUKLA (*Alternate*)
Climaveneta Climate Technologies (P) Ltd, Bengaluru	SHRI ANIL DEV SHRI NANTHAGOPALAN T. K. (*Alternate* I) SHRI AKSHAY DEV (*Alternate* II)
Comfort Care System Pvt Ltd, New Delhi	SHRI YOGESH MALHOTRA
Daikin Air-conditioning India Pvt Ltd, Gurgram	SHRI KANWALJEET JAWA SHRI SANJAY GOYAL (*Alternate* I) SHRI GAURAV MEHTANI (*Alternate* II)
Delhi Fire Services, Govt of NCT of Delhi, New Delhi	DIRECTOR SHRI MUKESH VERMA (*Alternate*)
Delhi Metro Rail Corporation, New Delhi	SHRI ASHOK TEWARI SHRI RAJESH JAIN (*Alternate*)
Eskayem Consultants Pvt Ltd, Mumbai	SHRI GOUTHAM PITCHIKALA
Forum of Construction Utility Services, Bengaluru	SHRI K. D. SINGH SHRI RAMCHANDAR RAJU ADDHIPALLI (*Alternate* I) SHRI KAPIL KAPUR (*Alternate* II)
Indian Institute of Technology Delhi, New Delhi	DR MUKESH KHARE
Indian Society for Heating, Refrigeration & Air-Conditioning Engineers, New Delhi	SHRI K. RAMACHANDRAN SHRIMATI NIVEDITA JADHAV (*Alternate*)
International Ground Source Heat Pump Association, India Chapter, New Delhi	SHRI RICHIE MITTAL SHRI MADHUSUDHAN RAPOLE (*Alternate*)
Kanwal Industries Corporation, Noida	SHRI PAWANDEEP SINGH SHRI JAIVEER SINGH (*Alternate*)
Kirloskar Chillers Pvt Ltd, Pune	SHRI AVINASH MANJUL SHRI GAURANG DABHOLKAR (*Alternate* I) SHRI AMEY MAJGAONKAR (*Alternate* II)
Malaviya National Institute of Technology, Jaipur	DR JYOTIRMAY MATHUR
Military Engineer Services, Engineer-in-Chief's Branch, Army HQ, New Delhi	SHRI H. K. GUPTA SHRI ARVIND KUMAR (*Alternate*)
Proion Consultants Private Limited, New Delhi	SHRI SANDEEP GOEL
Schneider Electric India Pvt Ltd, Gurgram	SHRI HIMANSHU NIGAM

Organization	*Representative*(*s*)
Shinryo Suvidha Engineers India Private Limited, Noida	Shri Ashok K. Virmani Shri Sanjay Mookerjee (*Alternate*)
Sterling India Consulting Engineers, New Delhi	Shri G. C. Modgil Ms Khushboo Modgil (*Alternate*)
The Institution of Engineers (India), Kolkata	Shri Pradeep Chaturvedi Shri Anirban Datta (*Alternate*)
The Chemours Company, Gurugram	Dr Avinash Shaligram Shri Vikas Mehta (*Alternate*)
UL India Pvt Ltd, Bengaluru	Shri V. Manjunath Shri Satish Kumar (*Alternate* I) Shrimati Pallavi Tripathi (*Alternate* II)
Voltas Limited, New Delhi	Shri Ashwani Sharma Shri Pankaj Goel (*Alternate*)
In Personal Capacity (*C-9*, *9511*, *Vasant Kunj*, *New Delhi – 110070*)	Dr R. S. Agarwal
In Personal Capacity (*E 203*, *Belaire*, *Golf Course Road*, *Gurugram – 122022*)	Shri Prabhat Goel
In Personal Capacity (*262*, *Solanipuram*, *Roorkee – 247667*)	Dr P. K. Bhargava

Panel for Acoustics, Sound Insulation and Noise Control, CED 46:P15

Organization	*Representative*(*s*)
Interarch Building Products Private Limited, Noida	Shri Gautam Suri **(*Convener*)**
All India Radio, New Delhi	Ms Anuradha Aggarwal Shri Rajesh Kumar (*Alternate*)
Central Public Works Department, New Delhi	Senior Architect (Adg Projects Delhi) Architect (Adg Projects Delhi) (*Alternate*)
CSIR-Central Building Research Institute, Roorkee	Shri Soraj Kumar Panigarhi Shri Anup Kumar Prasad (*Alternate* I) Shri Kanti Lal Solanki (*Alternate* II)
CSIR-National Physical Laboratory, New Delhi	Dr Naveen Garg Dr Chitra Gautam (*Alternate*)
Indian Institute of Science, Bengaluru	Dr M. L. Munjal
Indian Institute of Technology Kharagpur, Kharagpur	Dr A. R. Mohanty Dr Amarnath Reddy (*Alternate*)
Indian Institute of Technology Madras, Chennai	Dr P. Chandramouli Dr Abhijit Sarkar (*Alternate*)
Indian Institute of Technology Roorkee, Roorkee	Dr E. Rajasekar

Organization	*Representative*(*s*)
Military Engineer Services, E-in-C's Branch, Army HQ, New Delhi	Shri Sameer Pandey Shri Niraj Kumar (*Alternate*)
P. S. Subramanian Associates, Chennai	Dr S. Kandaswamy Dr P. Senthil Kumar (*Alternate*)
School of Planning and Architecture, New Delhi	Dr Shuvojit Sarkar
The Indian Institute of Architects, Mumbai	Shri B. Sudhir Shri Vikas Dubey (*Alternate* I) Shri Shital Prashant Nemane (*Alternate* II)
The Institution of Engineers (India), Kolkata	Shri P. K. Adlakha
In Personal Capacity (*H109/2*, *7th Avenue*, *Besant Nagar*, *Chennai – 600090*)	Dr S. Narayanan

Panel for Installation of Lifts, Escalators and Moving Walks, CED 46:P16

Organization	*Representative*(*s*)
TAK Consulting Pvt Ltd, Mumbai	Shri T. A. K. Mathews **(*Convener*)**
Central Public Works Department, New Delhi	Chief Engineer (T&R)-LL SE (T) - Elect (*Alternate*)
Chief Electrical Inspectorate, Govt of Tamil Nadu, Chennai	Shri G. Joseph Arockiadoss Shri P. Palani (*Alternate*)
Delhi Development Authority, New Delhi	Shri Sanjay Kumar Khare Shri K. P. Yadav (*Alternate*)
Delhi Fire Services, Govt of NCT of Delhi, New Delhi	Director
Directorate of Maharashtra Fire & Emergency Services, Mumbai	Shri Santosh Warick Shri Kiran Hatyal (*Alternate*)
ECE Industries Limited, Ghaziabad	Shri Amit Kachroo Shri Anurag Manglik (*Alternate*)
Elevator and Escalator Component Manufacturing Association of India (EECMAI), Chennai	Shri Harish A. Nakman Shri Abey George (*Alternate*)
Electrical Inspectorate, Govt of NCT of Delhi, New Delhi	Shri Mukesh Kumar Sharma Shri Jogender Singh (*Alternate*)
Forum of Construction Utility Services, Bengaluru	Shri V. Jagadish Kumar
Fujitec India Pvt Ltd, Chennai	Shri R. Rajesh Shri S. Manokar (*Alternate*)
Indian Electrical and Electronics Manufacturers' Association (Elevator Division), Mumbai	Shri P. K. Dixit Shri Rushad Divecha (*Alternate* I) Shri Uttam Kumar (*Alternate* II)

Organization	*Representative*(*s*)
Johnson Lifts Pvt Ltd, Chennai	Shri T. Subramanian Shri V. Karthikeyan (*Alternate* I) Shri Sachin More (*Alternate* II)
Kone Elevator India Limited, Chennai	Shri U. Viswanathan Shri Balaji K. (*Alternate*)
Military Engineer Services, Engineer-in- Chief's Branch, Army HQ, New Delhi	Shri H. K. Gupta Shri Arvind Kumar (*Alternate*)
NBCC (India) Ltd, New Delhi	Shir Ram Bachan Shri Tej Prakash Dhabhai (*Alternate*)
Otis Elevator Company (India) Limited, Bengaluru	Shri Abhijit Dandekar Shri Shrihari Vispute (*Alternate* I) Shri Praveena Siddaramanna (*Alternate* II)
Public Works Department, Govt of Maharashtra, Mumbai	Shri Sandeep A. Patil Shri Uday U. Dambe (*Alternate*)
Schindler India Pvt Limited, Mumbai	Shri Nimish Deshpande Shri Nitin Vithal Kadam (*Alternate*)
TAK Consulting Pvt Ltd, Mumbai	Shri Gaurav Ghag Ms Pranali Pawaskar (*Alternate*)
TK Elevator India Pvt Ltd, New Delhi	Shri Vishnu Parashar Shri Deepak Balani (*Alternate* I) Shri Sachin Agashe (*Alternate* II)
The Indian Institute of Architects, New Delhi	Shri Prakash Deshmukh Shri M. R. Kumarchandra (*Alternate* I) Ms Anagha Vishwas Kotkar (*Alternate* II)
The Institution of Engineers (India), Kolkata	Dr R. K. Dave
Wohr Parking Systems Pvt Ltd, Pune	Shri Sandeep Kulkarni Shri Vikas Pathak (*Alternate*)
In Personal Capacity (*43*, *Juhu Gaurav*, *Gulmohar Cross Road No. 11*, *J.V.P.D. Scheme*, *Mumbai – 400049*)	Shri P. M. Tipnis

Panel for Plumbing Services, CED 46:P17

Organization	*Representative*(*s*)
Indian Plumbing Association, New Delhi	Shri B. S. Aswathnarayan **(*Convener*)**
Brihan Mumbai Licenced Plumbers' Association, Mumbai	Shri Bijal M. Shah Shri H. G. Gandhi (*Alternate*)
Central Ground Water Board, Faridabad	Member (SML) Regional Director (*Alternate*)
Central Pollution Control Board, New Delhi	Dr A. B. Akolkar Dr Sanjeev Agrawal (*Alternate*)

Organization	*Representative*(*s*)
Central Public Health and Environmental Engineering Organisation, New Delhi	DR RAMAKANT SHRI VIPIN KUMAR PATEL (*Alternate*)
Central Public Works Department, New Delhi	CHIEF ENGINEER (WORKS CUM TLQA) SE & PD, CIRCLE-1 (*Alternate*)
CSIR-Central Building Research Institute, Roorkee	DR KISHOR KULKARNI DR NAVEEN NISHANT (*Alternate* I) DR VEENA CHAUDHARY (*Alternate* II)
CSIR-National Environmental Engineering Research Institute, Nagpur	SHRI A. S. DUBEY SHRI M. KARTHIK (*Alternate*)
Delhi Development Authority, New Delhi	SHRI K. S. MEENA SHRI PANKAJ KUMAR VERMA (*Alternate*)
Delhi Jal Board, New Delhi	CHIEF ENGINEER (CENTRAL & NORTH)
Envirotech Instruments Pvt Ltd, New Delhi	SHRI S. K. GUPTA
Indian Plumbing Association, New Delhi	SHRI MUKESH ASIJA DR ANANTHA SIVA IYER (*Alternate*)
Indraprastha Gas Ltd, New Delhi	SHRI PANKAJ SHARMA SHRI AVIJIT NARAYAN (*Alternate*)
Mahanagar Gas Ltd, Mumbai	SHRIMATI PRATIBHA BIJAY
Maple Engineering Design Services (India) Pvt Ltd, Bengaluru	SHRI S. L. PRASANNA KUMAR
MKG Consultants, New Delhi	SHRI M. K. GUPTA SHRI NISHANT GUPTA (*Alternate* I) SHRI HIMANSHU PARIHAR (*Alternate* II)
Military Engineer Services, Engineer-in-Chief's Branch, Army HQ, New Delhi	SHRI H. K. GUPTA COL PANKAJ BANIYAL (*Alternate*)
Ministry of Jal Shakti, New Delhi	SHRI SAURABH GUPTA SHRI SANTOSH KUMAR (*Alternate*)
Municipal Corporation of Greater Mumbai, Mumbai	DY HYDRAULIC ENGINEER (PLANNING & CONTROL) EXECUTIVE ENGINEER (PLANNING & RESEARCH) (*Alternate*)
Nous Hospital Consultants Pvt Ltd, New Delhi	DR K. B. SOOD
Pratham Envirotech Solutions, Navi Mumbai	SHRI PURSHOTTAM YEMUL
Proion Consultants Private Limited, New Delhi	SHRI SANDEEP GOEL
Tata Consulting Engineers Limited, Mumbai	SHRI DHEERAJ KAUSHIK
The Indian Institute of Architects, New Delhi	SHRI UDAYA SHANKAR DONI SHRI RAJ KUMAR PRAJAPATI (*Alternate* I) MS SWOPNADUTTA MOHANTY (*Alternate* II)
The Institution of Engineers (India), Kolkata	DR D. ELANGO DR V. S. PRIYA (*Alternate*)
Water Management & Plumbing Skill Council, New Delhi	SHRI VINAY GUPTA SHRIMATI SHRUTI GOEL (*Alternate*)

Organization	*Representative*(*s*)
In Personal Capacity (*Flat No 514*, *Charms Solitaire Apartment*, *Plot No 14*, *Mall Road*, *AK-2*, *Indirapuram*, *Ghaziabad – 201014*)	DR BHARAT BHUSHAN NAGAR

Panel for Glass and Glazing, CED 46:P20

Organization	*Representative*(*s*)
Central Public Works Department, New Delhi	SHRI PRADEEP GARG **(*Convener*)**
All India Glass Manufacturers' Federation, New Delhi	SHRI SHAILESH RANJAN SHRI RUPINDER SHELLY (*Alternate*)
Bureau of Energy Efficiency Ministry of Power, New Delhi	MS PRAVATANALINI SAMAL SHRI PANKAJ SHARMA (*Alternate*)
BES Consultants Pvt Ltd, Mumbai	SHRI RAJAN GOVIND SHRI VENUGOPAL B. (*Alternate*)
Central Public Works Department, New Delhi	SENIOR ARCHITECT (NATIONAL CPWD ACADEMY) ARCHITECT (NCA) (*Alternate*)
Creative Design Consultants & Engineers Pvt Ltd, Greater Noida	SHRI AMAN DEEP SHRI BARJINDER SINGH GHAI (*Alternate*)
CSIR-Central Building Research Institute, Roorkee	DR CHANDAN SWAROOP MEENA DR NAGESH BABU BALAM (*Alternate* I) DR KISHOR S. KULKARNI (*Alternate* II)
Dow Chemical International Private Limited, Mumbai	SHRI RAVISHANKAR SUBRAMANIAN
Facade India Testing Inc, Thane	SHRI V. S. RAVI
Glazing Society of India, Chennai	SHRI G. N. GOHUL DEEPAK MS DILNA SUBRAMANIAN (*Alternate* I) MS RANJANI. A (*Alternate* II)
GSC Glass Ltd, Greater Noida	SHRI C. J. SINGH
Hilti India Private Limited, New Delhi	SHRI SHOUNAK MITRA SHRI RAGHAVENDRA KUMAR VAKKALAGADDA (*Alternate*)
Indian Association of Structural Engineers, New Delhi	SHRI MAHESH TANDON DR S. P. ANCHURI (*Alternate*)
International Fenestration Forum, Noida	SHRI ARUN SHARMA
Indian Institute of Technology Madras (Structural Glass Research & Testing Facility), Chennai	DR S. ARUL JAYACHANDRAN DR ALAGAPPAN PONNALAGU (*Alternate*)
Indian Institute of Technology Roorkee, Roorkee	DR AVLOKITA AGRAWAL DR E. RAJASEKAR (*Alternate*)
Larsen & Toubro Ltd, Chennai	SHRI STHALADIPTI SAHA SHRI SURYA PRAKASH KARRI (*Alternate*)
Meinhardt Facade Technology India Pvt Ltd, Chennai	SHRI MAHESH ARUMUGAM
Municipal Corporation of Greater Mumbai (Mumbai Fire Brigade), Mumbai	CHIEF FIRE OFFICER DY CHIEF FIRE OFFICER (*Alternate*)

Organization	*Representative*(*s*)
NBCC (India) Limited, New Delhi	Shri Anuj Kumar Goyal Shri Vinay Kumar Khullar (*Alternate*)
Procural Private Limited, Telangana	Shri Satish Kumar Shri Santhanam Rengaswamy (*Alternate*)
Saint-Gobain Glass India Pvt Ltd, Chennai	Shri Shoaib Shaikh Shri U. Gopinath (*Alternate* I) Ms Kaarnika M. (*Alternate* II)
Schueco India Pvt Ltd, Bengaluru	Shri Antony John V. S. Shri Kushagra Awasthi (*Alternate*)
The Indian Institute of Architects, New Delhi	Shri Rupinder Ahuja Shri Ashutosh Kumar Agarwal (*Alternate* I) Shrimati Jyoti Rajeev Panse (*Alternate* II)
The Institution of Engineers (India), Kolkata	Er M. Nagaraj Er Inderdeep Singh Oberoi (*Alternate*)
UPVC Windows and Doors Manufacturers Association, New Delhi	Shri Ullas Guliani Shri Mario Schmidt (*Alternate* I) Shri Satish Kumar (*Alternate* II)
Winwall Technology India Pvt Ltd, Chennai	Shri P. Jothi Ramalingam

Panel for Information and Communication Enabled Installations, CED 46:P21

Organization	*Representative*(*s*)
In Personal Capacity (*C501*, *Shivam Apartments*, *Plot 14*, *Sector 12*, *Dwarka*, *New Delhi – 110078*)	Shri A. K. Mittal **(*Convener*)**
Broadband India Forum, New Delhi	Shri T. V. Ramachandran Brig Anil Tandan (*Alternate*)
Building Industry Consulting Service International, Mumbai	Shri Ninad Mohan Desai
Cellular Operators Association of India, New Delhi	Shri Vikram Tiwathia Shrimati Vertika Misra (*Alternate*)
Central Industrial Security Force, New Delhi	Shri Naresh Kumar Shri Sanjeev Kumar Saddi (*Alternate*)
Central Public Works Department, New Delhi	Chief Engineer (T&R)-LL SE (T)-Elect (*Alternate*)
CMAI Association of India, New Delhi	Dr N. K. Goyal
Department of Telecommunication, New Delhi	Shri Ashok Kumar Shri Rajat Jain (*Alternate*)
Dept of Electronics & Information Technology, Ministry of Electronics and Information Technology, New Delhi	Dr Anil Kumar Kaushik Shri Prakash Kumar (*Alternate*)
Digital Infrastructure Providers Association, New Delhi	Shri Manoj Kumar Singh Shri Ramakant Gupta (*Alternate* I) Shri Greesh Kumar (*Alternate* II)

Organization	*Representative*(*s*)
Gujarat International Finance Tec City Company Limited, Gandhinagar	SHRI RAMAKANT JHA DR NILESH KUMAR PUREY (*Alternate*)
Military Engineer Services, Engineer-in-Chief's Branch, Army HQ, New Delhi	SHRI S. K. GUPTA SHRI BIJENDRA PAL SINGH (*Alternate*)
Ministry of Railways, New Delhi	SHRIMATI VINITA NARERA
Proion Consultants Private Limited, New Delhi	SHRIMATI SHRUTI GOEL
Roads and Buildings Department, Govt of Telangana, Hyderabad	SHRI G. RAMAKRISHNA KUMAR DEPUTY CHIEF ENGINEER (*Alternate*)
Shyam Spectra Private Limited, Gurugram	SHRI HEM CHAND RAJPUT
Sterlite Technologies Limited, Pune	SHRI S. N. GUPTA MD SHAHID KHAN (*Alternate*)
Telecom Equipment Manufacturers Association of India, New Delhi	SHRI BHUPESH YADAV SHRI RAHUL DUBEY (*Alternate*)
Telecom Engineering Centre, New Delhi	SHRI JASVEER SINGH PANESAR
The Indian Institute of Architects, Mumbai	DR JYOTI PANSE
The Institution of Engineers (India), Kolkata	DR LAXMI KANT MISHRA ER RAKESH KUMAR RATHORE (*Alternate*)
Town and Country Planning Organization, New Delhi	SHRI NARESH KUMAR DHIRAN SHRI PARESH KUMAR DURIA (*Alternate* I) SHRI R. SRINIVAS (*Alternate* II)
In Personal Capacity (*Cedar 102*, *SJR Park Vista Aptts*, *Haralur Road*, *Ambalipura*, *Bengaluru – 560012*)	SHRI J. N. BHAVANI PRASAD

WORKING GROUPS UNDER THE PANEL, CED 46:P2

Working Group for Smoke Management, CED 46:P2:WG1

Organization	*Representative*(*s*)
Directorate of Maharashtra Fire Services, Mumbai	SHRI SANTOSH S. WARICK (***Convener***)
Fire and Security Association of India, Chennai	SHRI SRINIVAS VALLURI
Indian Society of Heating, Refrigerating and Air Conditioning Engineers, New Delhi	SHRI K. RAMACHANDRAN

Working Group for Electrical Safety, CED 46:P2:WG2

Organization	*Representative*(*s*)
Fire and Security Association of India, Chennai	SHRI SRINIVAS VALLURI (***Convener***)
National Federation of Engineers for Electrical Safety, Chennai	SHRI S. GOPA KUMAR
In Personal Capacity (*27A*, *Tapovan Senior Citizens Foundation*, *Coimbatore – 641010*)	SHRI T. R. A. KRISHNAN

Drafting Group of the Fire and Life Safety Chapter, CED 46:P2:WG3

Organization	*Representative*(*s*)
Fire Safe India Foundation, Mumbai	Shri M. V. Deshmukh (***Convener***)
Fire and Security Association of India, Chennai	Shri Srinivas Valluri
Kapse Consulting Engineers Private Limited, Thane	Shri Vinod Kapse
Directorate of Maharashtra Fire Services, Mumbai	Shri Santosh S. Warick Shri Kiran Hatyal (*Alternate*)
Proion Consultants Private Limited, New Delhi	Shri Sandeep Goel
TTS Consultant, Kolkata	Shri Tarak Chakraborty
In Personal Capacity (*Shop No. 15*, *Natraj Building*, *Shiv Srishti Complex*, *M.G.Link Road Mulund* (*W*) *Mumbai – 400080*)	Shri Shashikant L. Jadhav
In Personal Capacity (*Flat No. 9221*, *ATS Pristine*, *Sector 150*, *Noida – 201 310*)	Dr G. C. Misra
In Personal Capacity (*Ganeshkunj A-10 Chanakyapuri*, *New Sama Road*, *Baroda – 390008*)	Shri Abhay D. Purandare

Advisory Group for Revision of Part 4, CED 46:P2:WG4

Organization	*Representative*(*s*)
In Personal Capacity (*K-33-A*, *Green Park*, (*First Floor*), *New Delhi – 110016*)	Shri S. K. Dheri (***Convener***)
Delhi Fire Services, New Delhi	Director
In Personal Capacity (*27A*, *Tapovan Senior Citizens Foundation*, *Coimbatore – 641010*)	Shri T. R. A. Krishnan
In Personal Capacity (*D-317*, *IInd Floor*, *Nirman Vihar*, *New Delhi – 110 092*)	Shri R. C. Sharma
In Personal Capacity (*'Isa Vasyam' TC-15/1675*, *B-8/2-Lakshmi Nagar*, *Kesavadaspuram – 695004*)	Shri V. Suresh

Metro Related Provisions, CED 46:P2/WG5

Organization	*Representative*(*s*)
In Personal Capacity (*Flat No. 9221*, *ATS Pristine*, *Sector 150*, *Noida – 201310*)	Dr G. C. Misra (***Convener***)
Chennai Metro Rail Limited, Chennai	Shrimati Rajalakshmi. S
Delhi Metro Rail Corporation Limited, Delhi	Shri Ashok Tewari Shrimati Rashmi Bhardwaj (*Alternate* I) Ms Nabila Maryam (*Alternate* II)
National Capital Region Transport Corporation, New Delhi	Shri Gautam Bhardwaj
In Personal Capacity (*27A*, *Tapovan Senior Citizens Foundation*, *Coimbatore – 641010*)	Shri T. R. A. Krishnan

WORKING GROUP UNDER THE PANEL, CED 46:P3

Expert Group for Revision, CED 46:P3/WG1

Organization	*Representative*(*s*)
Central Public Works Department, New Delhi	SHRI DINESH K. UJJAINIA (***Convener***)
AEON Design & Development LLP, Noida	MS SHEETAL RAKHEJA
Builders' Association of India, Mumbai	REPRESENTATIVE
CSIR - Central Building Research Institute, Roorkee	DR NEERAJ JAIN
Indian Institute of Technology Madras, Chennai	DR AMLAN KUMAR SENGUPTA
Larsen and Toubro Construction, Chennai	SHRI PRAVEEN KUMAR RAI
Military Engineer Services, Engineer-in-Chief's Branch, Army HQ, New Delhi	SHRIMATI S. GAYATRI MUKHERJEE
National Council for Cement and Building Materials, Faridabad	SHRI P. N. OJHA
The Indian Institute of Architects, New Delhi	DR VENU SHREE

WORKING GROUPS UNDER THE PANEL, CED 46:P6

Working Group for Bamboo, CED 46:P6/WG1

Organization	*Representative*(*s*)
Wonder Grass Initiative Private Limited, Nagpur	SHRI VAIBHAV KALEY (***Convener***)
Bamboo Society of India, Bengaluru	SHRI PUNATI SRIDHAR
Centre for Green Building Materials & Technology, Bengaluru	MS NEELAM MANJUNATH
CSIR - Central Building Research Institute, Roorkee	ER MICKEY MECON DALBEHERA
Forest Research Institute, Dehradun	DR AJAY THAKUR

Working Group for Engineered Bamboo, CED 46:P6/WG2

Organization	*Representative*(*s*)
ICFRE-Institute of Wood Science and Technology, Bengaluru	SHRI ANAND NANDANWAR (***Convener***)
CEPT University, Ahmedabad	DR DHARA SHAH
Forest Research Institute, Dehradun	DR AJAY THAKUR
Indian Institute of Technology Delhi, New Delhi	SHRI SURESH BHALLA
ICFRE-Institute of Wood Science and Technology, Bengaluru	DR NARASIMHAMURTHY
Mutha Industries Pvt Ltd, Mumbai	SHRI ANIL MUTHA
North East Centre for Technology Application and Research, Shillong	SHRI KRISHNA KUMAR

Working Group for Timber, CED 46:P6/WG3

Organization	*Representative*(*s*)
Forestry Innovation Consulting India Pvt Ltd, Mumbai	DR JIMMY THOMAS
Forest Research Institute, Dehradun	SHRI RAJESH BHANDARI
Forum of Scientists, Engineers and Technologists, Kolkata	DR PARTHASARATHI MUKHOPADHYAY
ICFRE-Institute of Wood Science and Technology, Bengaluru	SHRI ANAND NANDANWAR SHRI AMITAVA SIL
In Personal Capacity (*P.O. New Forest*, *Dehradun – 248006*)	DR SADHNA TRIPATHI

Working Group for Engineered Timber, CED 46:P6/WG4

Organization	*Representative*(*s*)
ICFRE-Institute of Wood Science and Technology, Bengaluru	SHRI ANAND NANDANWAR (***Convener***)
CEPT University, Ahmedabad	DR DHARA SHAH
Forest Research Institute, Dehradun	SHRI RAJESH BHANDARI
North East Centre for Technology Application and Research, Shillong	SHRI KRISHNA KUMAR
Windsor Wood (India) Pvt Ltd, Mumbai	SHRI PRAKASH NARMADASHANKAR SUTHAR

WORKING GROUPS UNDER THE PANEL, CED 46:P12

Working Group for Building Orientation, CED 46:P12/WG1

Organization	*Representative*(*s*)
Ashok B Lall Architects, New Delhi	SHRI ASHOK B. LALL (***Convener***)
Ministry of New and Renewable Energy, New Delhi	DR A. K. TRIPATHI

Working Group for Building Lightning, CED 46:P12/WG2

Organization	*Representative*(*s*)
CEPT University, Ahmedabad	DR MINU AGARWAL (***Convener***)
CSIR-Central Building Research Institute, Roorkee	SHRI ANUP KUMAR PRASAD

Working Group for Ventilation, CED 46:P12/WG3

Organization	*Representative*(*s*)
CEPT University, Ahmedabad	DR RAJAN RAWAL (***Convener***)
Military Engineer Services, Engineer-in-Chief's Branch, Army HQ, New Delhi	SHRI ASHOK KUMAR

WORKING GROUPS UNDER THE PANEL, CED 46:P13

Working Group for Electric Vehicles, Battery Storage, and Load Factor, CED 46:P13/WG2

Organization	*Representative(s)*
In Personal Capacity (*Cedar 102, SJR Park Vista Aptts, Haralur Road, Ambalipura, Bengaluru – 560012*)	SHRI J. N. BHAVANI PRASAD (***Convener***)
Automotive Research Association of India, Pune	SHRI A. A. DESHPANDE
Cape Electric Private Limited, Kancheepuram	SHRI S. GOPA KUMAR
Central Public Works Department, New Delhi	SHRI VIKAS RANA
Directorate of Maharashtra Fire Services, Mumbai	SHRI SANTOSH S. WARICK
India Energy Storage Alliance, Pune	SHRI DEBI PRASAD DASH
Indian Institute of Technology Madras, Chennai	DR ASHOK JHUNJHUNWALA
Tata Motors Limited, Pune	SHRI SENTHILNATHAN THANGAVELU
In Personal Capacity (*J-403 Second Floor, New Rajinder Nagar, New Delhi – 110060*)	SHRI CHAITANYA KUMAR VARMA

Working Group for Revision of the Chapter, CED 46:P13/WG3

Organization	*Representative(s)*
Cape Electric Private Limited, Kancheepuram	SHRI S. GOPA KUMAR (***Convener***)
Aeon Integrated Building Design Consultants, Noida	SHRI PUNEET GUPTA
Central Electricity Authority, New Delhi	SHRI ASHOK KUMAR RAJPUT
Central Public Works Department, New Delhi	SHRI VIKAS RANA
Government of Tamil Nadu, Chief Electrical Inspectorate, Chennai	SHRI P. PALANI
Ministry of New and Renewable Energy, New Delhi	SHRI A. K. TRIPATHI
National Federation of Engineers for Electrical Safety, Chennai	SHRI ABHISHEK SINGH
Obo Bettermann India Private Limited, Oragadam	SHRI K. JANAKI RAMAN
ProtegoPlus Electrotech Private Limited, Mumbai	SHRI KRISH THEOBALD
Proion Consultants Private Limited, New Delhi	SHRIMATI SHRUTI GOEL
Public Works Department, Government of Maharashtra, Mumbai	SHRI HEMANT M. SALI
Schneider Electric India Private Limited, Gurugram	SHRI DEBDAS GOSWAMI

Working Group for Solar Energy and Power from Multiple Sources and Related Protection and Earthing, CED 46:P13/WG4

Organization	*Representative*(*s*)
Proion Consultants Private Limited, New Delhi	SHRIMATI SHRUTI GOEL (***Convener***)
Cape Electric Private Limited, Kancheepuram	SHRI S. GOPA KUMAR
Central Public Works Department, New Delhi	SHRI VIKAS RANA
Government of Tamil Nadu, Chief Electrical Inspectorate, Chennai	SHRI P. PALANI
Ministry of New and Renewable Energy, New Delhi	DR A. K. TRIPATHI
Obo Bettermann India Private Limited, Oragadam	SHRI K. JANAKI RAMAN
Public Works Department, Government of Maharashtra, Mumbai	SHRI HEMANT M SALI
Solar Energy Corporation of India Limited, New Delhi	SHRI C. K. SINGH
The Institution of Engineers (India), Kolkata	DR S. SENTHILKUMAR

WORKING GROUP UNDER THE PANEL, CED 46:P14

Core Group for Revision of HVAC Chapter, CED 46:P14/WG1

Organization	*Representative*(*s*)
ACR Project Consultants Private Limited, Pune	SHRI HARSHAL SURANGE
Adani Energy Solution Pvt Ltd, Ahmedabad	SHRI PRAMOD PRABHAKAR
Anna University, Chennai	DR R. SARAVANAN
Blowtech Air Devices Private Limited, Noida	SHRI SUSHIL K. CHOUDHURY
Breathe Easy Labs, New Delhi	SHRI BARUN AGARWAL
CBRE India, Gurugram	SHRI ANEESH KADYAN
CEPT University, Ahmedabad	DR YASH SHUKLA
Degree Day Private Limited, Indore	SHRI NISHANT GUPTA
Dynacraft Air Controls, Mumbai	SHRI V. KRISHNAN
ELM Enterprises Private Limited, Delhi	SHRI PRASHANT DESAI
Enova HVAC & MEP Consulting, Mumbai	MS SANGITA JHANGIANI
Eskayem Consultants Private Limited, Mumbai	SHRI GOUTHAM PITCHIKALA
Envirocon Engineering Services, New Delhi	SHRIMATI SAMTA BAJAJ

Organization	*Representative*(*s*)
Genex Consultants, Hyderabad	SHRI CHANDRASEKAR NARAYANAN
Godrej & Boyce Manufacturing Company Limited, Mumbai	SHRI MUKESH SUTHAR
Impec Filters Private Limited, Chennai	DR SHANKAR RAJASEKARAN
Indian Society of Heating, Refrigerating and Air Conditioning Engineers, New Delhi	SHRI ASHISH RAKHEJA SHRI K. RAMACHANDRAN SHRIMATI NIVEDITA JADHAV
International Ground Source Heat Pump Association, New Delhi	SHRI MADHUSUDAN RAPOLE
Lead Consultancy and Engineering Services (India) Private Limited, Bengaluru	SHRI M. SELAVARASU
Malaviya National Institute of Technology, Jaipur	DR JYOTIRMAY MATHUR
Overdrive Engineering Private Limited, New Delhi	SHRI RICHIE MITTAL
Paharpur Cooling Towers Limited, Kolkata	SHRI VARUN SWARUP
Proion Consultants Private Limited, New Delhi	SHRI SANDEEP GOEL
Reliance Industries Limited, Bengaluru	SHRI AJAJ KAZI
3S Green SSS Consultants, Bengaluru	SHRI C. SUBRAMANIAM
Sanelac Consultants Private Limited, New Delhi	SHRI VARUN JAIN
Sterling India Consulting Engineers, New Delhi	SHRI G. C. MODGIL
The Chemours India Private Limited, Gurugram	SHRI VIKAS MEHTA
UL India Private Limited, Bengaluru	SHRI V. MANJUNATH
Univac Environment Systems Private Limited, Mumbai	SHRI VIKRAM MURTHY
Vision Electro Mechanical Consultants Private Limited, Pune	DR NITIN DEODHAR
In Personal Capacity (*E-203, Belaire, Golf Course Road, Gurugram – 122022*)	SHRI PRABHAT GOEL
In Personal Capacity (*Experiqs Pvt Ltd*, *7022*, *RBTIC Building*, *IIT Bombay*, *Powai*, *Mumbai – 400076*)	SHRI AVINASH G. SHALIGRAM

WORKING GROUP UNDER THE PANEL, CED 46:P15

Expert Group for Revision, CED 46:P15/WG1

Organization	*Representative*(*s*)
Interarch Building Products Private Limited, Noida	SHRI GAUTAM SURI (***Convener***)
CSIR-National Physical Laboratory, New Delhi	DR NAVEEN GARG

Organization	*Representative*(*s*)
Indian Institute of Science, Bengaluru	Dr M. L. Munjal
Indian Institute of Technology Madras, Chennai	Dr S. Narayanan
Indian Institute of Technology Roorkee, Roorkee	Dr E. Rajasekar
P. S. Subramanian Associates, Chennai	Dr S. Kandaswamy
The Indian Institute of Architects, New Delhi	Shri B. Sudhir

WORKING GROUP UNDER THE PANEL, CED 46:P16

Working Group for Revision of the Chapter, CED 46:P16/WG1

Organization	*Representative*(*s*)
TAK Consulting Private Limited, Mumbai	Shri T. A. K. Mathews **(*Convener*)**
Directorate of Maharashtra Fire Services, Mumbai	Shri Santosh S. Warick
ECE Industries Limited, New Delhi	Shri Amit Kachroo Shri Anurag Manglik (*Alternate*)
Elevator and Escalator Component Manufacturers' Association of India, Chennai	Shri Harish A. Nakman Shri Abey George (*Alternate*)
Energy Department, Government of Maharashtra, Mumbai	Shri Sandeep A. Patil Shri Uday U. Dambe (*Alternate*)
Fujitec India Private Limited, Gurugram	Shri R. Rajesh Shri Manokar S. (*Alternate* I) Shri Arun Sankar (*Alternate* II)
IEEMA Elevator Division, Mumbai	Shri P. K. Dixit Shri Rushad Divecha (*Alternate* I) Shri Uttam Kumar (*Alternate* II)
Johnson Lifts Pvt Limited, Chennai	Shri V. Karthikeyan Shri Sachin More (*Alternate*)
Kone Elevator India Private Limited, Chennai	Shri U. Viswanathan Shri Balaji K. (*Alternate*)
Otis Elevator Company (India) Limited, Bengaluru	Shri Shrihari Vispute Shri Abhijit Dandekar (*Alternate* I) Shri Praveena Siddaramanna (*Alternate* II)
Schindler India Private Limited, Mumbai	Shri Nimish Deshpande Shri Rajagopalan Renganathan (*Alternate* I) Shri Nitin Vithal Kadam (*Alternate* II)
TAK Consulting Private Limited, Mumbai	Shri Gaurav Ghag
TK Elevator India Private Limited, New Delhi	Shri Vishnu Parashar Shri Deepak Balani (*Alternate*)
Wohr Parking Systems Pvt Ltd, Pune	Shri Sandeep Kulkarni

Organization	*Representative*(*s*)
In Personal Capacity (*43*, *Juhu Gaurav*, *Gulmohar Cross Road No. 11*, *J.V.P.D. Scheme*, *Mumbai – 400 049*)	SHRI P. M. TIPNIS

WORKING GROUPS UNDER THE PANEL, CED 46:P17

Working Group for Water Supply, CED 46:P17/WG1

Organization	*Representative*(*s*)
Indian Plumbing Association, New Delhi	SHRI B. S. ASWATHNARAYAN (***Convener***)
CSIR-Central Building Research Institute, Roorkee	SHRI CHANDAN SWAROOP MEENA
D' Plumbing Consultants, Mumbai	SHRI DEEPAK
Indian Plumbing Association Maple Engineering - Design Services India Private Limited, Bengaluru	SHRI S. L. PRASANNAKUMAR
Indian Plumbing Association, New Delhi	SHRI MUKESH ASIJA
Ministry of Heavy Industries and Public Enterprises, New Delhi	SHRI VIJAY PRAKASH
Municipal Corporation of Greater Mumbai, Mumbai	DR DEEPAK NAGARSOGE
Nous Hospital Consultants Pvt Ltd, New Delhi	DR K. B. SOOD
Proion Consultants Private Limited, New Delhi	SHRI SANDEEP GOEL
Tata Consulting Engineers Limited, Navi Mumbai	SHRI DHEERAJ KAUSHIK

Working Group for Drainage and Sanitation, CED 46: P17/WG2

Organization	*Representative*(*s*)
MKG Consultants, New Delhi	SHRI M. K. GUPTA (***Convener***)
Brihan Mumbai Licensed Plumbers' Association, Mumbai	SHRI H. G. GANDHI
Central Public Works Department, New Delhi	SHRI DINESH K. UJJAINIA
Maple Engineering Design Services (India) Private Limited, Bengaluru	SHRI S. L. PRASANNA KUMAR
Military Engineer Services, Engineer-in-Chief's Branch, Army HQ, New Delhi	SHRI N. K. GOEL
The Indian Institute of Architects, New Delhi	SHRI RAJ KUMAR PRAJAPATI
In Personal Capacity (*610*, *Technology Apartments*, *24*, *Patparganj*, *New Delhi – 110002*)	SHRI SUBIR PAUL

Working Group for Solid Waste Management, CED 46: P17/WG3

Organization\	*Representative*(*s*)
Central Public Health Environmental Engineering Organisation, New Delhi	DR RAMAKANT (***Convener***)

Organization	*Representative(s)*
CSIR-Central Building Research Institute, Roorkee	Dr Ajay Chourasia
Central Pollution Control Board, New Delhi	Dr A. B. Akolkar Dr Sanjeev Agrawal (*Alternate*)
Indian Institute of Technology Bombay, Mumbai	Dr Hariharan S. Shankar
The Institution of Engineers (India), Kolkata	Shri D. Elango
In Personal Capacity (*377*, *Church View Apartment*, *Sector 29*, *Noida – 201303*)	Capt Manju Minhas

Working Group for Gas Supply, CED 46:P17/WG4

Organization	*Representative(s)*
Indian Plumbing Association, New Delhi	Shri B. S. Aswathnarayan **(*Convener*)**
Indraprastha Gas Limited, New Delhi	Shri Pankaj Sharma
CSIR-National Environmental Engineering Research Institute, Nagpur	Shri A. S. Dubey
Ministry of Heavy Industries and Public Enterprises, New Delhi	Shri Vijay Prakash
Tata Consulting Engineers Limited, Navi Mumbai	Shri Ganesh Kumar Singh

WORKING GROUPS UNDER THE PANEL, CED 46:P20

Working Group for Energy and Thermal Performance, CED 46:P20/WG1

Organization	*Representative(s)*
Indian Institute of Technology Roorkee, Roorkee	Dr E. Rajasekar **(*Convener*)**
Bureau of Energy Efficiency, New Delhi	Shri Saurabh Diddi
Glazing Society of India, Chennai	Shri Gohul Deepak G. N.
International Fenestration Forum, New Delhi	Shri Arun Sharma
Larsen & Toubro Ltd, Chennai	Shri Surya Prakash Karri
Schueco India Private Limited, Bengaluru	Shri Kushagra Awasthi

Working Group for Special Glass, CED 46:P20/WG2

Organization	*Representative(s)*
Meinhardt Facade Technology India Private Limited, Chennai	Shri Mahesh Arumugam **(*Convener*)**
Central Public Works Department, New Delhi	Shri Pradeep Garg

Organization	*Representative*(*s*)
Defence Research and Development Organisation, Terminal Ballistics Research Laboratory, Chandigarh	SHRIMATI SAKSHI ARORA DR PREETI JAIN (*Alternate*)
Glazing Society of India, Chennai	SHRI GOHUL DEEPAK G. N.
International Fenestration Forum, New Delhi	SHRI ARUN SHARMA
Larsen & Toubro Ltd, Chennai	SHRI SURYA PRAKASH KARRI
Saint-Gobain Glass India Private Limited, Chennai	SHRI AVINASH GOWRA
Schueco India Private Limited, Bengaluru	SHRI ANTONY JOHN V. S.

Working Group for Fire Safety Aspects, CED 46:P20/WG3

Organization	*Representative*(*s*)
Indian Institute of Technology Gandhinagar, Gandhinagar	DR GAURAV SRIVASTAVA (***Convener***)
Aadit Fire Testing Laboratory Private Limited, Gummidipoondi	SHRI P. JOTHI RAMALINGAM DR MANIGANDAN SHRI AKHIL CHACKO
All India Glass Manufacturers' Federation, New Delhi	SHRI NAGENDRA KUMAR
BES Consultants Private Limited, Mumbai	SHRI RAJAN GOVIND
CSIR-Central Building Research Institute, Roorkee	SHRI S. K. NEGI
Glazing Society of India, Chennai	SHRI GOHUL DEEPAK G. N.
Hilti India Private Limited, New Delhi	SHRI RAGHAVENDRA KUMAR VAKKALAGADDA
Indian Institute of Technology Tirupati, Yerpedu	DR JASHNAV PANCHETI

Working Group for Structural Design Aspects, CED 46:P20/WG4

Organization	*Representative*(*s*)
BES Consultants Private Limited, Mumbai	SHRI RAJAN GOVIND (***Convener***)
Glazing Society of India, Chennai	SHRI GOHUL DEEPAK G. N.
Hilti India Private Limited, New Delhi	SHRI SHOUNAK MITRA
Indian Association of Structural Engineers, New Delhi	SHRI MAHESH TANDON
Indian Institute of Technology Madras, Chennai	DR ALAGAPPAN PONNALAGU
Larsen & Toubro Ltd, Chennai	SHRI SURYA PRAKASH KARRI
Schueco India Private Limited, Bengaluru	SHRI ANTONY JOHN V. S.

Working Group for Performance and Testing, CED 46:P20/WG5

Organization	*Representative*(*s*)
Schueco India Private Limited, Bengaluru	SHRI ANTONY JOHN V. S. (***Convener***)
Eminent International Testing Centre Private Limited, Hyderabad	SHRI REJI BHAMI
Facade India Testing Inc, Thane	SHRI V. S. RAVI
Glazing Society of India, Chennai	SHRI GOHUL DEEPAK G. N.
Winwall Technology India Private Limited, Chennai	SHRI P. JOTHI RAMALINGAM

WORKING GROUPS UNDER THE PANEL, CED 46:P21

Working Group for Indoor and Outdoor Plants, CED 46:P21/WG1

Organization	*Representative*(*s*)
ITS India Forum, New Delhi	DR SHIV KUMAR (***Convener***)
Broadband India Forum, New Delhi	SHRI ATUL JAIN
Building Industry Consulting Service International, Mumbai	SHRI NINAD MOHAN DESAI
Ranext Technologies Private Limited, Gurugram	SHRI JAGMOHAN SINGH
Sterlite Technologies Limited, Pune	SHRI SHAHID KHAN
Telecom Regulatory Authority of India, New Delhi	SHRI VIRENDRA SINGH RAJPUT

Working Group for Wireless Systems, CED 46:P21/WG2

Organization	*Representative*(*s*)
In Personal Capacity (*C501*, *Shivam Apartments*, *Plot 14*, *Sector 12*, *Dwarka*, *New Delhi – 110078*)	SHRI A. K. MITTAL (***Convener***)
Broadband India Forum, New Delhi	SHRI DEBASHISH BHATTACHARYA
Cellular Operators Association of India, New Delhi	SHRI VIKRAM TIWATHIA SHRI DHANANJAY GAWANDE
Crest Digitel Private Limited, Gurugram	SHRI VINAY KUMAR
Digital Infrastructure Providers Association, New Delhi	SHRI MANOJ KUMAR SINGH
Telecom Engineering Centre, New Delhi	SHRI JASVEER SINGH PANESAR
Telecom Regulatory Authority of India, New Delhi	SHRI TEJPAL SINGH

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART A INTRODUCTION

BUREAU OF INDIAN STANDARDS

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NATIONAL BUILDING CONSTRUCTION STANDARDS

PART A INTRODUCTION

This Part covers guidelines to be followed for judicious implementation of the provisions of various Parts/Sections of the National Building Construction Standards (NBCS), following a systematic approach.

In order to provide safe and resilient habitat, careful consideration needs to be paid to the building construction activity. Building planning, designing and construction activities have developed over the centuries. Large number of ancient monuments and historical buildings all over the world bear testimony to the growth of civilization from the prehistoric era with the extensive use of manual labour and simple systems as appropriate to those ages to the present day mechanized and electronically controlled operations for designing and constructing buildings and for operating and maintaining systems and services. Technological and socio-economic developments in recent times have led to remarkable increase in demand for more and more sophistication in buildings resulting in ever increasing complexities. For achieving these performance demand high levels of inputs from professionals of different disciplines such as architecture, civil engineering, structural engineering, functional and life safety services including special aspects relating to utilities, landscaping in conceptualization, spatial planning, design and construction of buildings of various material and technology streams, and various services including operation, maintenance, repairs and rehabilitation aspects throughout the service life of the building.

Present day construction scenario enables freedom of action to adopt appropriate practices and provides for building planning, designing and construction for absorbing traditional practices as well as latest developments in knowledge in the various disciplines as relevant to a building including computer aided and/or other modern sensors aided activities in the various stages of conceptualization, planning, designing, constructing, maintaining and repairing the buildings. India being a large country with substantial variations from region to region, this document has endeavoured to meet the requirements of different regions of the country, both urban and rural, by taking into consideration factors such as climatic and environmental conditions, geographical terrain, vulnerability to natural disasters, ecologically appropriate practices, use of eco-friendly materials, use of appropriate conventional and alternative technologies, and also socio-economic considerations, towards the creation of sustainable human settlements and built environment.

Buildings can be classified based on occupancy and types of construction as below:

Occupancy classification

a) Residential;
b) Educational;
c) Institutional;
d) Assembly;
e) Business;
f) Mercantile;
g) Industrial;
h) Storage; and
j) Hazardous.

Types of construction — Based on fire resistance rating for different set of components (suitably covered under Part F — Fire and Life Safety) are:

i) Type 1;
ii) Type 2;
iii) Type 3; and
iv) Type 4.

Buildings have various parts (such as plinth, habitable rooms, kitchen, bathroom and water closets, ledges, mezzanine, store room, garage, basement, parapet, cabin, boundary wall, wells, septic tanks, meter rooms, staircases, roofs) and specific requirements such as essential habitable sizes/ heights, distance between well and septic tanks, to name a few that ensure a liveable environment thereby addressing health, safety and public safety. The safe distance between buildings and electric lines is also essential towards occupant safety. Accessibility for persons with disabilities and the elderlies in specific public buildings and low income housing are also essential towards inclusivity in the built spaces. Open spaces within a plot also play a crucial part for harnessing natural lighting and ventilation, apart from movement space for fire tenders/emergency vehicles. Commensurate vehicular parking facilities within a built environment are also important so as to not burden the public spaces like roads/right of way. Such aspects may vary from place to place be it in the plains, hills and coastal areas; for which the state/local authorities should specify the specific criteria.

Based on their complexity, buildings may be classified as high rise buildings or special buildings in which the number of inmates and the requirement for their safe and habitable living are to be addressed. Importantly, the constructed buildings need to be well maintained and periodically audited covering structural audit, electrical audit, fire audit, accessibility audit to be carried out over the useful life of a building, say every 3 to 5 years.

A building project and the built facility in each stage necessarily requires professionals of many disciplines who should work together as a well-coordinated team to achieve the desired product delivery with quality, safety and other objectives, in an effective manner.

In large/complex projects, appropriate multi-disciplinary teams may be constituted to successfully meet the requirements of different stages. These may be design team, project management/execution team and operation and maintenance teams. Each team may comprise need-based professionals out of the following depending upon the nature, magnitude and complexity of the project:

1) architect;

2) civil engineer;

3) structural engineer;

4) geotechnical engineer;

5) electrical engineer;

6) plumbing engineer;

7) fire protection engineer;

8) heating, ventilation and air conditioning engineer;

9) lift, escalator and moving walk specialist;

10) acoustics specialist;

11) information/communication technology engineer;

12) health, safety and environment specialist;

13) environment/sustainability specialist;

14) town planner;

15) urban designer;

16) landscape architect;

17) security system specialist;

18) interior designer;

19) quantity surveyor;

20) project/construction manager;

21) project planning and construction digitization specialist;

22) accessibility and universal design specialist; and

23) other subject specialist(s).

This NBCS (Part A) gives an overall direction for understanding the provisions of different types of buildings and built environment, and proposes guidance for utilizing appropriate knowledge and experience of qualified professionals, right from the conceptualization through construction and completion stages of a building project and indeed during the entire life cycle.

This part has been so formulated as to necessitate guidance to ensure quality and safety in the whole gamut of activities, primarily divided into planning, design and execution of a building or built environment. This may be ensured by obtaining assistance from the registered professionals involved in planning, design, execution, and supervision. Apart from these, various other resource groups are involved whose contribution may be duly taken into account depending on the type, nature, magnitude and complexity of the project, such as security system specialist, environment specialist/sustainability and green building specialist, accessibility specialist, project management consultant, interior designer in proper construction/erection, commissioning and operation of buildings and built environment. In this endeavour, a guide for qualification and competence of the associated professionals, is included in Annex A.

The aim of this Part is to get the maximum benefit from the building and its services in terms of objectives such as quality, timeliness and cost-effectiveness by following a team approach. In the team approach, which is an essential pre-requisite for a unified approach, the aim clearly is to maximize the efficiency of the total system through appropriate optimization of each of its sub-systems, and ensuring coordination among various disciplines and agencies that are involved during planning, design, construction, operation and maintenance of buildings and the associated infrastructure. In other words, in the team, the timely inputs from each of the professional disciplines have to be so optimized that the total system's efficiency becomes maximum. These teams may be design team, construction/execution team, and operation and maintenance team.

It is important that leaders and members of the teams, depending on the size and complexity of the project, are carefully selected considering their qualification, experience and expertise in these fields.

Tools like building information modelling (BIM) may be adopted in all major and complex building projects as they help in managing and sharing information throughout the life cycle of the project enabling better collaboration, planning and decision making. In such projects, BIM may be strategically adopted to enhance the multi-disciplinary approach in design and execution and as a fundamental tool in the planning and development stages.

After the useful service life of a building is over, or for other reasons such as redevelopment and proposed change in use of the land and built facility, it may be required to deconstruct a building. Such a deconstruction is preceded by an organized decommissioning. The decommissioning and deconstruction needs to be well planned and coordinated among concerned building professionals so as to ensure safety during such operations, as also retrieval of appropriate components and systems, for their possible reuse or recycling, or disposal as may be appropriate. This may in turn require a comprehensive decommissioning and deconstruction (including demolition) plan, which may be prepared during the initial stages of the project and kept available for use at the end of life cycle of the same.

ANNEX A

GUIDE FOR THE QUALIFICATIONS AND COMPETENCE OF REGISTERED BUILDING PROFESSIONALS

A-1 ESSENTIAL REQUIREMENTS

Every building/development work should be planned, designed and supervised by registered professionals. The registered professionals for carrying out the various activities should be: (a) architect, (b) engineer, (c) structural engineer, (d) geotechnical engineer, (e) supervisor, (f) town planner, (g) landscape architect, (h) urban designer, and (j) utility services engineer. Requirements of registration for various professionals by the Authority or by the body governing such profession and constituted under a statute, as applicable to practice within the local body's jurisdiction, are given in **A-2.1** to **A-2.8**. The competence of such registered personnel to carry out various activities is also indicated in **A-2.1.1** to **A-2.8.1**.

The qualification and competence of the engineers for utility services and of builder/constructor is prescribed in **A-2.9** and **A-2.10**, respectively. The qualification and competence of the professionals involved in peer reviewing/ proof checking with respect to structural design is prescribed in **A-2.11.**

A-2 REQUIREMENTS FOR REGISTRATION AND COMPETENCE OF BUILDING PROFESSIONALS

A-2.1 Architect

The minimum qualifications for an architect should be the qualifications as provided for in the *Architects Act*, 1972 for registration with the Council of Architecture.

A-2.1.1 *Competence*

The registered architect should be competent to carry out the work related to the building/development permit as given below:

a) Preparation of all plans and information connected with building permit except engineering services of high rise/special buildings;

b) Issuing certificate of supervision and completion of all buildings pertaining to architectural aspects;

c) Preparation of subdivision/layout plans and related information connected with development permit of area up to 1 ha for metro-cities, and 2 ha for other places; and

d) Issuing certificate of supervision for development of land of area up to 1 ha for metro-cities, and 2 ha for other places.

A-2.2 Engineer

The minimum qualifications for an engineer should be graduate in civil engineering/architectural engineering of recognized Indian or foreign university, or the Corporate Member of Civil Engineering Division/Architectural Engineering Division of the Institution of Engineers (India) or the member of the statutory body governing such profession, as and when established.

A-2.2.1 *Competence*

The registered engineer should be competent to carry out the work related to the building/development permit as given below:

a) Preparation of all plans and information connected with building permit;

b) Structural details and calculations of buildings including sub-surface investigation on plot up to 500 m^2 and up to 5 storeys or 16 m in height;

c) Issuing certificate of supervision and completion for all buildings;

d) Preparation of subdivision/layout plans and related information connected with development permit of area up to 1 ha for metro-cities, and 2 ha for other places;

e) Preparation of all service plans and related information connected with development permit; and

f) Issuing certificate of supervision for development of land for all area.

A-2.3 Structural Engineer

The minimum qualifications for a structural engineer should be graduate in civil engineering of recognized Indian or foreign university, or Corporate Member of Civil Engineering Division of Institution of Engineers (India), and with minimum 3 years' experience in structural engineering practice with designing and field work.

NOTE — The 3 years' experience may be relaxed to 2 years in the case of post graduate degree of recognized Indian or foreign university in the branch of structural engineering. In case of doctorate in structural engineering, the experience required would be one year.

A-2.3.1 *Competence*

The registered structural engineer should be competent to prepare the structural design, calculations and details for all buildings and carry out supervision.

A-2.3.1.1 In case of buildings having special structural features, as decided by the Authority, which are within the horizontal areas and vertical limits specified in **A-2.2.1**(b) and **A-2.5.1**(a) should be designed only by structural engineers.

A-2.4 Geotechnical Engineer

The minimum qualifications for a geotechnical engineer should be graduate in civil engineering of recognized Indian or foreign university, or Corporate Member of Civil Engineering Division of Institution of Engineers (India), and with minimum 3 years' experience in geotechnical engineering practice with designing and field work.

NOTE — The 3 years' experience may be relaxed to 2 years in the case of post graduate degree of recognized Indian or foreign university in the branch of geotechnical engineering. In case of doctorate in geotechnical engineering, the experience required would be one year.

A-2.4.1 *Competence*

The registered geotechnical engineer should be competent to carry out sub-surface investigations and give report thereof. These may *inter-alia* include performing various tests required to determine engineering properties of sub-strata and ground water and making recommendations about the type of foundation, soil bearing capacity and the depth at which the foundations shall be placed, considering the structural system and loads provided by the engineer/structural engineer.

A-2.4.1.1 In case of buildings to be founded on soils having special geotechnical conditions, as decided by the Authority, which are within the horizontal areas and vertical limits specified in **A-2.2.1**(b) and **A-2.5.1**(a) should be designed only by geotechnical engineers.

A-2.4.1.2 For specific information on pre-construction services and construction stage services to be provided by the geotechnical engineers, reference may be made to IS 19235 : 2025 'Geotechnical engineering services — Requirements'.

A-2.5 Supervisor

The minimum qualifications for a supervisor should be diploma in civil engineering or architectural assistantship, or the qualification in architecture or engineering equivalent to the minimum qualification prescribed for recruitment to non-gazetted service by the Government of India plus 5 years' experience in building design, construction and supervision.

A-2.5.1 *Competence*

The registered supervisor should be competent to carry out the work related to the building permit as given below:

a) All plans and related information connected with building permit for residential buildings on plot up to 200 m^2 and up to two storeys or 7.5 m in height; and

b) Issuing certificate of supervision for buildings as per (a).

A-2.6 Town Planner

The minimum qualification for a town planner should be the Associate Membership of the Institute of Town Planners or graduate or post-graduate degree in town and country planning.

A-2.6.1 *Competence*

The registered town planner should be competent to carry out the work related to the development permit as given below:

a) Preparation of plans for land subdivision/layout and related information connected with development permit for all areas; and

b) Issuing of certificate of supervision for development of land of all areas.

NOTE — However, for land layouts for development permit above 5 ha in area, landscape architect may also be associated, and for land development infrastructural services for roads, water supplies, sewerage/drainage, electrification, the registered engineers for utility services may be associated.

A-2.7 Landscape Architect

The minimum qualification for a landscape architect should be the bachelor master's degree in landscape architecture or equivalent from recognized Indian or foreign university.

A-2.7.1 *Competence*

The registered landscape architect should be competent to carry out the work related to landscape design for building/development permit for land areas 5 ha and above. In case of metro-cities, this limit of land area may be 2 ha and above.

NOTE — For smaller areas below the limits indicated above, association of landscape architect may also be considered from the point of view of desired landscape development.

A-2.8 Urban Designer

The minimum qualification for an urban designer should be the master's degree in urban design or equivalent from recognized Indian or foreign university.

A-2.8.1 *Competence*

The registered urban designer should be competent to carry out the work related to the building permit for urban design for land areas more than 5 ha and campus area more than 2 ha. He/she should also be competent to carry out the work of urban renewal for all areas.

NOTE — For smaller areas below the limits indicated above, association of urban designer may be considered from the point of view of desired urban design.

A-2.9 Engineers for Utility Services

The work of building and plumbing services should be executed under the planning, design and supervision of competent personnel. The qualification for registered mechanical engineer (including HVAC), electrical engineer and plumbing engineers for carrying out the work of air conditioning, heating and mechanical ventilation, electrical installations, lifts and escalators and water supply, drainage, sanitation and gas supply installations respectively should be as given in Part D 'Building Services' and Part E 'Plumbing Services' of this NBCS or as decided by taking into account practices of the national professional bodies dealing with the specialist engineering services.

Such an approach may be followed for association of other/multi-disciplinary professionals for taking inputs and associating with their areas of specialization. For example, specific to fire (as covered under Part F 'Fire and Life Safety' of this NBCS), the role of fire protection engineer is important, who could be, any of the following:

a) a graduate in fire protection engineering (or a related discipline like fire engineering, fire safety engineering, fire technology and safety engineering, of recognized Indian or foreign university);

b) a graduate in mechanical/civil/electrical/electronics engineering and having a post graduate degree in fire protection engineering;

c) a graduate in mechanical/civil/electrical/electronics engineering and having at least 10 years of experience in the field of planning, designing, and commissioning of fire protection work;

d) an advance diploma in fire engineering (Divisional Officers Course) from National Fire Service College, Nagpur and having atleast five years' experience in the field of fire prevention, fire protection and fire safety matters; and

e) a diploma in fire engineering from National Fire Service College, Nagpur and having atleast ten years' experience in the field of fire prevention, fire protection and fire safety matters.

NOTE — The existing fire protection professionals having graduation in science or diploma in engineering having experience of at least 10 years may be allowed for the activity.

A-2.10 BUILDER/CONSTRUCTOR

The minimum qualification for the builder/constructor or his representative for execution of respective works should be as given in **A-2.1**, **A-2.2**, **A-2.3**, **A-2.4**, **A-2.5**, **A-2.6**, **A-2.7**, **A-2.8** and **A-2.9** for the concerned professional.

A-2.10.1 Competence

The qualified builder/constructor or his representative should be competent to carry out execution of work, which should have the same extent as for supervision by such professional as prescribed in **A-2.1.1**, **A-2.2.1**, **A-2.3.1**, **A-2.4.1**, **A-2.5.1**, **A-2.6.1**, **A-2.7.1**, **A-2.8.1** and **A-2.9**.

A-2.11 PEER REVIEWER/PROOF CHECKER (FOR STRUCTURAL DESIGN)

The individual peer reviewer/proof checker or the team leader of the peer review/proof checking organization should have the following qualification, experience and competence:

a) *For buildings up to the height of 15 m*

B.E./B.Tech (Civil) with 7 years of experience in structural engineering practice with designing and field work of relevant structures. The 7 years of experience should comprise a minimum of 5 years exclusively in structural designing.

b) *For buildings of height more than 15 m and up to 50 m*

B.E./B.Tech (Civil) with 10 years of experience in structural engineering practice with designing and field work of relevant structures. The 10 years of experience should comprise a minimum of 7 years exclusively in structural designing.

c) *For buildings of height more than 50 m and specialized structures*

  1) Master's degree with major in structural engineering and 10 years of experience in structural engineering practice with designing and field work of relevant structures. The 10 years of experience should comprise a minimum of 7 years exclusively in structural designing; or

  2) B.E./B.Tech (Civil) with 15 years of experience in structural engineering practice with designing and field work of relevant structures. The 15 years of experience should comprise a minimum of 10 years exclusively in structural designing.

d) Peer review may also be carried out by reputed academic institutions/research institutions (such as IITs, NITs, IISc, leading engineering colleges, CSIR-SERC, CBRI, CRRI).

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART B BUILDING MATERIALS

BUREAU OF INDIAN STANDARDS

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National Building Code Sectional Committee, CED 46

FOREWORD

This NBCS (Part B) lists Indian Standard specifications for materials used in building construction. The Indian Standards for methods of tests, to ensure the requirements demanded of the materials in the various situations, are also included. This is with a view to ensuring the quality and effectiveness of building materials used in the construction and of their storage, which are as important as other aspects of building activity like planning, designing and constructing the building itself.

Historically, choice of building materials was determined by what was locally available, appropriateness to geo-climatic conditions and affordability of users. In the recent past, different initiatives have been taken in the areas of research and development, standardization, and development and promotion of innovative materials. A review of the recent trends indicates that the growth in the area of building materials covers emerging trends and latest developments in the use of wastes, mineral admixtures in cement and concrete, substitutes to conventional timber, composite materials and recycling of wastes, at the same time ensuring desired response of materials in relation to fire safety, long term performance and durability. In addition to these, nowadays, development of specific materials is being researched which may be structured and designed to meet needs to specially developed construction technologies in time to come, such as, for disaster prone areas or aggressive climatic and industrial situations.

To encourage use of appropriate materials, it may be desirable to have to the largest extent possible, performance oriented approach for specifications rather than prescriptive approach. The approach has been already adopted in some cases in development of standards, wherever found possible.

Indian Standards cover the requirements for most of the materials in use. However, there may be a gap between development of new materials and techniques of application and formulation of standards. It, therefore, becomes necessary for the NBCS to be flexible to recognize building materials other than those for which Indian Standards are available. This Part of NBCS, therefore, since its first version, duly takes care of this aspect and explicitly provides for use of new or alternate building materials, provided it is proved by authentic tests that the new or alternative material is effective and suitable for the purpose intended. However, it is worthwhile that more and more emphasis is given to the satisfaction of performance requirements expected of a building material, so that a wide range of such new or alternate materials can be evaluated and used, if found appropriate.

As already emphasized, quality of material is quite important for their appropriate usage, whether it is a material for which an Indian Standard is available or a new or alternative material as defined in **4** of this Part of the NBCS. While continuing to emphasize on conformity of building materials to available Indian Standards, this Part recommends that the building regulating authority may also recognize the use of building materials conforming to other specifications and test methods (*see* **4.2**), in case Indian Standards are not available for particular materials. Third party certification schemes available in the country for quality assurance of above materials can be used with advantage to ensure the appropriateness of these materials.

It is well recognized that buildings during their construction and subsequently in their operation consume lot of resources. The holistic approach for ensuring proper and sustainable developments is to take care of the concerned aspects affecting sustainability during the conceptualization, planning, design, construction, and operation and maintenance stages. The building material production, transportation and utilization assume a substantial component of the embodied energy that goes into a building. It is therefore important that sustainability of building materials is well understood and ensured in a building project. This Part of the NBCS recognizes this aspect and covers appropriate provision therefore.

This Part of the Code was first published in 1970 as part of the National Building Code of India and subsequently revised in 1983, 2005 and 2016 as Part 5 of NBC 2016. The first and second revision of this Part incorporated an updated version of the list of Indian Standards given at the end of this Part of the Code. Also the list of building materials was completely revised to make it more user-friendly. The third revision of this Part included a new clause on sustainable building materials, expanded the clause on new/alternative materials to provide examples of some potential new/alternative materials, reorganized some of the existing categories and added new categories either under the existing principal categories or as separate principal categories. Additionally, the list of Indian Standards was updated.

In this revision, this publication has been renamed as National Building Construction Standards (NBCS).

This fourth revision of this Part, while basically retaining the structure of previous version, incorporates the following modifications:

a) The clause on new/alternative materials has been updated with examples of some potential new/alternative materials;

b) A clause on recycled materials has been added to address/encourage the usage of recycled materials in building construction; and

c) The list at the end of this Part has been updated to reflect the latest available Indian Standard specifications and methods of test.

A reference to SP 21 : 2005 ‘Summaries of Indian Standards for Building Materials’ may be useful. This publication gives the summaries of Indian Standards covering various building materials, fittings and components except standards relating to paints.

All standards cross-referred in the main text of this Part, are subject to revision. The parties to agreement based on this Part are encouraged to investigate the possibility of applying the most recent editions of the standards.

As the regulation of land development and buildings is a State subject and is dealt by the States and local bodies such as urban local bodies within their jurisdiction through building regulatory documents like building regulations, building byelaws, and fire regulations, this document is voluntary in nature and is non-binding. The implementation depends on adoption by concerned parties or stipulations in a contract or by appropriate adoption by the concerned authorities.

For the purpose of deciding whether a particular requirement of this Part is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 ‘Rules for rounding off numerical values (*second revision*)’. The number of significant places retained in the rounded off value should be the same as that of the specified value in this Part.

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART B BUILDING MATERIALS

1 SCOPE

This NBCS (Part B) covers the requirements of building materials and components, and criteria for accepting new or alternative building materials and components.

2 MATERIALS

Every material used in fulfilment of the requirements of this Part, unless otherwise specified in this NBCS or approved, shall conform to the relevant Indian Standards. A list of Indian Standard specifications as the 'accepted standards' is given at the end of this Part of the NBCS. At the time of publication of this NBCS, the editions indicated were valid. All standards are subject to amendments and revisions. The Authority shall take cognizance of such amendments and revisions. The latest version of a specification shall, as far as possible, be adopted at the time of enforcement of this Part of the NBCS.

3 SUSTAINABLE MATERIALS

Choice of building materials is important in sustainable design because of the extensive network of activities such as extraction, processing and transportation steps required for making a material, and activities involved thereafter till building construction and even thereafter. These activities may pollute the air, soil and water, as well as destroy natural habitats and deplete natural resources. One of the most effective strategies for minimizing the environmental impacts of material usage is to reuse existing buildings. Rehabilitation of existing building, and their shell and non-shell components, not only reduces the volume of solid waste generated and its subsequent diversion to landfills but also the environmental impacts associated with the production, delivery and use or installation of new building materials. However, the use of sustainable building materials is one of the best strategies in the pursuit to sustainable buildings.

An ideal sustainable building material is not only environment friendly but also causes no adverse impact on health of occupants, is readily available, can be reclaimed and recycled, and is not only made from renewable raw material, but also uses predominantly renewable energy in its extraction, production, transportation, fixing and ultimate disposal. Practically, this kind of ideal material may not be available and hence, it may be best to choose materials which fulfil most of these criteria. Sustainable building materials also offer specific benefits to the building owner and building occupants, such as, reduced maintenance/replacement costs over the life of the building; energy conservation; improved occupant health and productivity; lower costs associated with changing space configurations; and greater design flexibility.

The use of used materials (*see* **6**) and recycled and waste materials (*see* **7**) contribute substantially towards sustainability of building material usage.

The selection of sustainable building materials may be made in accordance with relevant guidelines/best practices (Handbook on 'Sustainability in Buildings').

4 NEW OR ALTERNATIVE MATERIALS

4.1 The provisions of this Part are not intended to prevent the use of any material not specifically prescribed under **2**. Any such material may be approved by the Authority or an agency appointed by them for the purpose, provided it is established that the material is satisfactory for the purpose intended and the equivalent of that required in this Part or any other specification issued or approved by the Authority. The Authority or an agency appointed by them shall take into account the following parameters, as applicable to the concerned new or alternative building material:

a) Requirements of the material specified/expected in terms of the provisions given in the standards on its usage, including its applicability in geo-climatic condition;

b) General appearance;

c) Dimension and dimensional stability;

d) Structural stability including strength properties;

e) Fire safety;

f) Durability;

g) Thermal properties;

h) Mechanical properties;

j) Acoustical properties;

k) Optical properties;

m) Biological effect;

n) Environmental aspects;

p) Working characteristics;

q) Ease of handling;

r) Consistency and workability;

s) UV resistance; and

t) Toxicity.

Some of such new/alternative materials may be decorative concrete, polymer concrete, plastic waste bricks, recycled plastic lumber, micro-concrete repair materials, dry-mix mortar, non-shrink grout, special materials for bunkers/blast resistant structures, artificial stones, nanotechnology based advanced materials, vermiculite based boards, exfoliated perlite, pervious concrete, high-pressure laminate sheet, aluminium honeycomb panels, zinc composite panels, stainless steel insulated water tanks, etc.

For establishing the performance of the material/component, laboratory/field tests, and field trials, as required, and study of historical data are recommended. For sampling and frequency of tests for new or alternate materials, similar product standards shall be referred to.

The above materials would no longer be treated as new/alternative materials as soon as Indian Standards for the same are established.

4.2 Approval in writing of the Authority or an agent appointed by them for the purpose of approval of material, shall be obtained by the owner or his agent before any new, alternative or equivalent material is used. The Authority or their agent shall base such approval on the principle set forth in **4.1** and shall require that tests be made (*see* **9.1**) or sufficient evidence or proof be submitted, at the expense of the owner or his agent, to substantiate any claim for the proposed material.

5 THIRD PARTY CERTIFICATION

For ensuring the conformity of materials for which Indian Standards exist and for new or alternative building materials, to requisite quality parameters the services under the third party certification schemes of the Government, may be utilized with advantage.

6 USED MATERIALS

Utilization of used materials and recycled materials may not be precluded provided these meet the requirements of this Part for new materials.

7 RECYCLED MATERIALS AND WASTE MATERIALS

7.1 A recycled building material refers to any product or material that has been previously utilized in another construction context. Various materials, such as brick, steel, timber, and even entire components like doors, windows and tiles, can be reused and repurposed. This term also encompasses building materials produced from waste, such as recycled plastic bricks, or concrete made from recycled aggregate from buildings, structures and pavements. Using suitable technological interventions, the natural and industrial by-products/ wastes can be gainfully utilized in the construction activity, not merely as fillers, but in combination with traditional materials or through repurposing. Some such potential materials include: fly ash, bottom ash, red mud, flue gas desulfurization (FGD) gypsum, phosphogypsum, fluorogypsum, blast furnace slag, Linz-Donawitz (LD) slag, textile sludge, marble waste (from cutting and processing), granite waste (from cutting and processing), iron tailings, mine tailings, copper tailings, copper slag, coal mining waste (coal tailings), rice husk ash, jarosite, broken glass and ceramics, kiln dust, galvanizing waste, tannery waste, stone waste (from crusher units), metal plating industry sludge, lime sludge, vermiculite, perlite and bagasse and other agro-wastes. One of such recycled/waste derived materials is aggregate derived from construction and demolition (C&D) waste, as described in **7.1.1** and **7.1.2**.

7.1.1 *Recycled Mixed Aggregate and Recycled Concrete Aggregate*

Recycled mixed aggregate (RMA) is made from construction and demolition (C&D) waste which may comprise concrete, brick, tiles, stones, etc. C&D waste is generated from construction, renovation, repair, and demolition of buildings and other structures. Recycled concrete aggregate (RCA) on the other hand is derived from concrete waste after requisite processing. Recycled concrete aggregate (RCA) comprises not only the original aggregate, but also the hydrated cement paste adhering to its surface.

7.1.2 *Reclaimed Asphalt Pavement Aggregates*

Milling or demolition of distressed bituminous/flexible pavements generates reclaimed asphalt pavement (RAP) aggregates. These aggregates consist of natural stones fully coated with 2 percent to 7.5 percent (by mass) of bitumen/asphalt binder and are typically used in the construction of new bituminous roads. The use of RAP in cement concrete pavements is rather a new approach and has been found to enhance the workability and toughness characteristics. The strength properties should also be evaluated before permitting for use. Suitably, the coarser fraction of RAP can be used as part replacement (in the order of 10 percent to 20 percent) of natural aggregates for non-structural lean-concrete applications such as paver blocks, kerb stones, etc.

8 STORAGE OF MATERIALS

All building materials shall be stored on the building site in such a way as to prevent deterioration or the loss or impairment of their structural and other essential properties [see relevant guidelines/best practices (Handbook on 'Construction Management, Practices and Safety in Buildings')].

9 METHODS OF TEST

9.1 Every test of material as required in this Part or by the Authority shall be carried out in accordance with the methods of test prescribed in relevant Indian Standards. In cases of methods of tests for which Indian Standards are not available, the same shall conform to the methods of tests issued by the Authority or their agent. A list of Indian Standard methods of test is given at the end of this Part of the NBCS as the 'accepted standards'. Laboratory tests shall be conducted by recognized laboratories acceptable to the Authority.

9.1.1 The manufacturer/supplier shall satisfy himself that materials conform to the requirements of the specifications and if requested shall supply a certificate to this effect to the purchaser or his representative. When such test certificates are not available, the specimen of the material shall be tested.

LIST OF STANDARDS

Following are the Indian Standards for various building materials and components, to be complied with in fulfilment of the requirements of this NBCS.

In the following list, while enlisting the Indian Standards, the materials have been categorized in such a way as to make the list user friendly. In the process, if so required, some of the standards have been included even in more than one category of products, such as in the category based on composition as well as on end application of the materials. The list has been arranged in alphabetical order of their principal category as given below:

1. Aluminium and other light metals and their alloys
2. Bitumen and tar products
3. Bricks, blocks and other masonry building units
4. Builder’s hardware
5. Building chemicals
6. Building lime and products
7. Clay and stabilized soil products
8. Cement and concrete (including steel reinforcement for concrete)
9. Composite matrix products (including cement and resin matrix products)
10. Conductors and cables
11. Doors, windows and ventilators
12. Electrical wiring, fittings and accessories
13. Fillers, stoppers and putties
14. Floor covering, roofing and other finishes
15. Glass
16. Gypsum based materials
17. Mortar (including sand for mortar)
18. Paints and allied products
19. Polymers, plastics and geosynthetics/geotextiles
20. Sanitary appliances and water fittings
21. Steel and its alloys
22. Stones
23. Structural sections
24. Thermal insulation materials
25. Threaded fasteners, rivets and nails
26. Timber, bamboo and other lignocellulosic building materials
27. Unit weights of building materials
28. Waterproofing and damp-proofing materials
29. Welding electrodes and wires
30. Wire ropes and wire products (including wire for fencing)

1 ALUMINIUM AND OTHER LIGHT METALS AND THEIR ALLOYS

IS No.	*Title*
IS 733 : 2025	Wrought aluminium and aluminium alloy bars, rods, sections, extruded tubes, hollow sections and profiles for general engineering purposes — Specification (*fourth revision*)
IS 734 : 1975	Specification for wrought aluminium and aluminium alloy forging stock and forgings (for general engineering purposes) (*second revision*)
IS 736 : 1986	Specification for wrought aluminium and aluminium alloys plate for general engineering purposes (*third revision*)
IS 737 : 2024	Wrought aluminium and aluminium alloys sheet and strip for general engineering purposes — Specification (*fifth revision*)
IS 738 : 1994	Wrought aluminium and aluminium alloys — Drawn tube for general engineering purposes — Specification (*third revision*)
IS 739 : 1992	Wrought aluminium and aluminium alloys — Wire for general engineering purposes — Specification (*third revision*)
IS 740 : 1977	Specification for wrought aluminium and aluminium alloys rivet stock for general engineering purposes (*second revision*)
IS 1254 : 2025	Corrugated aluminium sheet (*fifth revision*)
IS 1284 : 2024	Wrought aluminium alloys bolt and screw stock (for general engineering purposes) — Specification (*third revision*)
IS 1500	Metallic materials — Brinell hardness test:
(Part 1) : 2019	Test method (*fifth revision*)
(Part 2) : 2021	Verification and calibration of testing machines (*fifth revision*)
(Part 3) : 2019	Calibration of reference blocks (*fifth revision*)
(Part 4) : 2019	Table of hardness values (*fifth revision*)
IS 1501	Metallic materials — Vickers hardness test:
(Part 1) : 2025	Test method (*sixth revision*)
(Part 2) : 2020	Verification and calibration of testing machines (*fifth revision*)
(Part 3) : 2020	Calibration of reference blocks (*fifth revision*)
(Part 4) : 2020	Tables of hardness values (*fifth revision*)
IS 1586	Metallic materials — Rockwell hardness test:
(Part 1) : 2025/ ISO 6508-1 : 2023	Test method (*sixth revision*)
(Part 2) : 2025/ ISO 6508-2 : 2023	Verification and calibration of testing machines and indenters (*sixth revision*)

IS No.	*Title*
IS 1586 (Part 3) : 2025/ ISO 6508-3 : 2023	Metallic materials — Rockwell hardness test: Part 3 Calibration of reference blocks (*sixth revision*)
IS 1716 : 2023	Metallic materials wire reverse bend test (*third revision*)
IS 1717 : 2018	Metallic materials — Wire — Simple torsion test (*fourth revision*)
IS 1757	Metallic materials — Charpy pendulum impact test:
(Part 1) : 2020	Test method (*fourth revision*)
(Part 2) : 2020	Verification of testing machines (*fourth revision*)
(Part 3) : 2020	Preparation and characterization of charpy V-notch test pieces for indirect verification of pendulum impact machines (*fourth revision*)
IS 1772 : 2024	Electroplated coatings of copper — Specification (*second revision*)
IS 1828 (Part 1) : 2022	Metallic materials — Calibration and verification of static uniaxial testing machines: Part 1 Tension/Compression testing machines — Calibration and verification of the force-measuring system (*fifth revision*)
IS 2258 : 2023	Rolled zinc plate, sheet and strip — Specification (*third revision*)
IS 2328 : 2018	Metallic materials — Tube — Flattening test (*third revision*)
IS 2479 : 1981	Colour code for the identification of aluminium and aluminium alloys for general engineering purposes (*second revision*)
IS 2605 : 2023	Zinc anodes for electroplating — Specification (*second revision*)
IS 2676 : 1981	Dimensions for wrought aluminium and aluminium alloys, sheet and strip (*first revision*)
IS 2677 : 1979	Dimensions for wrought aluminium and aluminium alloys, plates and hot rolled sheets (*first revision*)
IS 2782 : 2023	Refined nickel — Specification (*first revision*)
IS 3577 : 1992	Wrought aluminium and its alloys — Rivet, bolt and screw stock — Dimensions and tolerances (*first revision*)
IS 3711 : 2020	Steel and steel products — Location and preparation of samples and test pieces for mechanical testing (*third revision*)
IS 3965 : 1981	Dimensions for wrought aluminium and aluminium alloys bar, rod and section (*first revision*)
IS 4258 : 2018	Metallic materials — Conversion of hardness values (*third revision*)
IS 5075 : 2023	Metallic materials — Rotating bar bending fatigue testing (*second revision*)
IS 5528 : 2024/ ISO 9227 : 2022	Corrosion tests in artificial atmospheres — Salt spray tests (*second revision*)
IS 6477 : 1983	Dimensions for wrought aluminium and aluminium alloys extruded hollow sections (*first revision*)

IS No.	*Title*
IS 6885	Metallic materials — Knoop hardness test:
(Part 1) : 2025/ ISO 4545-1 : 2023	Test method (*third revision*)
(Part 2) : 2020	Verification and calibration of testing machines (*second revision*)
(Part 3) : 2020	Calibration of reference blocks (*second revision*)
(Part 4) : 2020	Tables of hardness values (*second revision*)
IS 7811 : 2019	Phosphor bronze rods and bars (*second revision*)
IS 8632 : 2023	Metallic materials — Designation of test specimen axes in relation to product texture (*first revision*)
IS 10175 : 2018	Metallic materials — Sheet and strip — Erichsen cupping test (*third revision*)
IS 11999 : 2022	Metallic materials — Sheet and strip — Determination of plastic strain ratio (*second revision*)
IS 12260 : 2018	Metallic materials — Tube — Ring —Expanding test (*first revision*)
IS 12278 : 2018	Metallic materials — Tube — Ring tensile test (*second revision*)
IS 12444 : 2020	Copper wire rods for electrical applications — Specification (*first revision*)
IS 12871 : 2022	Copper, lead, zinc and nickel concentrates — Sampling procedures for determination of metal and moisture content (*second revision*)
IS 14712 : 2025	Wrought aluminium and its alloys — Chequered/tread sheets for general engineering purposes — Specification (*first revision*)
IS 15756 : 2022	Metallic materials — Sheet and strip — Determination of tensile strain hardening exponent (*first revision*)
IS 15965 : 2012	Pre-painted aluminium zinc alloy metallic coated steel strip and sheet (Plain)
IS 16842 : 2022	Metallic materials — Fatigue testing — Fatigue crack growth method (*first revision*)
IS 16843 : 2018	Metallic materials — Fatigue testing — Strain-controlled thermomechanical fatigue testing method
IS 17143 : 2023	Metallic materials torque — Controlled fatigue testing (*first revision*)
IS 17144	Metallic materials — Instrumented indentation test for hardness and materials parameters:
(Part 1) : 2019	Test method
(Part 2) : 2019	Verification and calibration of testing machines
(Part 3) : 2019	Calibration of reference blocks
(Part 4) : 2019	Test method for metallic and non-metallic coatings

IS No.	*Title*
IS 17145	Metallic materials — Fatigue testing — Variable amplitude fatigue testing:
(Part 1) : 2019	General principles, test method and reporting requirements
(Part 2) : 2019	Cycle counting and related data reduction methods
IS 17149	Metallic materials — Leeb hardness test:
(Part 1) : 2019	Test method
(Part 2) : 2019	Verification and calibration of the testing devices
(Part 3) : 2019	Calibration of reference test blocks
IS 17151 : 2023	Metallic materials unified method of test for the determination of quasistatic fracture toughness (*first revision*)
IS 17413	Metallic materials — Tensile testing at high strain rates:
(Part 1) : 2020	Elastic-bar-type systems
(Part 2) : 2020	Servo-hydraulic and other systems
IS 17415 : 2023	Metallic materials torsion test at room temperature (*first revision*)
IS 17416 : 2024/ ISO 14556 : 2023	Metallic materials — Charpy V-Notch pendulum impact test — Instrumented test method (*first revision*)
IS 17418 : 2020	Metallic materials — Sheet and strip — Biaxial tensile testing method using a cruciform test piece
IS 17146 (Part 1) : 2023	Metallic materials determination of forming-limit curves for sheet and strip: Part 1 Measurement and application of forming-limit diagrams in the press shop (*first revision*)
IS 17417	Metallic materials — Dynamic force calibration for uniaxial fatigue testing:
(Part 1) : 2020	Testing systems
(Part 2) : 2020	Dynamic calibration device (DCD) instrumentation
IS 17419 : 2025	Metallic materials — Ductility testing — High speed compression test for porous and cellular metals (*first revision*)
IS 17679 : 2021	Metallic materials — Method of test for the determination of quasistatic fracture toughness of welds
IS 17682 : 2021	Aluminium composite panel specification
IS 17795 : 2025	Metallic materials — Uniaxial creep testing in tension — Method of test (*first revision*)
IS 17915 : 2022	Method for evaluation of tensile properties of metallic superplastic materials
IS 17937 : 2022	Mechanical testing of metals ductility testing compression test for porous and cellular metals
IS 18649 : 2024/	Corrosion of metals and alloys — Alternate immersion test in salt solution

IS No.	*Title*
ISO 11130 : 2017	
IS 18650 : 2024/ ISO 26146 : 2012	Corrosion of metals and alloys — Method for metallographic examination of samples after exposure to high-temperature corrosive environments

2 BITUMEN AND TAR PRODUCTS

IS No.	*Title*
IS 73 : 2013	Paving bitumen — Specification (*fourth revision*)
IS 212 : 2021	Crude coal tar for general use (*third revision*)
IS 216 : 2006	Coal tar pitch — Specification (*second revision*)
IS 217 : 2018	Cutback bitumen — Specification (*third revision*)
IS 218 : 1983	Specification for creosote oil for use as wood preservatives (*second revision*)
IS 334 : 2023	Glossary of terms relating to bitumen and tar (*fourth revision*)
IS 702 : 2022	Specification for industrial bitumen (*third revision*)
IS 1201 to IS 1220	Methods for testing tar and bituminous materials:
IS 1201 : 2021	Sampling (*second revision*)
IS 1202 : 2021	Determination of specific gravity (*second revision*)
IS 1203 : 2022	Determination of penetration (*second revision*)
IS 1204 : 2022	Determination of residue of specified penetration (*second revision*)
IS 1205 : 2022	Determination of softening point — Ring and ball apparatus (*second revision*)
IS 1206	Determination of viscosity:
(Part 1) : 2023	By volumetric flow rate method
(Part 2) : 2022	Absolute viscosity
(Part 3) : 2021	Kinematic viscosity
IS 1207 : 2022	Determination of equiviscous temperature EVT (*second revision*)
IS 1208	Methods for Testing Tar and Bituminous Materials
(Part 1) : 2023	Determination of ductility (*second revision*)
(Part 2) : 2023	Determination of elastic recovery (*second revision*)
IS 1209 : 2021	Determination of flash point and fire point (*second revision*)
IS 1210 : 2020	Float test (*second revision*)
IS 1211 : 2022	Determination of water content dean and stark method (*second revision*)
IS 1212 : 2022	Determination of loss on heating (*second revision*)

IS No.	*Title*
IS 1213 : 2025	Tar and bituminous materials — Distillation test — Methods of test (*third revision*)
IS 1215 : 2021	Determination of matter insoluble in toluene (*second revision*)
IS 1216 : 2023	Determination of solubility in trichloroethylene (*second revision*)
IS 1217 : 2024	Tar and bituminous materials — Determination of mineral matter (ash) — Methods of test (*second revision*)
IS 1218 : 2024	Tar and bituminous materials — Methods for test — Determination of phenols (*second revision*)
IS 1219 : 2024	Tar and bituminous materials — Methods for test — Determination of naphthalene (*second revision*)
IS 1220 : 2024	Tar and bituminous materials — Methods for test — Determination of volatile matter content *(second revision)*
IS 3117 : 2004	Bitumen emulsion for roads and allied applications (anionic type) — Specification (*first revision*)
IS 8887 : 2018	Bitumen emulsion for roads cationic type — Specification *(third revision)*
IS 9381 : 2024	Tar and bituminous materials — Determination of Fraass breaking point of bitumen — Methods of test (*first revision*)
IS 9382 : 2022	Methods for testing tar and bituminous materials — Determination of effect of heat and air by thin film oven test (*first revision*)
IS 10511 : 2024	Method for determination of asphaltenes in bitumen by precipitation with normal heptane (*first revision*)
IS 10512 : 2003	Method for determination of wax content in bitumen (*first revision*)
IS 13758	Coal tar pitch — Methods of test:
(Part 1) : 1993	Determination of matter insoluble in quinoline
(Part 2) : 1993	Determination of coking value
IS 14982 : 2022	Anti-Stripping agents for bitumen addition — Specification (*second revision*)
IS 15172 : 2002	Methods for testing tar and bituminous materials — Determination of curing index for cutback bitumens
IS 15173 : 2002	Methods for testing tar and bituminous materials — Determination of breaking point for cationic bitumen emulsion
IS 15174 : 2002	Methods for testing tar and bituminous material — Determination of breaking point for anionic bitumen emulsion
IS 15462 : 2019	Polymer modified bitumen (PMB) specification (*first revision*)
IS 15799 : 2021	Methods for testing tar and bituminous materials — Ageing of bitumen (RTFOT and PAV) (*first revision*)
IS 15808 : 2008	Multigrade bitumen for use in pavement construction — Specification
IS 17016 : 2018	Cationic modified bitumen emulsion — Specification

IS No.	*Title*
IS 17052 : 2018	Rejuvenating agents for hot mix recycling of bituminous surfacing — Specification
IS 17079 : 2019	Rubber modified bitumen (RMB) — Specification
IS 17116 : 2019	Determination of resistance of compacted bituminous mixture to moisture — Induced damage
IS 17124 : 2019	Crack sealants — Specification
IS 17127 : 2019	Determination of stability, flow and bulk density of bituminous mixes by Marshall method
IS 17335 : 2020	Determination of apparent viscosity of bituminous binders at elevated temperature by rotational viscometer
IS 18104 : 2022	Methods for testing tar and bituminous materials — Determination of draindown characteristics of uncompacted bitumen mixtures
IS 18130 : 2023	Method for recovery of bitumen from solution using rotary evaporator
IS 18883 : 2025	Trackless emulsion — Specification
IS 19008 : 2023	Determination of bitumen content in bituminous paving mixtures

3 BRICKS, BLOCKS AND OTHER MASONRY BUILDING UNITS

IS No.	*Title*
IS 1077 : 2025	Common burnt clay building bricks — Specification (*sixth revision*)
IS 1725 : 2023	Stabilized soil blocks used in general building construction — Specification (*third revision*)
IS 2180 : 1988	Specification for heavy duty burnt clay building bricks (*third revision*)
IS 2185	Specification for concrete masonry units:
(Part 1) : 2005	Hollow and solid concrete blocks (*third revision*)
(Part 2) : 1983	Hollow and solid lightweight concrete blocks (*first revision*)
(Part 3) : 1984	Autoclaved cellular (aerated) concrete blocks (*first revision*)
(Part 4) : 2008	Preformed foam cellular concrete blocks
IS 2222 : 1991	Specification for burnt clay perforated building bricks (*third revision*)
IS 2691 : 2017	Burnt clay facing bricks — Specification (*third revision*)
IS 2849 : 1983	Specification for non-load bearing gypsum partition blocks (solid and hollow types) (*first revision*)
IS 3115 : 1992	Specification for lime based blocks (*second revision*)
IS 3316 : 1974	Specification for structural granite (*first revision*)
IS 3495	Burnt clay building bricks method of tests:

IS No.	*Title*
(Part 1) : 2019	Determination of compressive strength (*fourth revision*)
(Part 2) : 2019	Determination of water absorption (*fourth revision*)
(Part 3) : 2019	Determination of efflorescence (*fourth revision*)
(Part 4) : 2019	Determination of warpage (*fourth revision*)
(Part 5) : 2021	Determination of initial rate of absorption
(Part 6) : 2022	Determination of modulus of rupture
IS 3583 : 1988	Specification for burnt clay paving bricks (*second revision*)
IS 3620 : 1979	Specification for laterite stone block for masonry (*first revision*)
IS 3952 : 2013	Burnt clay hollow bricks and blocks for walls and partitions — Specification (*third revision*)
IS 4139 : 1989	Specification for calcium silicate bricks (*second revision*)
IS 4860 : 1968	Specification for acid resistant bricks
IS 4885 : 1988	Specification for sewer bricks (*first revision*)
IS 5454 : 2024	Burnt clay bricks and burnt clay tiles — Methods of sampling (*second revision*)
IS 5751 : 1984	Specification for precast concrete coping blocks (*first revision*)
IS 5779 : 1986	Specification for burnt clay soling bricks (*first revision*)
IS 6165 : 1992	Dimensions for special shapes of clay bricks (*first revision*)
IS 9893 : 1981	Specification for precast concrete blocks for lintels and sills
IS 10360 : 1982	Specification for lime pozzolana concrete blocks for paving
IS 12440 : 1988	Specification for precast concrete stone masonry blocks
IS 12894 : 2002	Specification for pulverized fuel ash lime bricks (*first revision*)
IS 13757 : 1993	Burnt clay fly ash building bricks — Specification
IS 15658 : 2021	Concrete paving blocks — Specification (*first revision*)
IS 16720 : 2018	Pulverized fuel ash-cement bricks — Specification
IS 17165 : 2020	Manufacture of stabilized soil blocks — Guidelines

4 BUILDER’S HARDWARE

IS No.	*Title*
IS 204	Specification for tower bolts:
(Part 1) : 1991	Ferrous metals (*fifth revision*)
(Part 2) : 1992	Non-ferrous metals (*fifth revision*)

IS No.	*Title*
IS 205 : 1992	Specification for non-ferrous metal butt hinges (*fourth revision*)
IS 206 : 2010	Specification for tee and strap hinges (*fifth revision*)
IS 208 : 2020	Door handles — Specification (*sixth revision*)
IS 281 : 2009	Specification for mild steel sliding door bolts for use with padlocks (*fourth revision*)
IS 362 : 1991	Specification for parliament hinges (*fifth revision*)
IS 363 : 1993	Specification for hasps and staples (*fourth revision*)
IS 364 : 1993	Specification for fanlight catch (*third revision*)
IS 452 : 1973	Specification for door springs, rat-tail type (*second revision*)
IS 453 : 1993	Specification for double-acting spring hinges (*third revision*)
IS 729 : 2021	Drawer locks cupboard locks and box locks — Specification (*fourth revision*)
IS 1019 : 1974	Specification for rim latches (*second revision*)
IS 1341 : 2018	Steel butt hinges — Specification (*sixth revision*)
IS 1823 : 1980	Specification for floor door stoppers (*third revision*)
IS 1837 : 1966	Specification for fanlight pivots (*first revision*)
IS 2681 : 1993	Specification for nonferrous metal sliding door bolts for use with padlocks (*third revision*)
IS 3564 : 2025	Hydraulically regulated door closers — Specification (*fifth revision*)
IS 3818 : 1992	Specification for continuous (piano) hinges (*third revision*)
IS 3828 : 1966	Specification for ventilator chains
IS 3843 : 1995	Steel back flap hinges — Specification (*second revision*)
IS 4621 : 1975	Specification for indicating bolts for use in public baths and lavatories (*first revision*)
IS 4948 : 2020	Welded steel wire fabric for general use — Specification (*third revision*)
IS 4992 : 2024	Door handles for mortice locks — Specification (*second revision*)
IS 5187 : 1972	Specification for flush bolts (*first revision*)
IS 5899 : 1970	Specification for bathroom latches
IS 6315 : 2025	Hydraulically regulated floor springs — Specification (*third revision*)
IS 6318 : 1971	Specification for plastic window stays and fasteners
IS 6343 : 1982	Specification for door closers (pneumatically regulated) for light door weighing up to 40 kg (*first revision*)
IS 7196 : 1974	Specification for hold fast

IS No.	*Title*
IS 7197 : 1974	Specification for double action floor springs (without oil check) for heavy doors
IS 7534 : 1985	Specification for sliding locking bolts for use with padlocks (*first revision*)
IS 7881	Glossary of terms relating to builders' hardware:
(Part 1) : 2023	Locks (*first revision*)
(Part 2) : 2022	Latches (*first revision*)
IS 8756 : 1978	Specification for ball catches for use in wooden almirah
IS 9106 : 1979	Specification for rising butt hinges
IS 9131 : 2021	Rim locks and latches mechanically operated — Specification (*first revision*)
IS 9460 : 1980	Specification for flush drop handle for drawer
IS 9899 : 1981	Specification for hat coat and wardrobe hooks
IS 10019 : 1981	Specification for mild steel stays and fasteners
IS 10090 : 1982	Specification for numericals
IS 10342 : 1982	Specification for curtain rail system
IS 12817 : 2020	Stainless steel butt hinges — Specification (*third revision*)
IS 12867 : 1989	Specification for PVC hand rails covers
IS 14912 : 2001	Specification for door closers concealed type (hydraulically regulated)
IS 15833 : 2009	Stainless steel tower bolts — Specification
IS 15834 : 2020	Stainless steel sliding door bolts (Aldrops) for use with padlocks — Specification *(first revision)*
IS 16015 : 2022	Mortise locks and latches mechanically operated — Specification (*first revision*)
IS 16016 : 2013	Cylindrical locks with pin tumbler mechanism — Specification
IS 17296 : 2020	Stainless steel door stoppers — Specification
IS 17706 : 2022	Pull handles — Specification
IS 17954 : 2023	Telescopic ball bearing drawer slide — Specification
IS 18297 : 2023	Cabinet hinges — Specification

5 BUILDING CHEMICALS:

a) Anti-termite Chemicals

IS No.	*Title*
IS 5549 : 2023	Warfarin bait concentrates — Specification (*first revision*)
IS 7168 : 2023	Warfarin sodium salt water soluble powders — Specification (*first revision*)

IS No.	*Title*
IS 8703 : 2023	Diuron water dispersible powder concentrates — Specification (*first revision*)
IS 8944 : 2005	Chlorpyrifos emulsifiable concentrates — Specification (*first revision*)
IS 16706 : 2018	Carpropamid, technical — Specification
IS 16955 : 2019	Spiromesifen, suspension concentrate (SC) — Specification

b) Chemical Admixture/Water Proofing Compounds

IS No.	*Title*
IS 2645 : 2003	Integral waterproofing compounds for cement mortar and concrete — Specification (*second revision*)
IS 6925 : 1973	Methods of test for determination of water soluble chlorides in concrete admixtures
IS 9103 : 1999	Specification for concrete admixtures (*first revision*)

c) Sealants/Fillers

IS No.	*Title*
IS 1834 : 1984	Specification for hot applied sealing compound for joint in concrete (*first revision*)
IS 1838	Specification for preformed fillers for expansion joint in concrete pavements and structures (non extruding and resilient type):
(Part 1) : 1983	Bitumen impregnated fibre (*first revision*)
(Part 2) : 1984	CNSL aldehyde resin and coconut pith
(Part 3) : 2011	Polymer based
IS 10566 : 1983	Methods of tests for preformed fillers for expansion joint in concrete paving and structural construction
IS 10959 : 2024/ ISO 6927 : 2021	Sealants for building purposes — Glossary of terms (*second revision*)
IS 11433	Specification for one-part gun — Grade polysulphide-based joint sealants:
(Part 1) : 1985	General requirements
(Part 2) : 1986	Methods of test
IS 12118	Specification for two parts polysulphide-based sealants:
(Part 1) : 1987	General requirements
(Part 2) : 1987	Methods of test
IS 13923 : 2023	Lead seal — Specification (*first revision*)

d) Adhesives

IS No.	*Title*
IS 848 : 2025	Synthetic resin adhesives for plywood (phenolic, aminoplastic and bio-materials based) — Specification (*third revision*)
IS 851 : 1978	Specification for synthetic resin adhesives for construction work (non-structural) in wood (*first revision*)
IS 852 : 1994	Animal glue for general wood-working purposes — Specification (*second revision*)
IS 1508 : 1972	Specification for extenders for use in synthetic resin adhesives (urea-formaldehyde) for plywood (*first revision*)
IS 4835 : 1979	Specification for polyvinyl acetate dispersion-based adhesives for wood (*first revision*)
IS 5666 : 2024	Etch primer — Specification (*first revision*)
IS 9188 : 1979	Performance requirements for adhesive for structural laminated wood products for use under exterior exposure condition
IS 12830 : 1989	Rubber based adhesives for fixing PVC tiles to cement — Specification
IS 12994 : 1990	Epoxy adhesives, room temperature curing general purpose — Specification
IS 13238 : 2021	Epoxy based zinc phosphate primer (two pack) — Specification (*first revision*)
IS 15477 : 2019	Adhesives for use with ceramic tiles and mosaics (*first revision*)
IS 16239 : 2021	Polyurethane matt finish (two pack) — Specification
IS 16676 : 2024	Solventless liquid epoxy system for application on interior and exterior surfaces of steel water pipeline — Specification (*first revision*)
IS 16943 : 2019	Two components high build epoxy micaceous iron oxide (MIO) pigmented intermediate coat — Specification
IS 16944 : 2018	Two components high build epoxy titanium dioxide (TiO_2) pigmented intermediate coat — Specification
IS 17218 : 2019	Solar thermo-reflective exterior coating for cooling of roof top
IS 17545 : 2021	White cement based polymeric putty
IS 18837 : 2024	Solvent cements for chlorinated poly (vinyl chloride) (CPVC) plastic pipe and fittings

6 BUILDING LIME AND PRODUCTS

IS No.	*Title*
IS 712 : 1984	Specification for building limes (*third revision*)
IS 1624 : 1986	Method of field testing of building lime (*second revision*)
IS 2686 : 1977	Specification for cinder as fine aggregates for use in lime concrete (*first revision*)

IS No.	*Title*
IS 3068 : 1986	Specification for broken brick (burnt-clay) coarse aggregates for use in lime concrete (*second revision*)
IS 3115 : 1992	Specification for lime based blocks (*second revision*)
IS 3182 : 1986	Specification for broken bricks (burnt clay) fine aggregates for use in lime mortar (*second revision*)
IS 4098 : 1983	Specification for lime-pozzolana mixture (*first revision*)
IS 4139 : 1989	Specification for calcium silicate bricks (*second revision*)
IS 6932	Method of tests for building limes:
(Part 1) : 2025	Determination of insoluble residue in dilute acid and alkali, loss on ignition, insoluble residue in hydrochloric acid, silicon dioxide, ferric and aluminium oxide, calcium oxide and magnesium oxide (*first revision*)
(Part 2) : 2025	Determination of carbon dioxide content (*first revision*)
(Part 3) : 2025	Determination of residue on slaking of quicklime (*first revision*)
(Part 4) : 2025	Determination of fineness of hydrated lime (*first revision*)
(Part 5) : 2025	Determination of unhydrated oxide (*first revision*)
(Part 6) : 2025	Determination of volume yield of quicklime (*first revision*)
(Part 7) : 2025	Determination of compressive and transverse strength (*first revision*)
(Part 8) : 2025	Determination of workability (*first revision*)
(Part 9) : 2025	Determination of soundness (*first revision*)
(Part 10) : 2025	Determination of popping and pitting of hydrated lime (*first revision*)
(Part 11) : 2025	Determination of setting time of hydrated lime (*first revision*)
IS 10360 : 1982	Specification for lime pozzolana concrete blocks for paving
IS 10772 : 1983	Specification for quick setting lime pozzolana mixture
IS 12894 : 2002	Specification for pulverized fuel ash lime bricks (*first revision*)
IS 15648 : 2006	Pulverized fuel ash for lime-pozzolana mixture applications — Specification

7 CLAY AND STABILIZED SOIL PRODUCTS

a) Blocks

IS No.	*Title*
IS 3952 : 2013	Burnt clay hollow bricks and blocks for walls and partitions — Specification (*third revision*)

b) Stabilized Soil Products

IS No.	*Title*
IS 1725 : 2023	Stabilized soil blocks used in general building construction — Specification (*third revision*)

c) Bricks

IS No.	*Title*
IS 1077 : 2025	Common burnt clay building bricks — Specification (*sixth revision*)
IS 2180 : 1988	Specification for heavy duty burnt clay building bricks (*third revision*)
IS 2222 : 1991	Specification for burnt clay perforated building bricks (*third revision*)
IS 2691 : 2017	Burnt clay facing bricks — Specification (*third revision*)
IS 3495	Burnt clay building bricks — Method of tests
(Part 1) : 2019	Determination of compressive strength (*fourth revision*)
(Part 2) : 2019	Determination of water absorption (*fourth revision*)
(Part 3) : 2019	Determination of efflorescence (*fourth revision*)
(Part 4) : 2019	Determination of warpage (*fourth revision*)
(Part 5) : 2021	Determination of initial rate of absorption
(Part 6) : 2022	Determination of modulus of rupture
IS 3583 : 1988	Specification for burnt clay paving bricks (*second revision*)
IS 3952 : 2013	Burnt clay hollow bricks and blocks for walls and partitions — Specification (*third revision*)
IS 4885 : 1988	Specification for sewer bricks (*first revision*)
IS 5454 : 2024	Burnt clay bricks and burnt clay tiles — Methods of sampling (*second revision*)
IS 5779 : 1986	Specification for burnt clay soling bricks (*first revision*)
IS 6165 : 1992	Dimensions for special shapes of clay bricks (*first revision*)
IS 13757 : 1993	Burnt clay fly ash building bricks — Specification

d) Jallies

IS No.	*Title*
IS 7556 : 1988	Specification for burnt clay jallies (*first revision*)

e) Tiles

IS No.	*Title*
IS 654 : 2023	Clay roofing tiles Mangalore pattern — Specification (*fourth revision*)

IS No.	*Title*
IS 1464 : 2024	Clay ridge and ceiling tiles — Specification (*third revision*)
IS 1478 : 2023	Clay flooring tiles — Specification (*third revision*)
IS 2690	Burnt clay flat terracing tiles — Specification
(Part 1) : 2023	Machine made (*third revision*)
(Part 2) : 2023	Hand made (*second revision*)
IS 3367 : 2023	Burnt clay tiles for use in lining irrigation and drainage works — Specification (*third revision*)
IS 3951	Hollow clay tiles for floor and roofs — Specification
(Part 1) : 2023	Filler type (*third revision*)
(Part 2) : 2023	Structural type (*third revision*)
IS 8920 : 1978	Methods for sampling of burnt clay tiles
IS 13317 : 2023	Clay roofing county tiles half round and flat tiles — Specification (*first revision*)
IS 17190 : 2020	Grouts for filling of joints of tiles and stones — Specification
IS 17897 : 2022	Stone-polymer composite flooring tiles and planks — Specification
IS 18387 : 2023	Gypsum ceiling tiles — Specification

8 CEMENT AND CONCRETE (INCLUDING STEEL REINFORCEMENT FOR CONCRETE)

a) Aggregates

IS No.	*Title*
IS 383 : 2016	Coarse and fine aggregate for concrete — Specification (*third revision*)
IS 4961 : 2022	Determination of particle size of powders by air elutriation methods (*first revision*)
IS 650 : 1991	Specification for standard sand for testing of cement (*second revision*)
IS 1542 : 1992	Specification for sand for plaster (*second revision*)
IS 2116 : 1980	Specification for sand for masonry mortars (*first revision*)
IS 2386	Methods of test for aggregates for concrete:
(Part 1) : 1963	Particle size and shape
(Part 2) : 1963	Estimation of deleterious materials and organic impurities
(Part 3) : 1963	Specific gravity, density, voids, absorption and bulking
(Part 4) : 1963	Mechanical properties
(Part 5) : 1963	Soundness

IS No.	*Title*
(Part 6) : 1963	Measuring mortar making properties of fine aggregates
(Part 7) : 1963	Alkali aggregate reactivity
(Part 8) : 1963	Petrographic examination
IS 2430 : 1986	Methods of sampling of aggregates of concrete (*first revision*)
IS 4879 : 2023	Particulate materials — Sampling and sample splitting technique (*first revision*)
IS 5282	Determination of particle size distribution by gravitational liquid sedimentation methods:
(Part 1) : 2023	General principles and guidelines (*first revision*)
(Part 2) : 2023	Fixed pipette method (*first revision*)
(Part 3) : 2023	X-Ray gravitational technique *(first revision)*
(Part 4) : 2023	Balance method *(first revision)*
IS 6579 : 1981	Specification for coarse aggregate for water bound macadam (*first revision*)
IS 9142	Artificial light-weight aggregates for concrete — Specification:
(Part 1) : 2018	For concrete masonry blocks and for applications other than for structural concrete (*first revision*)
(Part 2) : 2018	Sintered fly ash coarse aggregate (*first revision*)
IS 10086 : 2021	Specification for moulds for use in tests of cement and concrete (*first revision*)
IS 18657	Representation of results of particle size analysis:
(Part 1) : 2024/ ISO 9276-1 : 1998	Graphical representation
(Part 2) : 2024/ ISO 9276-2 : 2014	Calculation of average particle sizes/diameters and moments from particle size distributions
(Part 3) : 2024/ ISO 9276-3 : 2008	Adjustment of an experimental curve to a reference model
(Part 4) : 2024/ ISO 9276-4 : 2001	Characterization of a classification process
(Part 5) : 2024/ ISO 9276-5 : 2005	Methods of calculation relating to particle size analyses using logarithmic normal probability distribution
(Part 6) : 2024/ ISO 9276-6 : 2008	Descriptive and quantitative representation of particle shape and morphology

b) Cement

IS No.	*Title*
IS 269 : 2015	Ordinary portland cement — Specification (*sixth revision*)
IS 455 : 2015	Portland slag cement — Specification (*fifth revision*)

IS 1489	Portland pozzolana cement — Specification:
(Part 1) : 2015	Flyash based (*fourth revision*)
(Part 2) : 2015	Calcined clay based (*fourth revision*)
IS 3466 : 2026	Masonry cement — Specification (*third revision*)
IS 6452 : 1989	Specification for high alumina cement for structural use (*first revision*)
IS 6909 : 2026	Supersulphated cement — Specification (*second revision*)
IS 8041 : 2026	Rapid hardening portland cement — Specification (*third revision*)
IS 8042 : 2015	White portland cement — Specification (*third revision*)
IS 8043 : 2026	Hydrophobic portland cement — Specification (*third revision*)
IS 12330 : 1988	Specification for sulphate resisting portland cement
IS 12600 : 1989	Portland cement, low heat — Specification
IS 16415 : 2015	Composite cement — Specification
IS 16993 : 2018	Microfine ordinary portland cement — Specification
IS 17908 : 2023	Fibre cement sheet — Lightweight concrete sandwich panels specification
IS 18189 : 2023	Portland calcined clay limestone cement — Specification

c) Supplementary Cementitious Materials (Mineral Admixtures and Pozzolanas)

IS No.	*Title*
IS 1344 : 1981	Specification for calcined clay pozzolana (*second revision*)
IS 1727 : 1967	Methods of test for pozzolanic materials (*first revision*)
IS 3812	Pulverized fuel ash — Specification:
(Part 1) : 2013	For use as pozzolana in cement, cement mortar and concrete (*third revision*)
(Part 2) : 2013	For use as admixture in cement mortar and concrete (*third revision*)
IS 6491 : 1972	Method of sampling of flyash
IS 12089 : 1987	Specification for granulated slag for manufacture of portland slag cement
IS 12870 : 1989	Methods of sampling calcined clay pozzolana
IS 15388 : 2003	Specification for silica fume
IS 16354 : 2015	Metakaolin for use in cement, cement mortar and concrete — Specification
IS 16714 : 2018	Ground granulated blast furnace slag for use in cement mortar and concrete — Specification
IS 16715 : 2018	Ultrafine ground granulated blast furnace slag — Specification
IS 19058 : 2024	Ultrafine fly ash — Specification

d) Chemical Admixtures

IS No.	*Title*
IS 6925 : 1973	Methods of test for determination of water soluble chlorides in concrete admixtures
IS 9103 : 1999	Specification for admixtures for concrete (*first revision*)

e) Concrete

IS No.	*Title*
IS 456 : 2000	Code of practice for plain and reinforced concrete (*fourth revision*)
IS 1343 : 2012	Code of practice for prestressed concrete (*second revision*)
IS 4926 : 2003	Code of practice for ready-mixed concrete (*second revision*)

f) Cement and Concrete Sampling and Methods of Test

IS No.	*Title*
IS 516	Hardened concrete methods of test:
(Part 1/Sec 1) : 2021	Testing of strength of hardened concrete, Section 1 Compressive, flexural and split tensile strength (*first revision*)
(Part 2)	Properties of hardened concrete other than strength,
(Sec 1) : 2018	Density of hardened concrete and depth of water penetration under pressure (*first revision*)
(Sec 2) : 2020	Initial surface absorption (*first revision*)
(Sec 3) : 2022	Oxygen permeability index (*first revision*)
(Sec 4) : 2021	Determination of the carbonation resistance by accelerated carbonation method (*first revision*)
(Part 4) : 2018	Sampling preparing and testing of concrete cores (*first revision*)
(Part 5)	Non-destructive testing of concrete,
(Sec 1) : 2018	Ultrasonic pulse velocity testing (*first revision*)
(Sec 2) : 2021	Half-cell potentials of uncoated reinforcing steel in concrete (*first revision*)
(Sec 3) : 2021	Carbonation depth test (*first revision*)
(Sec 4) : 2020	Rebound hammer test (*first revision*)
(Part 6) : 2020	Determination of drying shrinkage and moisture movement of concrete samples (*first revision*)
(Part 8/Sec 1) : 2020	Determination of modulus of elasticity, Section 1 Static modulus of elasticity and poissons ratio in compression (*first revision*)
(Part 11) : 2020	Determination of portland cement content of hardened hydraulic cement concrete (*first revision*)

IS No.	*Title*
IS 1199	Fresh concrete — Methods of sampling testing and analysis:
(Part 1) : 2018	Sampling of fresh concrete (*first revision*)
(Part 2) : 2018	Determination of consistency of fresh concrete (*first revision*)
(Part 3) : 2018	Determination of density of fresh concrete (*first revision*)
(Part 4) : 2018	Determination of air content of fresh concrete (*first revision*)
(Part 5) : 2018	Making and curing of test specimens (*first revision*)
(Part 6) : 2018	Tests on fresh self-compacting concrete (*first revision*)
(Part 7) : 2018	Determination of setting time of concrete by penetration resistance (*first revision*)
IS 2770 (Part 1) : 1967	Methods of testing bond in reinforced concrete: Part 1 Pullout test
IS 3085 : 1965	Methods of test for permeability of cement mortar and concrete
IS 3535 : 1986	Methods of sampling hydraulic cement (*first revision*)
IS 4031	Methods of physical tests for hydraulic cement:
(Part 1) : 1996	Determination of fineness by dry sieving (*second revision*)
(Part 2) : 1999	Determination of fineness by specific surface by Blaine air permeability method (*second revision*)
(Part 3) : 1988	Determination of soundness (*first revision*)
(Part 4) : 1988	Determination of consistency of standard cement paste (*first revision*)
(Part 5) : 1988	Determination of initial and final setting times (*first revision*)
(Part 6) : 1988	Determination of compressive strength of hydraulic cement (other than masonry cement) (*first revision*)
(Part 7) : 1988	Determination of compressive strength of masonry cement (*first revision*)
(Part 8) : 1988	Determination of transverse and compressive strength of plastic mortar using prism (*first revision*)
(Part 9) : 1988	Determination of heat of hydration (*first revision*)
(Part 10) : 1988	Determination of drying shrinkage (*first revision*)
(Part 11) : 1988	Determination of density (*first revision*)
(Part 12) : 1988	Determination of air content of hydraulic cement mortar (*first revision*)
(Part 13) : 1988	Measurement of water retentivity of masonry cement (*first revision*)
(Part 14) : 1989	Determination of false set
(Part 15) : 1991	Determination of fineness by wet sieving
IS 4032 : 1985	Methods of chemical analysis for hydraulic cement (*first revision*)
IS 5816 : 1999	Method of test for splitting tensile strength of concrete (*first revision*)

IS No.	*Title*
IS 9013 : 1978	Method of making, curing and determining compressive strength of accelerated cured concrete test specimens
IS 9284 : 1979	Method of test for abrasion resistance of concrete
IS 12423 : 1988	Methods for colorimetric analysis of hydraulic cement
IS 12803 : 1989	Methods of analysis of hydraulic cement by X-ray fluorescence spectrometer
IS 12813 : 1989	Method of analysis of hydraulic cement by atomic absorption spectrophotometer
IS 13311	Methods of non-destructive testing of concrete:
(Part 2) : 1992	Rebound hammer
IS 14959	Method of test for determination of water soluble and acid soluble chlorides in mortar and concrete
(Part 1) : 2001	Fresh mortar and concrete
(Part 2) : 2001	Hardened mortar and concrete
IS 17161 : 2020	Flexural strength and toughness parameters of fibre reinforced concrete — Method of test
IS 17725 : 2022	Precast concrete circular manhole — Specification

g) Treatment of Concrete Joints

IS No.	*Title*
IS 1834 : 1984	Specification for hot applied sealing compound for joint in concrete (*first revision*)
IS 1838	Specification for preformed fillers for expansion joint in concrete pavements and structures (non extruding and resilient type):
(Part 1) : 1983	Bitumen impregnated fibre (*first revision*)
(Part 2) : 1984	CNSL aldehyde resin and coconut pith
(Part 3) : 2011	Polymer based
IS 10566 : 1983	Methods of test for preformed fillers for expansion joints in concrete paving and structural construction
IS 11433	Specification for one grade polysulphide based joint sealant:
(Part 1) : 1985	General requirements
(Part 2) : 1986	Methods of test
IS 12118	Specification for two parts polysulphide based sealants:
(Part 1) : 1987	General requirements
(Part 2) : 1987	Methods of test

h) Steel Reinforcement for Concrete

IS No.	*Title*
IS 432	Specification for mild steel and medium tensile steel bars and hard drawn steel wire for concrete reinforcement:
(Part 1) : 1982	Mild steel and medium tensile steel bars (*third revision*)
(Part 2) : 1982	Hard drawn steel wire (*third revision*)
IS 1566 : 1982	Specification for hard drawn steel wire fabric for concrete reinforcement (*second revision*)
IS 1599 : 2023/ ISO 7438 : 2020	Metallic materials — Bend test (*fifth revision*)
IS 1608	Metallic materials — Tensile testing:
(Part 1) : 2022/ ISO 6892-1 : 2019	Method of test at room temperature (*fifth revision*)
(Part 2) : 2020/ ISO 6892-2 : 2018	Method of test at elevated temperature (*fourth revision*)
(Part 3) : 2018/ ISO 6892-3 : 2015	Method of test at low temperature
IS 1785	Specification for plain hard drawn steel wire for pre-stressed concrete:
(Part 1) : 1983	Cold drawn stress-relieved wire (*second revision*)
(Part 2) : 1983	As drawn wire (*first revision*)
IS 1786 : 2008	High strength deformed steel bars and wires for concrete reinforcement Specification (*fourth revision*)
IS 2090 : 1983	Specification for high tensile steel bars used in prestressed concrete (*first revision*)
IS 6003 : 2010	Indented wire for prestressed concrete — Specification (*second revision*)
IS 6006 : 2014	Uncoated stress-relieved strand for prestressed concrete — Specification (*second revision*)
IS 9417 : 2018	Welding of high strength steel bars for reinforced concrete construction — Recommendations (*second revision*)
IS 10790	Methods of sampling of steel for prestressed and reinforced concrete:
(Part 1) : 1984	Prestressing steel
(Part 2) : 1984	Reinforcing steel
IS 12594 : 1988	Hot-dip zinc coating on structural steel bars for concrete reinforcement — Specification
IS 13620 : 1993	Specification for fusion bonded epoxy coated reinforcing bars
IS 14268 : 2022	Uncoated stress relieved low relaxation seven-wire ply strand for prestressed concrete — Specification (*second revision*)

IS No.	*Title*
IS 16172 : 2023	Reinforcement couplers for mechanical splices of steel bars in concrete — Specification (*first revision*)
IS 16644 : 2018	Stress-Relieved low relaxation steel wire for prestressed concrete — Specification
IS 16651 : 2017	High strength deformed stainless steel bars and wires for concrete reinforcement — Specification
IS 18255 : 2023	Fibre-Reinforced Polymer FRP bars for concrete reinforcement — Methods of test
IS 18256 : 2023	Solid round glass fibre reinforced polymer GFRP bars for concrete reinforcement — Specification
IS 19068 : 2025	Continuous Hot-dip galvanized steel bars for concrete reinforcement — Specification

9 COMPOSITE MATRIX PRODUCTS

a) Cement Matrix Products

i) *Precast Concrete Products*

IS No.	*Title*
IS 2174 : 1962	Specification for reinforced concrete dust bins
IS 2185	Specification for concrete masonry units:
(Part 1) : 2005	Hollow and solid concrete blocks (*third revision*)
(Part 2) : 1983	Hollow and solid lightweight concrete blocks (*first revision*)
(Part 3) : 1984	Autoclaved cellular (aerated) concrete blocks (*first revision*)
(Part 4) : 2008	Preformed foam cellular concrete blocks
IS 4996 : 1984	Specification for reinforced concrete fence posts (*first revision*)
IS 5751 : 1984	Specification for precast concrete coping blocks (*first revision*)
IS 5758 : 2020	Precast concrete kerbs channels edging quadrants and other associated fittings — Specification (*second revision*)
IS 5820 : 2024	Precast concrete cable covers — Specification (*first revision*)
IS 6072 : 2023	Autoclaved reinforced cellular concrete wall slabs — Specification (*first revision*)
IS 6073 : 2006	Specification for autoclaved reinforced cellular concrete floor and roof slabs (*first revision*)
IS 6441	Methods of test for autoclaved cellular concrete products:
(Part 1) : 1972	Determination of unit weight or bulk density and moisture content
(Part 2) : 1972	Determination of drying shrinkage

IS No.	*Title*
(Part 4) : 1972	Corrosion protection of steel reinforcement in autoclaved cellular concrete
(Part 5) : 1972	Determination of compressive strength
(Part 6) : 1973	Strength, deformation and cracking of flexural members subject to bending-short duration loading test
(Part 7) : 1973	Strength, deformation and cracking of flexural members subject to bending-sustained loading test
(Part 8) : 1973	Loading tests for flexural members in diagonal tension
(Part 9) : 1973	Jointing of autoclaved cellular concrete elements
IS 6523 : 1983	Specification for precast reinforced concrete door and window frames (*first revision*)
IS 9375 : 1979	Specification for precast reinforced concrete plant guards
IS 9872 : 1981	Specification for precast concrete septic tanks
IS 9893 : 1981	Specification for precast concrete blocks for lintels and sills
IS 12440 : 1988	Specification for precast concrete stone masonry blocks
IS 12592 : 2002	Specification for precast concrete manhole covers and frames (*first revision*)
IS 13356 : 1992	Specification for precast ferrocement water tanks (250 litres to 10 000 litres capacity)
IS 13990 : 1994	Specification for precast reinforced concrete planks and joists for flooring and roofing
IS 14143 : 1994	Specification for prefabricated brick panel and partially precast concrete joist for flooring and roofing
IS 14201 : 1994	Specification for precast reinforced concrete channel unit for construction of floors and roofs
IS 14241 : 1995	Specification for precast L-Panel units for roofing
IS 18661 : 2024	Precast concrete grating — Specification
IS 18889 : 2024	Precast concrete paving flags — Specification
IS 18894 : 2024	Precast concrete paving grids and grass pavers — Specification

ii) *Asbestos Fibre Cement Products*

IS No.	*Title*
IS 459 : 1992	Specification for corrugated and semi-corrugated asbestos cement sheets (*third revision*)
IS 1592 : 2003	Specification for asbestos cement pressure pipes and joints (*fourth revision*)
IS 1626	Specification for asbestos cement building pipes and pipe fittings, gutters and gutter fittings and roofing fittings:

IS No.	*Title*
(Part 1) : 1994	Pipes and pipe fittings (*second revision*)
(Part 2) : 1994	Gutters and gutter fittings (*second revision*)
(Part 3) : 1994	Roofing fittings (*second revision*)
IS 2096 : 1992	Specification for asbestos cement flat sheets (*first revision*)
IS 2098 : 1997	Specification for asbestos cement building boards (*first revision*)
IS 5913 : 2003	Methods of test for asbestos cement products (*second revision*)
IS 6908 : 1991	Specification for asbestos cement pipes and fittings for sewerage and drainage (*first revision*)
IS 7639 : 1975	Method of sampling asbestos cement products
IS 9627 : 1980	Specification for asbestos cement pressure pipes (light duty)
IS 13000 : 1990	Silica-asbestos-cement flat sheets — Specification
IS 13008 : 1990	Specification for shallow corrugated asbestos cement sheets

iii) *Other Fibre Cement Products*

IS No.	*Title*
IS 14862 : 2000	Specification for fibre cement flat sheets
IS 14871 : 2000	Specification for products in fibre reinforced cement long corrugated or asymmetrical section sheets and fittings for roofing and cladding

iv) *Concrete Pipes and Pipes Lined/Coated with Concrete or Mortar*

IS No.	*Title*
IS 458 : 2021	Precast concrete pipes with and without reinforcement (*fifth revision*)
IS 784 : 2019	Prestressed concrete pipes including specials — Specification (*third revision*)
IS 1916 : 2018	Steel cylinder pipes with concrete lining and coating — Specification (*second revision*)
IS 3597 : 1998	Methods of test for concrete pipes (*second revision*)
IS 4350 : 1967	Specification for concrete porous pipes for under drainage
IS 7319 : 1974	Specification for perforated concrete pipes
IS 7322 : 1985	Specification for specials for steel cylinder reinforced concrete pipes (*first revision*)
IS 15155 : 2020	Barwire wrapped steel cylinder pipes with mortar lining and coating including specials specification (*first revision*)

b) Resin Matrix Products

IS No.	*Title*
IS 1998 : 1962	Methods of test for thermosetting synthetic resin bonded laminated sheets
IS 2036 : 1995	Specification for phenolic laminated sheets (*second revision*)
IS 2046	Decorative thermosetting synthetic resin bonded laminated sheets — Specification:
(Part 1) : 2025/ ISO 4586-1 : 2018	Introduction and general information (*third revision*)
(Part 2) : 2025/ ISO 4586-2 : 2018	Determination of properties (*third revision*)
(Part 3) : 2025/ ISO 4586-3 : 2018	Classification and specifications for laminates less than 2 mm thick and intended for bonding to supporting substrates (*third revision*)
(Part 4) : 2025 ISO 4586-4 : 2018	Classification and specifications for compact laminates of thickness 2 mm and greater (*third revision*)
(Part 5) : 2025 ISO 4586-5 : 2018	Classification and specifications for flooring grade laminates less than 2 mm thick intended for bonding to supporting substrates (*third revision*)
(Part 6) : 2025 ISO 4586-6 : 2018	Classification and specifications for exterior-grade compact laminates of thickness 2 mm and greater (*third revision*)
(Part 7) : 2025 ISO 4586-7 : 2018	Classification and specifications for design laminates (*third revision*)
(Part 8) : 2025 ISO 4586-8 : 2018	Classification and specifications for alternative core laminates (*third revision*)

10 CONDUCTORS AND CABLES

IS No.	*Title*
IS 694 : 2010	Polyvinyl chloride insulated unsheathed and sheathed cables/cords with rigid and flexible conductor for rated voltages up to and including 450/750 V (*fourth revision*)
IS 1554	Specification for PVC insulated (heavy duty) electric cables:
(Part 1) : 1988	For working voltages up to and including 1 100 volts (*third revision*)
(Part 2) : 1988	For working voltages from 3.3 kV up to and including 11 kV (*second revision*)
IS 3961	Recommended current ratings for cables:
(Part 2) : 2017	PVC insulated and PVC sheathed heavy duty cables (*first revision*)
(Part 3) : 1968	Rubber insulated cables
(Part 5) : 1968	PVC insulated light duty cables
(Part 6) : 2016	Crosslinked polyethylene insulated PVC sheathed cables
(Part 7) : 2017	Crosslinked polyethylene insulated thermoplastic sheathed cables

IS No.	*Title*
IS 4289	Specification for flexible cables for lifts and other flexible connections:
(Part 1) : 1984	Elastomer insulated cables (*first revision*)
(Part 2) : 2000	PVC insulated circular cables
IS 7098	Cross-linked polyethylene insulated sheathed cables — Specification
(Part 1) : 2025	For working voltage up to and including 1 100 V (*second revision*)
(Part 2) : 2011	For working voltages form 3.3 kV up to and including 33 kV (*second revision*)
(Part 3) : 1993	For working voltages from 66 kV upto and including 220 kV
IS 9968	Elastomer insulated cables — Specification:
(Part 1) : 2025	For working voltages up to and including 1 100 V (*second revision*)
(Part 2) : 2002	For working voltages from 3.3 kV up to and including 33 kV (*first revision*)
IS 10810	Methods of test for cables:
(Part 0) : 1984	General
(Part 1) : 1984	Annealing test for wires used in conductors
(Part 2) : 1984	Tensile test for aluminium wires
(Part 3) : 1984	Wrapping test for aluminium wires
(Part 4) : 1984	Persulphate test of conductor
(Part 5) : 1984	Conductor resistance test
(Part 6) : 1984	Thickness of thermoplastic and elastomeric insulation and sheath
(Part 7) : 1984	Tensile strength and elongation at break of thermoplastic and elastomeric insulation and sheath
(Part 8) : 1984	Breaking strength and elongation at break for impregnated paper insulation
(Part 9) : 1984	Tear resistance for paper insulation
(Part 10) : 1984	Loss of mass test
(Part 11) : 1984	Thermal ageing in air
(Part 12) : 1984	Shrinkage test
(Part 13) : 1984	Ozone resistance test
(Part 14) : 1984	Heat shock test
(Part 15) : 1984	Hot deformation test
(Part 16) : 1986	Accelerated ageing test by oxygen pressure method
(Part 17) : 1986	Tear resistance test for heavy duty sheath

IS No.	*Title*
(Part 19) : 1984	Bleeding and blooming test
(Part 20) : 1984	Cold bend test
(Part 21) : 1984	Cold impact test
(Part 22) : 1984	Vicat softening point
(Part 23) : 1984	Melt-flow index
(Part 24) : 1984	Water soluble impurities test of insulating paper
(Part 25) : 1984	Conductivity of water extract test of insulating paper
(Part 26) : 1984	*p*H value of water extract test of insulating paper
(Part 27) : 1984	Ash content test of insulating paper
(Part 28) : 1984	Water absorption test (Electrical)
(Part 29) : 1984	Environmental stress cracking test
(Part 30) : 1984	Hot set test
(Part 31) : 1984	Oil resistance test
(Part 32) : 1984	Carbon content test for polyethylene
(Part 33) : 1984	Water absorption test (Gravimetric)
(Part 34) : 1984	Measurement of thickness of metallic sheath
(Part 35) : 1984	Determination of tin in lead alloy for sheathing
(Part 36) : 1984	Dimensions of armouring material
(Part 37) : 1984	Tensile strength and elongation at break of armouring materials
(Part 38) : 1984	Torsion test on galvanized steel wires for armouring
(Part 39) : 1984	Winding test on galvanized steel strips for armouring
(Part 40) : 1984	Uniformity of zinc coating on steel armour
(Part 41) : 1984	Mass of zinc coating on steel armour
(Part 42) : 1984	Resistivity test of armour wires and strips and conductance test of armour (wires/strips)
(Part 43) : 1984	Insulation resistance
(Part 44) : 1984	Spark test
(Part 45) : 1984	High voltage test
(Part 46) : 1984	Partial discharge test
(Part 47) : 1984	Impulse test

IS No.	*Title*
(Part 48) : 1984	Dielectric power factor test
(Part 49) : 1984	Heating cycle test
(Part 50) : 1984	Bending test
(Part 51) : 1984	Dripping test
(Part 53) : 1984	Flammability test
(Part 54) : 1984	Static flexibility test
(Part 55) : 1986	Abrasion test
(Part 56) : 1987	Accelerated ageing by the air-pressure method
(Part 57) : 1987	Flexing test
(Part 58) : 1998	Oxygen index test
(Part 59) : 1988	Determination of the amount of halogen acid gas evolved during combustion of polymeric materials taken from cables
(Part 60) : 1988	Thermal stability of PVC insulation and sheath
(Part 61) : 1988	Flame retardant test
(Part 62) : 1993	Fire resistance test for bunched cables
(Part 63) : 1993	Smoke density of electric cables under fire conditions
(Part 64) : 2003	Measurement of temperature index
IS 12943 : 1990	Brass glands for PVC cables — Specification
IS 14763 : 2022	Conduit systems for cable management outside diameters of conduits for electrical installations and threads for conduits and fittings
IS 16205	Conduit systems for cable management:
(Part 1) : 2017	General requirements
(Part 21) : 2017	Particular requirements rigid conduit systems
(Part 22) : 2017	Particular requirements — Pliable conduit systems
(Part 23) : 2017	Particular requirements flexible conduit systems
(Part 24) : 2017	Particular requirements conduit systems buried under ground
IS 16783 : 2018	Cable cleats for electrical installations
IS 17048 : 2018	Halogen free flame retardant HFFR cables for working voltages up to and including 1 100 Volts — Specification
IS 17293 : 2020	Electric cables for photovoltaic systems for rated voltage 1 500 V d. c.

IS No.	*Title*
IS 17505 (Part 1) : 2021	Specification for thermosetting insulated fire survival cables for fixed installation having low emission of smoke and corrosive gases when affected by fire for working voltages upto and including 1 100 V a.c. and 1 500 V d.c.: Part 1 Requirements for armoured cables
IS 18833 : 2024/ IEC 62895 : 2017	High voltage direct current (HVDC) power transmission — Cables with extruded insulation and their accessories for rated voltages up to 320 kV for land applications — Test methods and requirements
IS/IEC 60371-3-7 : 1995	Specification for insulating materials based on MICA: Part 3 Specifications for Individual materials, Section 7 Polyester film mica paper with an epoxy resin binder for single conductor taping
IS/IEC 60371-3-8 : 1995	Specification for insulating materials based on MICA: Part 3 Specification for individual materials, Section 8 Mica paper tapes for flame resistant security cables
IS/IEC 62275 : 2018	Cable management systems — Cable ties for electrical installations (*first revision*)

11 DOORS, WINDOWS AND VENTILATORS

a) Wooden Doors, Windows and Ventilators

IS No.	*Title*
IS 1003	Specification for timber panelled and glazed shutters
(Part 1) : 2003	Door shutters (*fourth revision*)
(Part 2) : 1994	Window and ventilator shutters (*third revision*)
IS 2191	Wooden flush door shutters (cellular, hollow and tubular core type) — Specification
(Part 1) : 2022	Plywood face panels (*fifth revision*)
(Part 2) : 2022	Particle board high density fibre board medium density fibre board and fibre hardboard face panels (*fourth revision*)
IS 2202	Wooden flush door shutters solid core type — Specification
(Part 1) : 2023	Plywood face panels (*seventh revision*)
(Part 2) : 2022	Particle board high density fibre board medium density fibre board and hardboard face panels (*fourth revision*)
IS 4020	Method of tests for door shutters:
(Part 1) : 1998	General (*third revision*)
(Part 2) : 1998	Measurement of dimensions and squareness (*third revision*)
(Part 3) : 1998	Measurement of general flatness (*third revision*)
(Part 4) : 1998	Local planeness test (*third revision*)
(Part 5) : 1998	Impact indentation test (*third revision*)

IS No.	*Title*
(Part 6) : 1998	Flexure test (*third revision*)
(Part 7) : 1998	Edge loading test (*third revision*)
(Part 8) : 1998	Shock resistance test (*third revision*)
(Part 9) : 1998	Buckling resistance test (*third revision*)
(Part 10) : 1998	Slamming test (*third revision*)
(Part 11) : 1998	Misuse test (*third revision*)
(Part 12) : 1998	Varying humidity test (*third revision*)
(Part 13) : 1998	End immersion test (*third revision*)
(Part 14) : 1998	Knife test (*third revision*)
(Part 15) : 1998	Glue adhesion test (*third revision*)
(Part 16) : 1998	Screw withdrawal resistance test (*third revision*)
IS 4021 : 1995	Specification for timber door, window and ventilator frames (*third revision*)
IS 6198 : 1992	Specification for ledged, braced and battened timber door shutters (*second revision*)

b) Metal Doors, Windows Frames and Ventilators

IS No.	*Title*
IS 1038 : 1983	Specification for steel doors, windows and ventilators (*third revision*)
IS 1361 : 1978	Specification for steel windows for industrial buildings (*first revision*)
IS 1948 : 2024	Aluminium framed doors, windows and sliders — Specification (*first revision*)
IS 4351 : 2024	Steel Frames for Doors — Specification (*third revision*)
IS 6248 : 1979	Specification for metal rolling shutters and rolling grills (*first revision*)
IS 7452 : 1990	Specification for hot rolled steel sections for doors, windows and ventilators (*second revision*)
IS 10451 : 1983	Specification for steel sliding shutters (top hung type)
IS 10521 : 1983	Specification for collapsible gates
IS 18648 : 2024	Classification and performance requirements for doors, windows and sliders — Specification

c) Plastic Doors and Windows

IS No.	*Title*
IS 14856 : 2000	Specification for glass fibre reinforced plastic (GRP) panel type door shutters for internal use

IS 15380 : 2023	Moulded high density fibre HDF panelled door shutters — Specification (*first revision*)
IS 15931 : 2012	Solid panel foam UPVC door shutters — Specification
IS 17953 : 2023	uPVC profiles for windows and doors — Specification
IS 18648 : 2024	Classification and performance requirements for doors, windows and sliders — Specification

d) Concrete Doors and Windows

IS No.	*Title*
IS 6523 : 1983	Specification for precast reinforced concrete door and window frames (*first revision*)

e) Other Composite Material Doors and Windows

IS No.	*Title*
IS 16073 : 2013	Bamboo-jute composite panel door shutter — Specification
IS 16074 : 2024	Steel flush door shutters — Specification (*first revision*)
IS 16096 : 2013	Bamboo-Jute composite hollow core door shutter — Specification

f) Fire Check Doors

IS No.	*Title*
IS 3614 : 2021	Fire doors and doorsets — Specification (*first revision*)

g) Mesh/Net for Mosquito/Vector Prevention

IS No.	*Title*
IS 1568 : 1970	Specification for wire cloth for general purposes (*first revision*)
IS 3150 : 1982	Specification for hexagonal wire netting for general purposes (*second revision*)
IS 11199 : 2024	Textiles — High density polyethylene (HDPE) monofilament twine door nets — Specification (*first revision*)

h) Doors and Windows — Method of tests

IS No.	*Title*
IS 4020	Method of tests for door shutters:
(Part 1) : 1998	General (*third revision*)
(Part 2) : 1998	Measurement of dimensions and squareness (*third revision*)
(Part 3) : 1998	Measurement of general flatness (*third revision*)
(Part 4) : 1998	Local planeness test (*third revision*)
(Part 5) : 1998	Part 5 Impact indentation test (*third revision*)

IS No.	*Title*
(Part 6) : 1998	Flexure test (*third revision*)
(Part 7) : 1998	Edge loading test (*third revision*)
(Part 8) : 1998	Shock resistance test (*third revision*)
(Part 9) : 1998	Buckling resistance test (*third revision*)
(Part 10) : 1998	Slamming test (*third revision*)
(Part 11) : 1998	Misuse test (*third revision*)
(Part 12) : 1998	Varying humidity test (*third revision*)
(Part 13) : 1998	End immersion test (*third revision*)
(Part 14) : 1998	Knife test (*third revision*)
(Part 15) : 1998	Glue adhesion test (*third revision*)
(Part 16) : 1998	Screw withdrawal resistance test (*third revision*)
IS 12458 : 2019	Fire resistance of through penetration firestops — Method of test (*first revision*)
IS 17518 (Part 1) : 2022/ ISO 3008-1 : 2019	Fire resistance tests — Door and shutter assemblies: Part 1 General requirements
IS 17909 : 2022/ ISO 8274 : 2005	Windows and doors — Resistance to repeated opening and closing — Test method
IS 17910	Thermal performance of windows and doors — Determination of thermal transmittance by the hot-box method:
(Part 1) : 2022/ ISO 12567-1:2010	Complete windows and doors
(Part 2) : 2022/ ISO 12567-2 : 2005	Roof windows and other projecting windows
IS 17911 : 2022/ ISO 15099 : 2003	Thermal performance of windows, doors and shading devices — Detailed calculations
IS 17920 : 2022/ ISO 10077-2 : 2017	Thermal performance of windows, doors and shutters — Calculation of thermal transmittance — Numerical method for frames
IS 18268 : 2023/ ISO 9379 : 2005	Operating forces — Test methods — Doors
IS 18434 : 2023	Field measurement of air permeability and water penetration through installed curtain wall, windows, doors, sliders and skylights under static air pressure difference — Method of test
IS 18459 : 2024	Water penetration of curtain walls, windows, sliders, doors and skylights by uniform static air pressure difference — Method of test
IS 18473 : 2024	Wind resistance for curtain walls, windows, sliders, doors and skylights — Method of test

IS No.	*Title*
IS 18647 : 2024	Water penetration of curtain walls, windows, sliders and doors by dynamic air pressure — Method of test
IS 18648 : 2024	Classification and performance requirements for doors, windows and sliders — Specification
IS 19006 : 2023/ISO 8248 : 1985	Windows and door height windows — Mechanical tests

12 ELECTRICAL WIRING, FITTINGS AND ACCESSORIES

IS No.	*Title*
IS 302 (Part 1) : 2024/ IEC 60335-1 : 2020	Household and similar electrical appliances — Safety: Part 1 General requirements (*seventh revision*)
IS 302	Safety of household and similar electrical appliances:
(Part 2)	Particular requirements,
(Sec 21) : 2024/ IEC 60335-2-21 : 2022	Storage water heaters (*third revision*)
(Sec 35) : 2017	Electric instantaneous water heaters (*second revision*)
(Sec 74) : 2024/ IEC 60335-2-74 : 2021	Portable immersion heaters
IS 302-2-80 : 2017	Household and similar electrical appliances — Safety: Part 2-80 Particular requirements for fans (*first revision*)
IS 369 : 2019	Household electric direct — Acting room heaters — Performance requirements (*fourth revision*)
IS 371 : 1999	Specification for ceiling roses (*third revision*)
IS 374 : 2019	Specification for electric ceiling type fans and regulators (*third revision*)
IS 418 : 2004	Specification for tungsten filament lamp for domestic and similar general lighting purposes (*fourth revision*)
IS 1258 : 2024/ IEC 61184 : 2017	Bayonet lampholders (*fifth revision*)
IS 1293 : 2019	Plugs and socket-outlets of rated voltage up to and including 250 volts and rated current up to and including 16 amperes — Specification (*fourth revision*)
IS 1554	PVC insulated (heavy duty) electric cables:
(Part 1) : 1988	For working voltages upto and including 1 100 V (*third revision*)
(Part 2) : 1988	For working voltages from 3.3 kV upto and including 11 kV (*second revision*)
IS 2082 : 2018	Stationary storage type electric water heaters — Specification (*fifth revision*)
IS 2086 : 1993	Specification for carriers and bases used in re-wirable type electric fuses up to 650 volts (*third revision*)
IS 2215 : 2006	Specification for starters for fluorescent lamps (*third revision*)
IS 2418	Tubular fluorescent lamps for general lighting service:

IS No.	*Title*
(Part 1) : 2018	Safety requirements (*second revision*)
(Part 2) : 2018	Performance requirements (*second revision*)
(Part 3) : 1977	Dimensions of G-5 and G-13 bi-pin caps (*first revision*)
(Part 4) : 1977	Go and no-go gauges for G-5 and G-13 bi-pin caps (*first revision*)
IS 3323 : 1980	Specification for bi-pin lamp holders for tubular fluorescent lamps (*first revision*)
IS 3324 : 1982	Specification for holders for starters for tubular fluorescent lamps (*first revision*)
IS 3419 : 1988	Specification for fittings for rigid non-metallic conduits (*second revision*)
IS 3480 : 2024	Flexible steel conduits for electrical wiring — Specification (*first revision*)
IS 3724 : 2017	Cartridge type heating elements (non-embedded type) — Specification (*first revision*)
IS 3837 : 1976	Specification for accessories for rigid steel conduits for electrical wiring (*first revision*)
IS 3854 : 2023	Specification for switches for domestic and similar purposes (*third revision*)
IS 4159 : 2021	Mineral filled sheathed heating elements (*fourth revision*)
IS 4160 : 2005	Specification for interlocking switch socket outlets (*first revision*)
IS 4649 : 1968	Specification for adaptors for flexible steel conduits
IS 9385 (Part 1) : 2024/ IEC 60282-1 : 2020	High -voltage fuses: Part 1 Current-limiting fuses (*second revision*)
IS 9385 (Part 2) : 2018	High-voltage fuses: Part 2 Expulsion fuses (*first revision*)
IS 9385 (Part 6) : 2025/ IEC 60282-4 : 2020	High-voltage fuses: Part 6 Additional testing requirements for high-voltage expulsion fuses utilizing polymeric insulators
IS 9537	Specification for conduits for electrical installations:
(Part 1) : 1980	General requirements
(Part 2) : 1981	Rigid steel conduits
(Part 3) : 1983	Rigid plain conduits for insulating materials
(Part 4) : 1983	Pliable self-recovering conduits for insulating materials
(Part 5) : 2000	Pliable conduits of insulating materials
(Part 6) : 2000	Pliable conduits of metal or composite materials
(Part 8) : 2003	Rigid non threadable conduits of aluminium alloy
IS 9926 : 1981	Specification for fuse wires used in rewirable type electric fuses up to 650 volts

IS No.	*Title*
IS 10027 : 2018	Composite units of air-break switches and rewirable type fuses for voltages not exceeding 650 V a.c. — Specification (*second revision*)
IS 10322	Specification for luminaires:
(Part 1) : 2014	General requirements and tests (*first revision*)
(Part 5)	Particular requirements,
(Sec 1) : 2012	General purpose luminaires (*first revision*)
(Sec 2) : 2012	Recessed luminaires (*first revision*)
(Sec 3) : 2012	Luminaires for road and street lighting (*first revision*)
(Sec 4) : 1987	Portable general purpose luminaires
(Sec 5) : 2013	Flood light (*first revision*)
(Sec 6) : 2013	Hand lamps
(Sec 7) : 2017/ IEC 60598- 2-20 : 2014	Lighting chains (*first revision*)
(Sec 8) : 2013	Emergency lighting
(Sec 9) : 2017/ IEC 60598-2-21 : 2014	Rope lights
IS 11037 : 2019	Electronic type fan regulators specification (*first revision*)
IS 12640	Residual current operated circuit-breakers without integral overcurrent protection for household and similar uses (RCCBs):
(Part 1) : 2024/ IEC 61008-1 : 2013	General rules (*third revision*)
(Part 2) : 2016/ IEC 61009-1 : 2012	General rules (*second revision*)
(Part 3) : 2018/ IEC 1008-2-1 : 1990	Applicability of the general rule to RCCB's functionally independent of line voltage
(Part 4) : 2018/ IEC 61008-2-2 : 1990	Applicability of the general rules to RCCB's functionally dependent on line voltage
IS 12776 : 2002	Specification for galvanized strand for earthing (*first revision*)
IS 13010 : 2002	AC watt-hour meters, Class 0.5, 1 and 2 (*first revision*)
IS 13779 : 2020	a.c. static watthour meters class 1 and 2-Specefication (*second revision*)
IS 13947 (Part 5/Sec 2) : 2004/ IEC 60947-5-2(1999)	Low-voltage switchgear and controlgear — Specification: Part 5 Control circuit devices and switching elements, Section 2 Proximity switches
IS 14614 : 2023	Residual current — operated protective devices (RCDs) for household and similar use — Electromagnetic compatibility (*first revision*)

IS No.	*Title*
IS 14697 : 2021	a.c. Static transformer operated watthour meters (Class 0.2 S and 0.5 S) and Var-hour meters (Class 0.2 S, 0.5 S and 1 S) — Specification (*first revision*)
IS 14763 : 2022	Conduit systems for cable management outside diameters of conduits for electrical installations and threads for conduits and fittings (*first revision*)
IS 14768	Conduit fittings for electrical installations:
(Part 1) : 2000	General requirements
(Part 2) : 2003	Metal conduit fittings
IS 14772 : 2020	Boxes and enclosures for electrical accessories for household and similar fixed electrical installations general requirements (*first revision*)
IS 14897 : 2021	Glass bulb designation system for lamps (*first revision*)
IS 14927	Cable trunking systems and cable ducting systems for electrical installations:
(Part 1) : 2023	General requirements (*first revision*)
(Part 2/Sec 1) : 2023/ IEC 61084-2-1 : 2017	Cable trunking systems and cable ducting systems intended for mounting on walls and ceilings, Section 1 Particular requirements (*first revision*)
IS 15111	Self-Ballasted lamps for general lighting services:
(Part 1) : 2002	Safety requirements
(Part 2) : 2002	Performance requirements
IS 15368 : 2003	Cable reels for household and similar purposes
IS 15518 (Part 1) : 2004	Safety requirements for incandescent lamps: Part 1 Tungsten filament lamps for domestic and similar general lighting purposes
IS 15787 : 2025	Switched socket-outlets without interlock for fixed installations — Particular requirements (*first revision*)
IS 15968 : 2013	Ballasts for tubular fluorescent lamps — Performance requirements
IS 15974 : 2013	Auxiliaries for lamps — Starting devices (other than glow starters) — Performance requirements
IS 16102	Self-ballasted LED-lamps for general lighting services:
(Part 1) : 2026	Safety requirements (*first revision*)
(Part 2) : 2026	Performance requirements (*second revision*)
IS 16103	LED modules for general lighting:
(Part 1) : 2025/ IEC 62031 : 2018	Safety — Specifications (*first revision*)
(Part 2) : 2025/ IEC 62717 : 2019 CSV	Performance requirements (*first revision*)
IS 16148 : 2014/ IEC 61167 : 2011	Metal halide lamps — Performance specification

IS No.	*Title*
IS 16444 (Part 2) : 2017	a.c. Static transformer operated watthour and var-hour smart meters, class 0.2 s, 0.5 s and 1.0 s: Part 2 Specification transformer operated smart meters
IS 16463 (Part 12) : 2026/ IEC 61643-12 : 2020	Low-voltage surge protective devices: Part 12 Surge protective devices connected to low-voltage power distribution systems — Selection and application principles (*first revision*)
IS 16614	Double-capped LED linear lamps:
(Part 1) : 2026	Safety requirements (*first revision*)
(Part 2) : 2022	Performance requirements
IS 17119 : 2019	Residual current devices with or without overcurrent protection for socket-outlets for household and similar uses
IS 17121 : 2019/IEC 62606 : 2017	General requirements for arc fault detection devices
IS 17122 : 2019	Electrical accessories — Circuit-Breakers and similar equipment for household use — Auxiliary contact units
IS 17345	Power track system:
(Part 1) : 2020	General requirement
(Part 21) : 2020	Particular requirements for power track systems intended for wall and ceiling mounting
IS 18751 : 2024	Polymer coated inner tanks for storage water heater — Specification
IS 18830 : 2024	Cord extension sets — Specifications
IS/IEC 60079	Explosive atmospheres:
(Part 0) : 2017	General requirements (*third revision*)
(Part 1) : 2014	Equipment protection by flameproof enclosures “d” (*first revision*)
(Part 7) : 2017	Equipment protection by increased safety “e” (*second revision*)
(Part 13) : 2017	Equipment protection by pressurized room “p” and artificially ventilated room “v” (*first revision*)
(Part 15) : 2017	Equipment protection by type of protection “n” (*second revision*)
(Part 19) : 2019	Equipment repair overhaul and reclamation (*second revision*)
(Part 25) : 2020	Intrinsically safe electrical systems (*second revision*)
(Part 26) : 2021	Equipment with separation elements or combined levels of protection (*second revision*)
(Part 31) : 2022	Equipment dust ignition protection by enclosure “t” (*second revision*)
(Part 39) : 2015	Intrinsically safe systems with electronically controlled spark duration limitation

IS No.	*Title*
(Part 42) : 2019	Electrical safety devices for the control of potential ignition sources from ex-equipment
(Part 43) : 2017	Equipment in adverse service conditions
(Part 46) : 2017	Equipment assemblies
(Part 47) : 2021	Equipment Protection by 2-wire intrinsically safe ethernet concept (2-WISE)
IS/IEC 60127	Miniature fuses:
(Part 3) : 2015	Sub-miniature fuse-links
(Part 10) : 2001	User guide for miniature fuses
IS/IEC 60309	Plugs fixed or portable socket-outlets and appliance inlets for industrial purposes
(Part 1) : 2021	General requirements (*second revision*)
(Part 2) : 2021	Dimensional compatibility requirements for pin and contact-tube accessories (*second revision*)
IS/IEC 60320	Appliance couplers for household and similar general purposes
(Part 1) : 2021	General requirements (*first revision*)
(Part 2/Sec 3) : 2018	Particular requirement, Section 3 Appliance couplers with a degree of protection higher than IPX0 (*first revision*)
IS/IEC 60669 (Part 2/Sec 1) : 2021	Switches for household and similar fixed electrical installations: Part 2-1: Particular requirements electronic control devices (*first revision*)
IS/IEC 60794	Optical fibre cables:
(Part 1)	Generic specification,
(Sec 1) : 2015	General (*first revision*)
(Sec 2) : 2017	Basic optical cable test procedures — General guidance (*first revision*)
(Part 2) : 2017	Indoor cables, Sectional specification (*first revision*)
(Part 2/Sec 11) : 2020	Indoor cables, Section 11 Detailed specification for simplex and duplex cables for use in premises cabling (*first revision*)
(Part 4/Sec 20) : 2018	Sectional specification, Section 20 Aerial optical cables along electrical power lines family specification for ADSS all dielectric self-supported optical cables
IS/IEC 60898	Electrical accessories — Circuit-breakers for overcurrent protection for household and similar installations
(Part 1) : 2015	Circuit-breakers for a.c. operation (*first revision*)
(Part 2) : 2016	Circuit-breakers for a.c. and d.c. operation (*first revision*)
(Part 3) : 2019	Circuit-breakers for d.c. operation
IS/IEC 60947	Low-voltage switchgear and controlgear:

IS No.	*Title*
(Part 1) : 2020	General rules (*second revision*)
(Part 2) : 2016	Circuit-breakers (*first revision*)
(Part 3) : 2020	Switches, disconnectors, switch-disconnectors and fuse-combination units (*first revision*)
(Part 4)	Contactors and motor-starters,
(Sec 1) : 2023	Electromechanical contactors and motor-starters (*third revision*)
(Sec 2) : 2020	Semiconductor motor controllers, starters and soft-starters (*second revision*)
(Sec 3) : 2020	Semiconductor controllers and semiconductor contactors for non-motor loads *(third revision*)
(Part 5)	Control circuit devices and switching elements,
(Sec 1) : 2024	Electromechanical control circuit devices (*third revision*)
(Sec 2) : 2019	Proximity switches (*first revision*)
(Sec 5) : 2016	Electrical emergency stop devices with mechanical latching function
(Part 6)	Multiple function equipment,
(Sec 1) : 2021	Transfer switching equipment (*first revision*)
(Sec 2) : 2020	Control and protective switching devices or equipment (CPS) (*first revision*)
(Part 7)	Ancillary equipment,
(Sec 1) : 2009	Terminal blocks for copper conductors
(Sec 2) : 2009	Protective conductor terminal blocks for copper conductors
IS/IEC 61058	Switches for appliances:
(Part 1)	Particular requirements,
(Sec 1) : 2016	Mechanical switches
(Sec 2) : 2016	Particular requirements for electronics switches
IS/IEC 61439	Low-voltage switchgear and controlgear assemblies:
(Part 1) : 2020	General rules (*first revision*)
(Part 2) : 2020	Power switchgear and controlgear assemblies (*first revision*)
IS/IEC 61757 : 2018	Fibre optic sensors — Generic specification
IS/IEC/TR 62655 : 2013	Tutorial and application guide for high-voltage fuses
IS/IEC 63008 : 2020	Household and similar electrical appliances accessibility of control elements, doors, lids, drawers and handles

IS No.	*Title*
IS/ISO/IEC 80079	Explosive atmospheres:
(Part 20)	Material characteristics for gas and vapour classification,
(Sec 1) : 2017	Test methods and data
(Sec 2) : 2016	Combustible dusts test methods
(Part 36) : 2016	Non-electrical equipment for explosive atmospheres — Basic method and requirements
(Part 37) : 2016	Non-electrical equipment for explosive atmospheres — Non electrical type of protection constructional safety “c”, control of ignition source “b”, liquid immersion “k”

13 FILLERS, STOPPERS AND PUTTIES

IS No.	*Title*
IS 110 : 2017	Ready mixed paint brushing grey filler for enamels for use over primers — Specification (*third revision*)
IS 419 : 1967	Specification for putty for use on window frames (*first revision*)
IS 419 : 2023	Putty for use on window frames — Specification (*second revision*)
IS 423 : 1961	Specification for plastic wood, for joiner’s filler (*revised*)
IS 3709 : 1966	Specification for mastic cement for bedding of metal windows
IS 7164 : 1973	Specification for stopper
IS 13184 : 1991	Specification for mastic filler, epoxy based

14 FLOOR COVERING, ROOFING AND OTHER FINISHES

a) Concrete Flooring

IS No.	*Title*
IS 1237 : 2012	Specification for cement concrete flooring tiles (*second revision*)
IS 6073 : 2006	Autoclaved reinforced cellular concrete floor and roof slabs — Specification (*first revision*)
IS 13801 : 2013	Chequered cement concrete tiles — Specification (*first revision*)
IS 13990 : 1994	Specification for precast reinforced concrete planks and joists for flooring and roofing
IS 14201 : 1994	Precast reinforced concrete channel units for construction of floors and roofs — Specification
IS 15658 : 2021	Concrete paving blocks — Specification (*first revision*)

b) Flooring Compositions

IS No.	*Title*
IS 657 : 1982	Specification for materials for use in the manufacture of magnesium oxychloride flooring compositions (*second revision*)
IS 9162 : 1979	Methods of tests for epoxy resin, hardeners and epoxy resin composition for floor topping
IS 9197 : 1979	Specification for epoxy resin, hardness and epoxy resin compositions for floor topping
IS 10132 : 1982	Method of test for materials for use in the preparation of magnesium oxychloride flooring composition

c) Linoleum Flooring

IS No.	*Title*
IS 653 : 1992	Specification for linoleum sheets and tiles (*third revision*)
IS 9704 : 1980	Methods of tests for linoleum sheets and tiles

d) Rubber Flooring

IS No.	*Title*
IS 809 : 1992	Specification for rubber flooring materials for general purposes (*second revision*)

e) Stone Flooring

IS No.	*Title*
IS 1128 : 1974	Specification for limestone (slab and tiles) (*first revision*)
IS 1130 : 1969	Specification for marble (blocks, slabs and tiles)
IS 3316 : 1974	Specification for structural granite (*first revision*)
IS 3622 : 1977	Specification for sand stone (slabs and tiles) (*first revision*)
IS 14223 (Part 1) : 2023	Polished building stones specification: Part 1 Granite and similar stones (*first revision*)

f) Bituminous Flooring

IS No.	*Title*
IS 1195 : 2002	Specification for bitumen mastic for flooring (*third revision*)
IS 5317 : 2002	Specification for pitch-mastic for bridge decking and roads (*second revision*)
IS 8374 : 1977	Specification for bitumen mastic, anti-static and electrically conducting grade
IS 9510 : 1980	Specification for bitumen mastic acid resisting grade
IS 13026 : 1991	Specification for bitumen mastic for flooring for industries handling LPG and other light hydrocarbon products

IS 15194 : 2002	Specification for pitch-mastic flooring for industries handling heavy hydrocarbon products like kerosene, diesel and furnace oil

g) Plastic Flooring

IS No.	*Title*
IS 3461 : 1980	Specification for PVC asbestos floor tiles (*first revision*)
IS 3462 : 1986	Specification for unbacked flexible PVC flooring (*second revision*)
IS 3464 : 1986	Methods of test for plastic flooring and wall tiles (*second revision*)

h) Ceramic/Vitreous Flooring and Wall Finishing

IS No.	*Title*
IS 2333 : 2025	Plaster of Paris for ceramic and glass industry — Specification (*third revision*)
IS 4457 : 2007	Ceramic unglazed vitreous acid resisting tile — Specification (*second revision*)
IS 13630	Ceramic tiles methods of test sampling and basis for acceptance:
(Part 1) : 2019	Determination of dimensions and surface quality (*second revision*)
(Part 2) : 2019	Determination of water absorption and bulk density (*second revision*)
(Part 3) : 2019	Determination of moisture expansion using boiling water (*second revision*)
(Part 4) : 2019	Determination of linear thermal expansion (*second revision*)
(Part 5) : 2019	Determination of resistance to thermal shock (*second revision*)
(Part 6) : 2019	Determination of modulus of rupture and breaking strength (*second revision*)
(Part 7) : 2019	Determination of stain and chemical resistance of unglazed tiles (s*econd revision*)
(Part 8) : 2019	Determination of stain and chemical resistance of glazed tiles (*second revision*)
(Part 9) : 2019	Determination of crazing resistance of glazed tiles (*second revision*)
(Part 10) : 2019	Determination of frost resistance (*second revision*)
(Part 11) : 2019	Determination of resistance to surface abrasion of glazed tiles (*second revision*)
(Part 12) : 2019	Determination of resistance to deep abrasion of unglazed tiles (*second revision*)
(Part 13) : 2019	Determination of scratch hardness of surface according to Mohs scale (*second revision*)
(Part 14) : 2019	Determination of impact resistance by measurement of coefficient of restitution (*first revision*)
(Part 15) : 2019	Sampling and basis for acceptance (*first revision*)
(Part 16) : 2019	Determination of lead and cadmium given off by glazed tiles

IS No.	*Title*
IS 13712 : 2019	Ceramic tiles definitions classifications characteristics and marking (*second revision*)
IS 15622 : 2017	Pressed ceramic tiles — Specification (*first revision*)
IS 17933 : 2022	Fine ceramics (advanced ceramics, advanced technical ceramics) — Test method for flexural strength of monolithic ceramics at room temperature
IS 17935 : 2022	Fine ceramics (advanced ceramics, advanced technical ceramics) — Determination of density and apparent porosity
IS 17975 : 2022	Fine ceramics (advanced ceramics, advanced technical ceramics) — test method for fracture resistance of silicon nitride materials for rolling bearing balls at room temperature by indentation fracture (IF) method
IS 17981 : 2022	Fine ceramics (advanced ceramics, advanced technical ceramics) — Test method for elastic moduli of monolithic ceramics at room temperature by sonic resonance
IS 17991 : 2022	Fine ceramics (advanced ceramics, advanced technical ceramics) — Test method for hardness of monolithic ceramics at room temperature
IS 18221 : 2023	Fine ceramics (Advanced ceramics, advanced technical ceramics) — Test method for linear thermal expansion of monolithic ceramics by push-rod technique

j) Clay Flooring

IS No.	*Title*
IS 1478 : 2023	Clay flooring tiles specification (*third revision*)
IS 3951	Hollow clay tiles for floors and roofs specification:
(Part 1) : 2023	Filler type (*third revision*)
(Part 2) : 2023	Structural type (*third revision*)

k) Roofing

IS No.	*Title*
IS 277 : 2018	Galvanized steel strips and sheets plain and corrugated — Specification (*seventh revision*)
IS 459 : 1992	Specification for corrugated and semi-corrugated asbestos cement sheets (*third revision*)
IS 654 : 2023	Clay roofing tiles mangalore pattern specification (*fourth revision*)
IS 1464 : 2024	Clay ridge and ceiling tiles — Specification (*third revision*)
IS 2690	Burnt clay flat terracing tiles — Specification:
(Part 1) : 2023	Machine made (*third revision*)
(Part 2) : 2023	Handmade (*third revision*)

IS No.	*Title*
IS 3951	Hollow clay tiles for floors and roofs specification:
(Part 1) : 2023	Filler type (*third revision*)
(Part 2) : 2023	Structural type (*third revision*)
IS 6073 : 2006	Autoclaved reinforced cellular concrete floor and roof slabs (*first revision*)
IS 6250 : 1981	Specification for roofing slate tiles (*first revision*)
IS 10388 : 1982	Specification for corrugated coir wood wool cement roofing sheets
IS 12583 : 1988	Specification for corrugated bitumen roofing sheets
IS 12866 : 2021	Plastic translucent sheets made from thermo-setting polyester resin (glass fibre reinforced) — Specification (*first revision*)
IS 13317 : 2023	Clay roofing country tiles half round and flat tiles Specification (*first revision*)
IS 13990 : 1994	Specification for precast reinforced concrete planks and joists for flooring and roofing
IS 14201 : 1994	Precast reinforced concrete channel units for construction of floors and roofs — Specification
IS 14241 : 1995	Specification for precast L-Panel units for roofing
IS 14246 : 2024	Continuously pre-painted galvanized steel sheets and strips — Specification (*second revision*)
IS 15965 : 2012	Pre-Painted aluminium zinc alloy metallic coated steel strip and sheet (plain)
IS 18385 : 2023	Hot-Dip galvanized/galvannealed steel sheet, plate and strip for automotive applications — Specification

m) Other Floorings and Roofings

IS No.	*Title*
IS 4456	Methods of test for chemical resistant mortars:
(Part 1) : 2026	Silicate type and resin type (*first revision*)
(Part 2) : 2026	Sulphur type (*first revision*)
IS 4457 : 2007	Ceramic unglazed vitreous acid resisting tile — Specification (*second revision*)
IS 4832	Chemical resistant mortars specification:
(Part 1) : 2023	Silicate type (*first revision*)
(Part 2) : 2023	Resin type (*first revision*)
(Part 3) : 2023	Sulphur type (*first revision*)
IS 4860 : 1968	Specification for acid resistant bricks

IS No.	*Title*
IS 14862 : 2000	Specification for fibre cement flat sheets
IS 14143 : 1994	Specification for prefabricated brick panel and partially precast concrete joist for flooring and roofing
IS 14871 : 2000	Products in fibre reinforced cement — Long corrugated or asymmetrical section sheets and fittings for roofing and cladding — Specification
IS 18433	Measurement of surface frictional properties — Methods of test:
(Part 1) : 2023	Pendulum test
(Part 2) : 2023	Ramp test

n) Wall Coverings/Finishing

IS No.	*Title*
IS 1542 : 1992	Specification for sand for plaster (*second revision*)
IS 3952 : 2013	Burnt clay hollow bricks and blocks for walls and partitions — Specification (*third revision*)
IS 4456	Methods of test for chemical resistant mortars:
(Part 1) : 1967	Silicate type and resin type
(Part 2) : 1967	Sulphur type
IS 4832	Chemical resistant mortars specification:
(Part 1) : 2023	Silicate type (*first revision*)
(Part 2) : 2023	Resin type (*first revision*)
(Part 3) : 2023	Sulphur type (*first revision*)
IS 15418 : 2003	Wall coverings in roll form for finished wall papers, wall vinyls and plastic wall coverings — Specification

15 GLASS

IS No.	*Title*
IS 2553 (Part 1) : 2018	Safety glass — Specification: Part 1 Architectural building and general uses (*fourth revision*)
IS 2835 : 1987	Specification for flat transparent sheet glass (*third revision*)
IS 3438 : 2023	Silvered glass mirrors for general purposes specification (*third revision*)
IS 5437 : 2024	Rolled glass patterned extra clear patterned wired and wired-patterned glass specification (*second revision*)
IS 9154 : 2020	Method for determination of alkali resistance of glass (*first revision*)
IS 12869	Methods for determination of viscosity and viscometric fixed points of glass:
(Part 1) : 2022	Standard test methods (*first revision*)

IS No.	*Title*
(Part 2) : 2022	Determination of softening point (*first revision*)
IS 14900 : 2018	Transparent float glass — Specification (*first revision*)
IS 16526 : 2017	Atactic polypropylene (APP) modified bituminous waterproofing and damp-proofing membrane with glass fibre reinforcement — Specification
IS 16945 : 2018	Fire resistance test for glass walls
IS 16947 : 2018	Fire resistance tests for doors with glass panes, openable glass windows and sliding glass doors
IS 16978	Glass in building — Forced-entry security glazing:
(Part 1) : 2022	Test and classification by repetitive ball drop (*first revision*)
(Part 2) : 2018	Test and classification by repetitive impact of a hammer and axe at room temperature
(Part 3) : 2018	Test and classification by manual attack
(Part 4) : 2018	Test and classification by pendulum impact under thermally and fire stressed conditions
IS 16982 : 2018	Heat strengthened glass — Specification
IS 17004 : 2018	Testing methods for processed glass
IS 17346 : 2020	Insulating glazing unit — Specification
IS 18222 : 2023	Glass-Resistance to attack by hydrochloric acid at 100 °C — Flame emission or flame atomic absorption spectrometric method
IS 18518 : 2023	Bullet resistant security glass — Quality and performance requirements
IS 19328 : 2025	Fire resistant glass — Specification
IS 19331 : 2025	Tinted float glass — Specification

16 GYPSUM BASED MATERIALS

IS No.	*Title*
IS 2095	Specification for gypsum plaster boards:
(Part 1) : 2023	Plain gypsum plaster boards (*fourth revision*)
(Part 2) : 2022	Coated laminated gypsum plaster boards (*third revision*)
(Part 3) : 2022	Reinforced gypsum plaster boards tiles cornices and mouldings (*third revision*)
IS 2542	Gypsum plaster concrete and products methods of test:
(Part 1)	Plaster and concrete,
(Sec 1) : 2023	Determination of normal consistency of gypsum plaster (*second revision*)

IS No.	*Title*
(Sec 2) : 2023	Determination of normal consistency of gypsum concrete (*second revision*)
(Sec 3) : 2023	Determination of setting time of plaster and concrete (*second revision*)
(Sec 4) : 2023	Determination of transverse strength of gypsum plaster (*second revision*)
(Sec 5) : 2023	Determination of compressive strength and dry set density of gypsum plaster (*second revision*)
(Sec 6) : 2023	Determination of soundness of gypsum plaster (*second revision*)
(Sec 7) : 2023	Determination of impact resistance of gypsum plaster by dropping ball test (*second revision*)
(Sec 8) : 2023	Determination of mass of coarse particles (*second revision*)
(Sec 9) : 2023	Determination of expansion of gypsum plaster (*second revision*)
(Sec 10) : 2023	Determination of sand in set gypsum plaster (*second revision*)
(Sec 11) : 2023	Determination of wood fibre content in wood fibre gypsum plaster (*second revision*)
(Sec 12) : 2023	Determination of dry bulk density (*second revision*)
(Sec 13) : 2023	Determination of free water (*second revision*)
(Sec 14) : 2023	Determination of fineness (*second revision*)
(Part 2)	Gypsum products,
(Sec 1) : 1981	Measurement of dimensions (*first revision*)
(Sec 2) : 1981	Determination of mass (*first revision*)
(Sec 3) : 1981	Determination of mass and thickness of paper surfacing (*first revision*)
(Sec 4) : 1981	Transverse strength (*first revision*)
(Sec 5) : 1981	Compressive strength (*first revision*)
(Sec 6) : 1981	Gypsum products, Section 6 Water absorption (*first revision*)
(Sec 7) : 1981	Moisture content (*first revision*)
(Sec 8) : 1981	Nail retention of precast reinforced gypsum slabs (*first revision*)
IS 2547	Specification for gypsum building plaster:
(Part 1) : 1976	Excluding premixed lightweight plaster (*first revision*)
(Part 2) : 1976	Premixed lightweight plaster (*first revision*)
IS 2849 : 1983	Specification for non-load bearing gypsum partition blocks (solid and hollow types) (*first revision*)
IS 8272 : 1984	Specification for gypsum plaster for use in the manufacture of fibrous plasterboards (*first revision*)

IS No.	*Title*
IS 9498 : 1980	Specification for inorganic aggregates for use in gypsum plaster
IS 12679 : 2023	By-Product gypsum for construction — Specification (*second revision*)
IS 17400 : 2021	Glass fibre reinforced gypsum building panels – Specification
IS 18387 : 2023	Gypsum ceiling tiles — Specification

17 MORTAR (Including Sand for Mortar)

IS No.	*Title*
IS 2116 : 1980	Sand for masonry mortars — Specification (*first revision*)
IS 2250 : 1981	Code of practice for preparation and use of masonry mortars (*first revision*)
IS 3085 : 1965	Method of test for permeability of cement mortar and concrete
IS 4098 : 1983	Specification for lime-pozzolana mixture (*first revision*)
IS 4456	Methods of test for chemical resistant mortars:
(Part 1) : 1967	Silicate type and resin type
(Part 2) : 1967	Sulphur type
IS 4832	Chemical resistant mortars specification:
(Part 1) : 2023	Silicate type (*first revision*)
(Part 2) : 2023	Resin type (*first revision*)
(Part 3) : 2023	Sulphur type (*first revision*)
IS 13077 : 1991	Guide for preparation and use of mud mortar in masonry
IS 14959	Method of test determination of water soluble and acid soluble chlorides in mortar and concrete
(Part 1) : 2001	Fresh mortar and concrete
(Part 2) : 2001	Hardened mortar and concrete

18 PAINTS AND ALLIED PRODUCTS

a) Water Based Paints and Pigments

IS No.	*Title*
IS 427 : 2013	Distemper, dry, colour as required — Specification (*third revision*)
IS 428 : 2013	Washable distemper — Specification (*third revision*)
IS 5410 : 2013	Specification for cement paint (*second revision*)
IS 15489 : 2024	Paint, plastic emulsion — Specification (*second revision*)

b) Ready Mixed Paints, Enamels and Powder Coatings

IS No.	*Title*
IS 101	Methods of sampling and test for paints, varnishes and related products:
(Part 1)	Tests on liquid paints general and physical,
(Sec 1) : 2023	Sampling (*fourth revision*)
(Sec 2) : 2023/ ISO 1513 : 2010	Preliminary examination and preparation of samples for testing (*fourth revision*)
(Sec 3) : 1986	Preparation of panels (*third revision*)
(Sec 4) : 2024	Brushing test (*fourth revision*)
(Sec 5) : 2024	Consistency (*fourth revision*)
(Sec 5) : 2024	Consistency (*fourth revision*)
(Sec 6) : 1987	Flash point (*third revision*)
(Sec 7) : 2020/ ISO 2811-1	Mass per 10 litres determination of density pycnometer method (*fourth revision*)
(Sec 8) : 2022/ ISO 787-9 : 2019	Pigments and extenders determination of *p*H value of an aqueous suspension (*first revision*)
(Part 2)	Test on liquid paints chemical examination,
(Sec 1) : 2018	Water content (*fourth revision*)
(Sec 2) : 2025	Determination of non-volatile matter content (*fourth revision*)
(Sec 3) : 2015/ ISO 11890-1	Determination of volatile organic compound VOC content — Difference method
(Sec 4) : 2022/ ISO 11890-2 : 2020	Determination of volatile organic compound VOC and or semi volatile organic compounds SVOC content gas-chromatographic (*first revision*)
(Sec 5) : 2017/ ISO 17895 : 2005	Determination of volatile organic compound content of low-VOC emulsion paints (In-Can VOC)
(Part 3)	Tests on paint film formation,
(Sec 1) : 1986	Drying time (*third revision*)
(Sec 2) : 2025/ ISO 2808 : 2019	Determination of film thickness (*fourth revision*)
(Sec 4) : 1987	Finish (*third revision*)
(Sec 5) : 2022/ ISO 1524 : 2020	Determination of fineness of grind (*fifth revision*)
(Sec 6) : 2024/ ISO 19403-3 : 2017	Determination of the surface tension of liquid using the pendant drop method
(Part 4)	Optical test,

IS No.	*Title*
(Sec 1) : 1988	Opacity (*third revision*)
(Sec 2) : 2021/ ISO 3668 : 2017	Colour-visual comparison of colour of paints (*fourth revision*)
(Sec 3) : 1988	Light fastness test (*third revision*)
(Sec 4) : 2020/ ISO 2813 : 2014	Gloss determination of gloss value at 20°, 60° and 85° (*fourth revision*)
(Part 5)	Mechanical test on paint films,
(Sec 1) : 1988	Hardness tests (*third revision*)
(Sec 2) :1988	Flexibility and adhesion (*third revision*)
(Sec 3) : 2019/ ISO 6272-1 : 2011	Impact resistance — Falling-weight test large-area indenter (*fifth revision*)
(Sec 4) : 1988	Print free test (*third revision*)
(Sec 5) : 2019/ ISO 6272-2 : 2011	Impact resistance — Falling-weight test small-area indenter
(Sec 6) : 2024/ ISO 7784-1 : 2023	Determination of resistance to abrasion by abrasive-paper covered wheels and rotating test specimen
(Sec 7) : 2024/ ISO 7784-2 : 2023	Determination of resistance to abrasion by abrasive rubber wheels and rotating test specimen
(Part 6)	Durability tests,
(Sec 1) : 1988	Resistance to humidity under conditions of condensation (*third revision*)
(Sec 2) : 1989	Keeping properties (*third revision*)
(Sec 3) : 1990	Moisture vapour permeability (*third revision*)
(Sec 4) : 1991	Degradation of coatings (pictorial aids for evaluation)
(Sec 5) : 1997	Accelerated weathering test (*third revision*)
(Part 7)	Environmental tests on paint films,
(Sec 1) : 1989	Resistance to water (*third revision*)
(Sec 2) : 1990	Resistance to liquids (*third revision*)
(Sec 3) : 2020/ ISO 3248 : 2016	Determination of the effect of heat (*fourth revision*)
(Sec 4) : 1990	Resistance to bleeding of pigments (*third revision*)
(Part 8)	Tests for pigments and other solids,
(Sec 1) : 1989	Residue on sieve (*third revision*)
(Sec 2) : 1990	Pigments and non –volatile matter (*third revision*)

IS No.	*Title*
(Sec 3):1993	Ash content (*third revision*)
(Sec 4) : 2015	Phthalic anhydride (*fourth revision*)
(Sec 5) : 2022	Lead restriction test (*fourth revision*)
(Sec 6) : 1993	Volume solids
(Part 9)	Tests for lacquers and varnish,
(Sec 1) : 1993	Acid value (*third revision*)
(Sec 2) : 1993	Rosin test (*third revision*)
(Part 10)	Instrumental analysis,
(Sec 1) : 2022/ ISO 13320 : 2020	Particle size analysis — Laser diffraction methods (*first revision*)
(Sec 2) : 2018/ ISO 16773-1 : 2016	Electrochemical impedance spectroscopy EIS on coated and uncoated metallic specimens — Terms and definitions
(Sec 3) : 2018/ ISO 16773-2 : 2016	Electrochemical impedance spectroscopy EIS on coated and uncoated metallic specimens — Collection of data
(Sec 4) : 2018/ ISO 16773-3 : 2016	Electrochemical impedance spectroscopy EIS on coated and uncoated metallic specimens — Processing and analysis of data from dummy cells
(Sec 5) : 2018/ ISO 16773-4	Electrochemical impedance spectroscopy EIS on coated and uncoated metallic specimens — Examples of spectra of polymer — Coated and uncoated specimens
(Part 11)	Evaluation of degradation of coatings — Designation of quantity and size of defects and of intensity of uniform changes in appearance,
(Sec 2) : 2024/ ISO 4628-2 : 2016	Assessment of degree of blistering
(Sec 5) : 2024/ ISO 4628-5 : 2022	Assessment of degree of flaking
IS 104 : 2017	Specification for ready mixed paint brushing zinc chrome priming (*third revision*)
IS 109 : 2017	Specification for ready mixed paint finishing priming plaster to Indian Standard colour no 361 light stone and no 631 light grey white and off — white (*second revision*)
IS 137 : 2017	Ready mixed paint brushing matt or eggshell flat finishing interior to Indian standard colour as required — Specification (*second revision*)
IS 151 : 2017	Ready mixed paint, spraying, finishing, stoving, enamel for general purposes, colour as required — Specification (*second revision*)
IS 158 : 2015	Ready mixed paint brushing bituminous black acid alkali and heat resisting — Specification (*fourth revision*)
IS 159 : 2024	Ready mixed paint, brushing, acid resisting — Specification (*second revision*)
IS 164 : 2023	Ready mixed paint for road marking — Specification (*third revision*)

IS No.	*Title*
IS 168 : 2024	Ready mixed paint air drying for general purpose — Specification (*fifth revision*)
IS 341 : 2016	Black japan, types A, B and C — Specification (*second revision*)
IS 486 : 2023	Brushes, sash tool for paints and varnishes — Specification (*fifth revision*)
IS 2074 : 2023	Ready mixed paint air drying red oxide zinc chrome priming — Specification (*fourth revision*)
IS 2075 : 2017	Ready mixed paint stoving red oxide zinc chrome priming — Specification (*third revision*)
IS 2339 : 2013	Specification for aluminium paint for general purposes (*first revision*)
IS 2932 : 2025	Air drying enamel paint for architectural and industrial applications — Specification (*fifth revision*)
IS 3536 : 2016	Ready mixed paint, brushing, wood primer — Specification (*second revision*)
IS 3537 : 2017	Ready mixed paint, finishing, interior, for general purposes, to Indian Standard colours — Specification (*first revision*)
IS 3539 : 1966	Specification for ready mixed paint, undercoating, for use under oil finishes, to Indian Standard colours, as required
IS 3585 : 2018	Ready mixed paint, aluminium, brushing, priming, water resistant for woodwork — Specification (*first revision*)
IS 3678 : 2016	Ready mixed paint, thick white, for lettering — Specification (*first revision*)
IS 8687	Vitreous enamels and frits — Method of test:
(Part 1) : 2023	Sieve analysis (*first revision*)
(Part 2) : 2020	Fusion flow test (*first revision*)
IS 8709 : 2023	Colour retention of vitreous enamel coatings — Method of test (*first revision*)
IS 8767 : 2020	Calcium carbonate, precipitated, and activated, for paints —Specification (*first revision*)
IS 9862 : 2017	Specification for ready mixed paint brushing bituminous black acid alkali water and chlorine resisting (*first revision*)
IS 11883 : 2017	Ready mixed paint, brushing, red oxide, priming for metals – Specification (*first revision*)
IS 12744 (Part 1) : 2013	Ready mixed paint, air drying, red oxide — Zinc phosphate, priming – Specification: Part 1 For domestic and decorative applications (*fourth revision*)
IS 13183 : 1991	Specification for aluminium paints, heat resistant
IS 13213 : 2018	Polyurethane full gloss enamel (two pack) — Specification (*first revision*)
IS 13607 : 1992	Specification for ready mixed paint, finishing, general purposes, synthetic
IS 13871 : 2021	Powder coating — Specification (*first revision*)
IS 14506 : 1998	Epoxy redoxide zinc phosphate weldable primer, two component — Specification

IS No.	*Title*
IS 14589 : 1999	Zinc priming paint, epoxy based, two pack — Specification
IS 16719 : 2022	Solvent free polyurethane coatings for exterior of steel pipe and fittings — Specification (*first revision*)
IS 16942 : 2018	Silicone soya alkyd exterior paint — Specification
IS 17044 : 2018	Intumescent fire retardant paint (water based) — Specification
IS 17680 (Part 1) : 2021/ ISO 18314-1 : 2015	Analytical colorimetry: Part 1 Practical colour measurement
IS 18563 : 2024	Nanomodified paints and coatings — Code of practice
IS 19003 : 2022	Re-dispersible polymer powder — Specification

c) Thinners and Solvents

IS No.	*Title*
IS 82:1973	Methods of sampling and test for thinners and solvents for paints (*first revision*)
IS 384	Flat brushes for paints and varnishes — Specification:
(Part 1) : 2023	Heavy duty (*seventh revision*)
(Part 2) : 2023	Household purposes *(seventh revision)*
IS 430 : 1972	Specification for paint remover, solvent type, non-flammable (*second revision*)
IS 431 : 1972	Specification for Paint remover, solvent type, flammable (*second revision*)
IS 486 : 2023	Brushes, sash tool for paints and varnishes — Specification (*fifth revision*)
IS 487 : 2023	Brushes, paints and varnishes – Oval, ferrule bound; and round, ferrule bound (*sixth revision*)
IS 533:2007	Specification for gum spirit of turpentine (oil of turpentine) (*third revision*)
IS 644 : 2023	Dipentene for paints — Specification (*third revision*)
IS 5667 : 1970	Specification for thinner for cellulose nitrate based paints and lacquers
IS 14314 : 1995	Specification for thinner general purposes for synthetic paints and varnishes

d) Varnishes and Lacquers

IS 344 : 2023	Varnish stoving — Specification (*second revision*)
IS 347 : 2023	Varnish shellac for general purposes — Specification (*second revision*)
IS 348 : 1968	Specification for French polish (*first revision*)
IS 524 : 2024	Varnish for general purpose — Specification (*third revision*)
IS 642 : 2024	Varnish medium for aluminium paint — Specification *(second revision)*

IS 5691 : 2024	Lacquer, cellulose nitrate, pigmented, finishing, glossy — Specification (*first revision*)
IS 6127 : 2023	Varnish, spar and fungicidal — Specification (*first revision*)
IS 10018:1981	Specification for lacquer, cellulose, nitrate clear, finishing, glossy for wood

19 POLYMERS, PLASTICS AND GEOSYNTHETICS/GEOTEXTILES

IS No.	*Title*
IS 1998 : 1962	Methods of test for thermosetting synthetic resin bonded laminated sheets
IS 2036 : 1995	Specification for phenolic laminated sheets (*second revision*)
IS 2046 : 2025/ ISO 4586 : 2018	Decorative thermosetting synthetic resin bonded laminated sheets — Specification:
(Part 1) : 2025	Introduction and general information (*third revision*)
(Part 2) : 2025	Determination of properties (*third revision*)
(Part 3) : 2025	Classification and specifications for laminates less than 2 mm thick and intended for bonding to supporting substrates (*third revision*)
(Part 4) : 2025	Classification and specifications for compact laminates of thickness 2 mm and greater (*third revision*)
(Part 5) : 2025	Classification and specifications for flooring grade laminates less than 2 mm thick intended for bonding to supporting substrates (*third revision*)
(Part 6) : 2025	Classification and specifications for exterior-grade compact laminates of thickness 2 mm and greater (*third revision*)
(Part 7) : 2025	Classification and specifications for design laminates (*third revision*)
(Part 8) : 2025	Classification and specifications for alternative core laminates (*third revision*)
IS 2076 : 1981	Specification for unsupported polyvinyl chloride sheeting (*first revision*)
IS 2508 : 2024	Polyethylene films and sheets — Specification (*fourth revision*)
IS 6307 : 2023	Rigid PVC sheets — Specification (*second revision*)
IS 10889 : 2004	Specification for high density polyethylene films (*first revision*)
IS 12830:1989	Specification for rubber based adhesives for fixing PVC tiles to cement
IS 13162	Geotextiles — Methods of test:
(Part 2) : 2024	Determination of resistance to the exposure of ultraviolet light, moisture and heat (xenon-arc type apparatus) (*first revision*)
(Part 3) : 2021	Single layers (*first revision*)
(Part 4) : 2025	Dynamic perforation test (cone drop test) (*first revision*)
IS 13262 : 1992	Specification for pressure sensitive adhesive tapes with plastic base

IS No.	*Title*
IS 13325 : 1992	Method of test for the determination to tensile properties of extruded polymer geogrids using the wide strip
IS 13326 (Part 1) : 2025/ ISO 12957-1 : 2018	Geosynthetics — Determination of friction characteristics: Part 1 Direct shear test (*first revision*)
IS 14182 : 1994	Specification for solvent cement for use with unplasticized polyvinylchloride plastic pipe and fittings
IS 14293 : 2024	Geotextiles — Method for determination of trapezoid tearing strength (*first revision*)
IS 14294 : 2024	Geotextiles — Method for determination of apparent opening size by dry sieving technique (*first revision*)
IS 14324 : 2025/ ISO 11058 : 2019	Geotextiles and geotextile-related products — Determination of water permeability characteristics normal to the plane, without load (*first revision*)
IS 14443 : 1997	Specification for polycarbonate sheets
IS 14500 : 1998	Linear low-density polyethylene (LLDPE) films — Specification
IS 14643 : 1999	Specification for unsintered polytetrafluoroethylene (PTFE) Tape for thread sealing applications
IS 14706 : 2024/ ISO 9862 : 2023	Geosynthetics — Sampling and preparation of test specimens (*first revision*)
IS 14714 : 2024	Geotextiles — Determination of abrasion resistance (*first revision*)
IS 14715	Jute geotextiles:
(Part 1) : 2016	Strengthening of sub-grade in roads — Specification (*second revision*)
(Part 2) : 2016	Control of bank erosion in rivers and waterways — Specification (*second revision*)
IS 14716 : 2021	Geosynthetics — Test method for the determination of mass per unit area of geotextiles and geotextile-related products (*first revision*)
IS 14739 : 2026/ ISO 13431 : 1999	Geotextiles and geotextile-related products: Determination of tensile creep and creep rupture behaviour (*second revision*)
IS 14753 : 1999	Specification for poly(methyl) methacrylate (PMMA) (acrylic) sheets
IS 14986 : 2001	Guidelines for application of jute geotextile for rain water erosion control in road and railway embankments and hill slopes
IS 15060 : 2018/ ISO 10321 : 2008	Geosynthetics tensile test for joint seams by wide-width strip method (*first revision*)
IS 15351 : 2015	Agro textiles laminated high density polyethylene HDPE woven geomembrane for water proof lining — Specification (*second revision*)
IS 15869 : 2020	Textiles-Open weave coir Bhoovastra — Specification (*first revision*)
IS 15909 : 2020	PVC geomembranes for lining — Specification (*second revision*)

IS No.	*Title*
IS 16352 : 2020	Geosynthetics — High density polyethylene (HDPE) geomembranes for lining-specification (*first revision*)
IS 16362 : 2024	Geosynthetics — Geotextiles for subsurface drainage, subgrade separation, subgrade stabilization, filtration and erosion control (in hard armor systems) applications — Specification (*second revision*)
IS 16380 : 2020	Geosynthetics — Method of test for measuring pullout resistance of geosynthetics in soil (*first revision*)
IS 16483 : 2017	Geosynthetics — Method for microscopic evaluation of the dispersion of carbon black in polyolefin geosynthetics
IS 16493 : 2017	Geosynthetics — Method of test for determination of pyramid puncture resistance of unprotected and protected geomembranes
IS 16627 : 2017	Agro textiles — High density polyethylene (HDPE) laminated woven lay flat tube for use in mains and submains of drip irrigation system — Specification
IS 16635 : 2026	Geosynthetics — Wide-width tensile test (*first revision*)
IS 16653 : 2017	Geosynthetics — Needle punched nonwoven geobags for coastal and waterways protection — Specification
IS 16654 : 2017	Geosynthetics — Polypropylene multifilament woven geobags for coastal and waterways protection — Specification
IS 17179 : 2025/ ISO 12958 : 2020	Geotextiles and geotextile-related products — Determination of water flow capacity in their plane:
(Part 1)	Index text
(Part 2)	Performance test (*first revision*)
IS 17360 : 2020	Geosynthetics — Screening test method for determining the resistance of geotextiles and geotextile-related products to oxidation
IS 17363 : 2025	Geotextiles and geotextile-related products — Screening test method for determining the resistance to acid and alkaline liquids (*first revision*)
IS 17365 : 2025/ ISO/TS 20432 : 2022	Determination of the long-term strength of geosynthetics for soil reinforcement — Guidelines (*first revision*)
IS 17368 : 2020	Geosynthetics — Determination of damage to geosynthetic caused during installation
IS 17369	Geotextiles and geotextile-related products — Strength of internal structural junctions:
(Part 1) : 2020/ ISO 13426-1 : 2019	Geocells
(Part 2) : 2025/ ISO 13426-2 : 2005	Geocomposites (*first revision*)
IS 17371 : 2020	Geosynthetics — Geogrids for flexible pavements — Specification
IS 17372 : 2020	Geosynthetics — Polymeric strip/geostrip used as soil reinforcement in retaining structures — Specification

IS No.	*Title*
IS 17373 : 2020	Geosynthetics — Geogrids used in reinforced soil retaining structures — Specification
IS 17374 : 2020	Geosynthetics — Reinforced HDPE membrane for effluents and chemical resistance lining — Specification
IS 17420 : 2020	Geosynthetics — Index test procedure for the evaluation of mechanical damage under repeated loading-damage caused by granular material (laboratory test method)
IS 17483	Geosynthetics — Geocells — Specification:
(Part 1) : 2020	Load bearing application
(Part 2) : 2020	Slope erosion protection application
IS 17544 : 2022	Multilayer (PE-AL-PE) plastic piping system for indoor gas installations with a maximum operating pressure up to and including 500 KPA (5 Bar) — Specification
IS 17728 : 2021	Agro textiles — High density polyethylene (HDPE) laminated woven lay flat tube and fittings for use in rain irrigation system — Specification
IS 17880 : 2022	Geosynthetics — Synthetic polymer rope gabions for coastal and waterways protection — Specification
IS 18309 : 2023	Geosynthetics — Prefabricated vertical drains for quick consolidation of very soft plastic soil-Specification
IS 18998 : 2025/ ISO 24187 : 2023	Principles for the analysis of microplastics present in the environment
IS 19050 : 2025/ ISO 17541 : 2014	Plastics — Quantitative evaluation of scratch-induced damage and scratch visibility
IS 19169 : 2025/ ISO 21475 : 2019	Plastics — Methods of exposure to determine the wavelength dependent degradation using spectrally dispersed radiation
IS 19104 : 2025	Geosynthetics — Geotextile tubes for coastal and waterways protection — Specification
IS 19161 : 2025/ ISO 16869 : 2008	Plastics — Assessment of the effectiveness of fungistatic compounds in plastics formulations
IS 19162 : 2025/ ISO 15314 : 2018	Plastics — Methods for marine exposure
IS 19165 : 2025/ ISO 22196 : 2011	Measurement of antibacterial activity on plastics and other non-porous surfaces
IS 19166 : 2025/ ISO 10640 : 2011	Plastics — Methodology for assessing polymer photoageing by FTIR and UV/visible spectroscopy
IS 19167 : 2025/ ISO 21702 : 2019	Measurement of antiviral activity on plastics and other non-porous surfaces
IS 19168 : 2025/ ISO 29664 : 2010	Plastics — Artificial weathering including acidic deposition

IS No.	*Title*
IS 19218 : 2025	Textiles — Coir non-woven stitched composite geotextiles for erosion control applications — Specification

20 SANITARY APPLIANCES AND WATER FITTINGS

a) General

IS No.	*Title*
IS 804 : 1967	Specification for rectangular pressed steel tanks (*first revision*)
IS 906 : 2024	Portable and fixed type revolving branch for firefighting — Specification (*fourth revision*)
IS 1726 : 1991	Specification for cast iron manhole covers and frames (*third revision*)
IS 2963 : 2013	Copper alloy waste fittings and waste plug for wash-basins and sinks — Specification (*second revision*)
IS 5219 : 2013	Cast copper alloy traps — Specification (*first revision*)
IS 5455 : 1969	Specification for cast-iron steps for manholes
IS 5961 : 1970	Specification for cast iron gratings for drainage purposes
IS 9140 : 1996	Method of sampling of vitreous and fire clay sanitary appliances (*second revision*)
IS 9872 : 1981	Specification for precast concrete septic tanks
IS 12592 : 2002	Specification for precast concrete manhole covers and frames (*first revision*)
IS 12701 : 1996	Specification for rotational moulded polyethylene water storage tanks (*first revision*)
IS 13356 : 1992	Specification for precast ferrocement water tanks (250 to 10 000 litres capacity)
IS 14399	Hot press moulded thermosetting glass fibre reinforced (GRP) sectional water storage tanks:
(Part 1) : 1996	Specification for panels
(Part 2) : 1996	Guidelines for assembly, installation and testing
IS 17650	Water efficient plumbing products — Requirements:
(Part 1) : 2021	Sanitaryware
(Part 2) : 2021	Sanitary fittings
IS 18666 : 2024	Rotationally moulded polyethylene septic tanks — Specification
IS 18797 : 2024	Packaged sewage treatment plant — Specification
IS 19315 : 2025	Ball valves for water works purposes — Specification

b) Pipes and Fittings excluding valves

i) *Brass and Copper Pipes and Fittings*

IS No.	*Title*
IS 407 : 1981	Specification for brass tubes for general purposes (*third revision*)
IS 2501 : 1995	Specification for solid drawn copper tubes for general engineering purposes (*third revision*)

ii) *Cast Iron Pipes and Fittings*

IS No.	*Title*
IS 1536 : 2001	Specification for centrifugally cast (spun) iron pressure pipes for water, gas and sewage (*fourth revision*)
IS 1536 : 2023	Centrifugally cast spun iron pressure pipes for water gas and sewage specification (*fifth revision*)
IS 1537 : 1976	Specification for vertically cast iron pressure pipes for water, gas and sewage (*first revision*)
IS 1538 : 1993	Specification for cast iron fittings for pressure pipes for water, gas and sewage (*third revision*)
IS 1729 : 2023	Sand cast iron spigot and socket pipes, fittings and accessories — Specification (*third revision*)
IS 1729 : 2023	Sand cast iron spigot and socket pipes fittings and accessories — Specification (*third revision*)
IS 1879 : 2010	Malleable cast iron pipe fittings — Specification (*third revision*)
IS 3989 : 2024	Centrifugally cast (spun) iron spigot and socket pipes, fittings and accessories — Specification (*fourth revision*)
IS 5531 : 2014	Cast iron specials for asbestos cement pressure pipes for water and sewage — Specification (*third revision*)
IS 6418 : 1971	Specification for cast iron and malleable cast iron flanges for general engineering purposes
IS 7181 : 1986	Specification for horizontally cast iron double flanged pipes for water, gas and sewage (*first revision*)
IS 8329 : 2000	Specification for centrifugally cast (spun) ductile iron pressure pipes for water, gas and sewage (*third revision*)
IS 8794 : 1988	Specification for cast iron detachable joints for use with asbestos cement pressure pipes (*first revision*)
IS 9523 : 2000	Ductile iron fittings for pressure pipes for water gas and sewage — Specification (*first revision*)
IS 10292 : 1988	Dimensional requirements for rubber sealing rings for C.I.D. Joints in asbestos cement piping (*first revision*)

IS No.	*Title*
IS 10299 : 1982	Cast iron saddle pieces for service connection from asbestos cement pressure pipes
IS 11606 : 1986	Methods of sampling cast iron pipes & fittings
IS 12820 : 2004	Dimensional requirements of rubber gaskets for mechanical joints and push-on joints for use with cast iron pipes and fittings for carrying water gas and sewage (*first revision*)
IS 12987 : 1991	Cast iron detachable joints for use with asbestos cement pressure pipes (light duty) — Specification
IS 12988 : 1991	Rubber sealing rings for CID joints for light duty AC pipes — Dimensional requirements
IS 13382 : 2018	Cast iron specials for mechanical and push-on flexible joints for pressure pipes for water gas and sewage — Specification (*second revision*)
IS 15905 : 2024	Hubless centrifugally cast (spun) iron pipes, fittings and accessories — Spigot series — Specification (*first revision*)

iii) *Lead Pipes and Fittings*

IS No.	*Title*
IS 404 (Part 1) : 1993	Specification for lead pipes: Part 1 For other than chemical purpose (*third revision*)

iv) *Fibre Pipes and Fittings*

IS No.	*Title*
IS 11925 : 1986	Specification for pitch-impregnated fibre pipes and fittings for drainage purposes

v) *Plastic Pipes and Fittings*

IS No.	*Title*
IS 4984 : 2016	Polyethylene pipes for water supply — Specification (*fifth revision*)
IS 4985 : 2021	Unplasticized PVC pipes for potable water supplies — Specification (*fourth revision*)
IS 7834	Specification for injection moulded PVC socket fittings with solvent cement joints for water supplies:
(Part 1) : 1987	General requirements (*first revision*)
(Part 2) : 1987	Specific requirements for 45° elbows (*first revision*)
(Part 3) : 1987	Specific requirements for 90° elbows (*first revision*)
(Part 4) : 1987	Specific requirements for 90° tees (*first revision*)
(Part 5) : 1987	Specific requirements for 45° tees (*first revision*)

IS No.	*Title*
(Part 6) : 1987	Specific requirements for sockets (*first revision*)
(Part 7) : 1987	Specific requirements for unions (*first revision*)
(Part 8) : 1987	Specific requirements for caps (*first revision*)
IS 8008 : 2022	Injection moulded machined polyethylene fittings for water supply — Specification (*second revision*)
IS 8360 : 2022	Fabricated polyethylene fittings for water supply — Specification (*first revision*)
IS 10124	Specification for fabricated PVC fittings for potable water supplies:
(Part 1) : 2009	General requirements (*second revision*)
(Part 2) : 2009	Specific requirements for sockets (*second revision*)
(Part 3) : 2009	Specific requirements of straight reducers (*second revision*)
(Part 4) : 2009	Specific requirements for caps (*second revision*)
(Part 5) : 2009	Specific requirements for equal tees (*second revision*)
(Part 6) : 2009	Specific requirements for flanged tail piece with metallic flanges (*second revision*)
(Part 7) : 2009	Specific requirements for threaded adaptors (*second revision*)
(Part 8) : 2009	Specific requirements for 90° bends (*second revision*)
(Part 9) : 2009	Specific requirements for 60° bends (*second revision*)
(Part 10) : 2009	Specific requirements for 45° bends (*second revision*)
(Part 11) : 2009	Specific requirements for 30° bends (*second revision*)
(Part 12) : 2009	Specific requirements for 22½° bends (*second revision*)
(Part 13) : 2009	Specific requirements for 11¼° bends (*second revision*)
IS 12235	Methods of test for unplasticised PVC pipes for potable water supplies:
(Part 1) : 2004	Measurement of dimensions (*first revision*)
(Part 2) : 2004	Determination of Vicat softening temperature (*first revision*)
(Part 3) : 2004	Test for opacity (*first revision*)
(Part 4) : 2004	Determining the detrimental effect on the composition of water (*first revision*)
(Part 5)	Longitudinal reversion:
(Sec 1) : 2004	Determination methods (*first revision*)
(Sec 2) : 2004	Determination parameters (*first revision*)
(Part 6) : 2004	Stress relief test (*first revision*)
(Part 7) : 2004	Resistance to sulphuric acid (*first revision*)

IS No.	*Title*
(Part 8)	Resistance to internal hydrostatic pressure,
(Sec 1) : 2004	Resistance to internal hydrostatic pressure at constant internal water pressure (*first revision*)
(Sec 2) : 2004	Leak-tightness of elastomeric sealing ring type socket joints under positive internal pressure and with angular deflection (*first revision*)
(Sec 3) : 2004	Leak-tightness of elastomeric sealing ring type socket joints under negative internal pressure and with angular deflection (*first revision*)
(Sec 4) : 2004	Leak-tightness of elastomeric sealing ring type socket joints under positive internal pressure without angular deflection (*first revision*)
(Part 9) : 2004	Resistance to external blows (impact resistance) at 0 °C (Round-the-clock method)
(Part 10) : 2004	Determination of organotin as tin aqueous solution (*first revision*)
(Part 11) : 2004	Resistance to dichloromethane at specified temperature (*first revision*)
(Part 12) : 2004	Determination of titanium dioxide content
(Part 13) : 2004	Determination of tensile strength and elongation
(Part 14) : 2004	Determination of density/relative density (specific gravity)
(Part 15) : 2004	Determination of vinyl chloride monomer content
(Part 16) : 2004	High temperature test
(Part 17) : 2004	Determination of ash content and sulphated ash content
(Part 18) : 2004	Determination of ring stiffness
(Part 19) : 2004	Flattening test
IS 12709 : 1994	Specification for glass-fibre reinforced plastic (GRP) pipes joints and fittings for use for potable water supply (*first revision*)
IS 12818 : 2010	Specification for unplasticized PVC screen and casing pipes for bore/tubewell (*second revision*)
IS 13592:2013	Unplasticized polyvinyl chloride (PVC-U) pipes for soil and waste discharge systemfor inside and outside buildings including ventilation and rainwater system — Specification (*first revision*)
IS 14333 : 2022	Polyethylene pipes for sewerage and industrial chemicals and effluent — Specification (*first revision*)
IS 14402 : 1996	Specification for GRP pipes, joints and fittings for use for sewerage, industrial waste and water (other than potable)
IS14735 : 1999	Specification for unplasticized polyvinyl chloride (UPVC) injection moulded fittings for soil and waste discharge system for inside buildings including ventilation and rain water system

IS No.	*Title*
IS 14885 : 2022	Polyethylene pipes for the supply of gaseous fuels — Specification (*first revision*)
IS 15328:2003	Specification for unplasticized non-pressure polyvinyl chloride (PVC-U) pipes for use in underground drainage and sewerage system
IS 15450 : 2022	Polyethylene-aluminium-polyethylene composite pressure pipes for hot and cold water supplies — Specification (*first revision*)
IS 15778 : 2007	Chlorinated polyvinyl chloride (CPVC) pipes for potable hot and cold water distribution supplies — Specification
IS 15801 : 2008	Polypropylene-random copolymer pipes for hot and cold water supplies — Specification
IS 15927	Specification for polyethylene fittings for use with polyethylene pipes for the supply of gaseous fuels:
(Part 1) : 2012	Fittings for sockets using heated tools
(Part 2) : 2012	Spigot fittings for butt fusion jointing or socket fusion using heated tools, spigot fittings for use with electro-fusion fittings
(Part 3) : 2011	Electro-fusion fittings
IS 16098	Structured — wall plastics piping systems for non-pressure drainage and sewerage — Specification
(Part 1) : 2013	Pipes and fittings with smooth external surface, Type A
(Part 2) : 2013	Pipes and fittings with non-smooth external surface, Type B
IS 16534 : 2017	Chlorinated polyvinyl chloride (CPCV) Pipe fittings for automatic sprinkler fire extinguishing system — Specification
IS 16647 : 2017	Oriented unplasticized polyvinyl chloride (PVC-O) pipes for water supply — Specification
IS 17546 : 2021	Chlorinated polyvinyl chloride (CPVC) fittings for potable hot and cold water distribution supplies — Specification

vi) *Steel Tubes, Pipes and Fittings*

IS No.	*Title*
IS 1239	Steel tubes tubulars and other wrought steel fittings — Specification:
(Part 1) : 2004	Steel tubes (*sixth revision*)
(Part 2) : 2011	Steel pipe fittings (*fifth revision*)
IS 3589 : 2001	Steel pipes for water and sewage 1 683 mm to 2 540 mm outside diameter — Specification (*third revision*)
IS 4270 : 2001	Steel tubes used for water wells — Specification (*third revision*)
IS 5504 : 2025	Spiral welded pipes — Specification (*second revision*)

IS 6286 : 1971	Specification for seamless and welded steel pipe for sub-zero temperature service
IS 6392 : 2020	Steel pipes flanges — Specification (*first revision*)

vii) *Stoneware Pipes and Fittings*

IS No.	*Title*
IS 651 : 2007	Glazed stoneware pipes and fittings — Specification (*sixth revision*)
IS 3006 : 1979	Specification for chemically resistant glazed stoneware pipes and fittings (*first revision*)

viii) *Asbestos Cement Pipes*

[*See* 9 (a) (ii) under the category ‘Composite Matrix Products’]

ix) *Concrete Pipes and Pipes lined/coated with Concrete or Mortar*

[*See* 9 (a) (iv) under the category ‘Composite Matrix Products’]

c) Kitchen and Sanitary Appliances

IS No.	*Title*
IS 774 : 2021	Ceramic vitreous china flushing cisterns for water closets and urinals — Specification (*sixth revision*)
IS 2548	Specification for plastic seats and covers for water-closets:
(Part 1) : 1996	Thermoset seats and covers (*fifth revision*)
(Part 2) : 1996	Thermoplastic seats and covers (*fifth revision*)
IS 2556	Vitreous china sanitary appliances — Specification:
(Part 1) : 2021	General requirements (*fourth revision*)
(Part 2) : 2024	Specific requirements of washdown water closets (*sixth revision*)
(Part 3) : 2024	Specific requirements of squatting pans (*sixth revision*)
(Part 4) : 2004	Specific requirements of wash basins (*fourth revision*)
(Part 5) : 1994	Specific requirements of laboratory sinks (*third revision*)
(Part 6) : 2021	Specific requirements of urinal and partition plates (*fifth revision*)
(Part 7) : 1995	Specific requirements of accessories for sanitary appliances (*third revision*)
(Part 8) : 2021	Specific requirements of close coupled and one-piece pedestal washdown and syphonic water closets (*sixth revision*)
(Part 9) : 2004	Specific requirements of pedestal type bidets (*fifth revision*)
(Part 14) : 2024	Specific requirements of integrated squatting pans (*second revision*)
(Part 15) : 2024	Specific requirements of universal water closets (*third revision*)

IS No.	*Title*
(Part 16) : 2024	Specific requirements of washdown wall mounted water closets (*first revision*)
(Part 17) : 2001	Specific requirements of wall mounted bidets
IS 6411 : 1985	Specification for gel-coated glass fibre reinforced polyester resin bath tubs (*first revision*)
IS 7231 : 2021	Plastic flushing cisterns for water closets and urinals — Specification (*third revision*)
IS 11246 : 1992	Specification for glass fibre reinforced polyester resins (GRP) squatting pans (*first revision*)
IS 13983 : 1994	Specification for stainless steel sinks for domestic purposes

d) Valves and Water Fittings (Including Ferrules)

IS No.	*Title*
IS 778 : 1984	Specification for copper alloy gate, globe, and check valves for water works purposes (*fourth revision*)
IS 781 : 1984	Specification for cast copper alloy screw-down bib taps and stop valves for water services (*third revision*)
IS 1701 : 1960	Specification for mixing valves for ablutionary and domestic purposes
IS 1703 : 2000	Water fittings — Copper alloy float valves (horizontal plunger type) — Specification (*fourth revision*)
IS 1711 : 1984	Specification for self-closing taps for water supply purposes (*second revision*)
IS 1795 : 1982	Specification for pillar taps for water supply purposes (*second revision*)
IS 2692 : 1989	Specification for ferrules for water services (*second revision*)
IS 3004 : 1979	Specification for plug cocks for water supply purposes (*first revision*)
IS 3042 : 1965	Specification for single faced sluice gates (200 mm to1 200 mm size)
IS 3950 : 1979	Specification for surface boxes for sluice valves (*first revision*)
IS 4038 : 1986	Specification for foot valves for water works purposes (*second revision*)
IS 4346 : 1982	Specification for washers for use with fittings for water services (*first revision*)
IS 5312	Specification for swing check type reflux (non-return) valves:
(Part 1) : 2004	Single door pattern (*second revision*)
(Part 2) : 2013	Multi-door pattern (*first revision*)
IS 8931 : 2021	Copper alloy single taps combination tap assemblies stop valves and single lever mixers for water services — Specification (*second revision*)
IS 9338 : 2013	Cast iron/S.G. iron, cast steel screw-down stop valves for water works purposes — Specification (*second revision*)

IS No.	*Title*
IS 9739 : 1981	Specification for pressure reducing valves for domestic water supply systems
IS 9758 : 1981	Specification for flush valves and fittings for water-closets and urinals
IS 9762 : 1994	Specification for polyethylene floats (spherical) for float valves (*first revision*)
IS 9763 : 2000	Plastic bib taps, pillar taps, angle valves, hot and cold water services — Specification (*second revision*)
IS 12234 : 2021	Plastic equilibrium float valves for cold water services — Specification *(first revision*)
IS 13049 : 1991	Specification for diaphragm type (plastic body) float operated valves for cold water services
IS 13114 : 1991	Specification for forged brass gate, globe and check valves for water works purposes
IS 13349 : 1992	Specification for single faced cast iron thimble mounted sluice gates
IS 14845 : 2000	Resilient seated cast iron air relief valves for water works purposes — Specification
IS 14846 : 2000	Sluice valves for water works purposes (50 mm to 1 200 mm) — Specification
IS 17585 : 2021	Beta (Outflow) valves for gravity type flushing cisterns — Specification

e) Water Meters

IS No.	*Title*
IS 779 : 1994	Specification for water meters (domestic type) (*sixth revision*)
IS 2373 : 1981	Specification for water meters (bulk type) (*third revision*)
IS 6784 : 1996	Method for performance testing of water meters (domestic type) (*second revision*)

21 STEEL AND ITS ALLOYS (*See* 23 FOR STRUCTURAL SECTIONS)

a) General

IS No.	*Title*
IS 1030 : 1998	Carbon steel castings for general engineering purposes (*fifth revision*)
IS 1136 : 2008	Preferred sizes for wrought metal products (*third revision*)
IS 1762 (Part 1) : 1974	Code for designation of steels: Part 1 Based on letter symbols (*first revision*)
IS 2049 : 1978	Colour code for the identification of wrought steel for general engineering purposes (*first revision*)
IS 2644 : 1994	High strength steel castings for general engineering and structural purposes — Specification (*fourth revision*)
IS 2708 : 1993	1.5 percent manganese steel castings for general engineering purposes — Specification (*third revision*)

IS No.	*Title*
IS 7598 : 1990	Classification of steels (*first revision*)
IS 10461	Resistance to inter-granular corrosion of austenitic stainless steels — Method for determination:
(Part 1) : 2025	Corrosion test in nitric acid medium by measurement of loss in mass (Huey Test) (*second revision*)
(Part 2) : 1994	Corrosion test in a sulphuric acid/copper sulphate medium in the presence of copper turnings (Monypenny strauss test) (*first revision*)
IS/ISO 11951 : 2016	Cold-reduced tinmill products — Blackplate *(first revision)*
IS 12591 : 2018	Cold-reduced tinmill products — Electrolytic chromium/chromium oxide — Coated steel (*second revision*)
IS 14126 : 2019	Metallic coatings — Measurement of coating thickness — Coulometric method by anodic dissolution (*first revision*)
IS 16733 : 2018	Ferritic-pearlitic engineering steels for precipitation hardening from hot-working temperatures
IS 16854 : 2018	Single pack zinc rich coating for cold application — Specification
IS 17111 : 2025/ ISO 683-17 : 2023	Heat-Treatable steels, alloy steels and free-cutting steels — Ball and roller bearing steels (*first revision*)
IS 18435 (Part 11) : 2023	Corrosion of metals and alloys — Stress corrosion testing: Part 11 Testing the resistance of metals and alloys to hydrogen embrittlement and hydrogen-assisted cracking — Guidelines
IS 18436 : 2023	Metallic and other inorganic coatings — Post-coating treatments of iron or steel to reduce the risk of hydrogen embrittlement
IS 18437 : 2023/ ISO 15324 : 2000	Corrosion of metals and alloys — Evaluation of stress cracking by the drop evaporation test
IS 18438 : 2023/ ISO 18069 : 2015	Corrosion of metals and alloys — Method for determination of the uniform corrosion rate of stainless steels and nickel based alloys in liquids
IS 18463 : 2023/ ISO 9587 : 2007	Metallic and other inorganic coatings — Pretreatment of iron or steel to reduce the risk of hydrogen embrittlement

b) Structural Steel

IS No.	*Title*
IS 1161 : 2014	Steel tubes for structural purposes — Specification (*fifth revision*)
IS 2062	Structural steel
(Part 1) : 2025	Hot rolled medium and high tensile steel (*eight revision*)
(Part 2) : 2025	Hot rolled quenched and tempered steel plates, sheets, strips and wide flats
IS 2830 : 2012	Specification for carbon steel cast billet ingots, billets, blooms and slabs for re-rolling into steel for general structural purposes (*third revision*)

IS No.	*Title*
IS 2831 : 2012	Specification for carbon steel billets ingots, blooms and slabs for re-rolling into structural steel (ordinary quality) (*fourth revision*)
IS 4923 : 2017	Hollow steel sections for structural use — Specification (*third revision*)
IS 8052 : 2006	Specification for steel ingots, billets and blooms for the production of springs, rivets and screws for general engineering applications (*second revision*)
IS 8952 : 1995	Steel ingots, blooms and billets for production of mild steel wire rods for general engineering purposes (*first revision*)
IS 11587 : 1986	Specification for structural weather resistant steels
IS 15103 : 2002	Fire resistant steel — Specification
IS 15911 : 2010	Structural steel (Ordinary quality) — Specification
IS 15962 : 2012	Structural steels for buildings and structures with improved seismic resistance
IS 16732 : 2019	Galvanized structural steel — Specification

c) Sheet and Strip

IS No.	*Title*
IS 277 : 2018	Galvanized steel strips and sheets plain and corrugated — Specification (*seventh revision*)
IS 412 : 1975	Specification for expanded metal steel sheets for general purposes (*second revision*)
IS 513	Cold reduced carbon steel sheet and strip:
(Part 1) : 2016	Cold forming and drawing purpose (*sixth revision*)
(Part 2) : 2016	High tensile and multi-phase steel (*sixth revision*)
IS 1079 : 2017	Hot rolled carbon steel sheet plate and strip — Specification (*seventh revision*)
IS 6911 : 2026	Stainless steel plate sheet and strip — Specification (*third revision*)
IS 7226 : 1974	Specification for cold rolled medium, high carbon and low alloy steel strip for general engineering purposes
IS 14246 : 2024	Continuously pre-painted galvanized steel sheets and strips — Specification (*second revision*)
IS 15961 : 2025	Hot-dip alumnium zinc alloy metallic coated steel strip and sheet — Specification (*first revision*)
IS 15965 : 2012	Pre-painted aluminium zinc alloy metallic coated steel strip & sheet (plain)
IS 18513 : 2023	Hot-dip zinc-aluminium-magnesium alloy coated steel sheets plates and strips — Specification
IS 18733 : 2024/ ISO 11531 : 2022	Metallic materials — Sheet and strip — Earing test

IS No.	*Title*
IS 19210 : 2025	Pre-Painted Zinc-aluminium-magnesium alloy coated steel strip and sheet
IS 19474 : 2026	Hot-dip aluminium and aluminium-silicon coated steel sheet and strip — Specification
IS 19608 : 2026	Hot-rolled carbon and alloy steel plates, sheets and strips — Specification
IS 19626 : 2026	Electrolytic Zinc-nickel alloy coated steel sheet and strip — Specification

d) Bars, Rods, Wire and Wire Rods

IS No.	*Title*
IS 280 : 2006	Mild steel wire for general engineering purposes — Specification (*fourth revision*)
IS 1148 : 2009	Steel rivet bars medium and high tensile — For structural purposes — For structural purposes (*fourth revision*)
IS 1673 : 1984	Specification for mild steel wire cold heading quality (*second revision*)
IS 1812 : 1982	Specification for carbon steel wire for the manufacture of wood screw (*second revision*)
IS 1835 : 1976	Specification for round steel wire for ropes (*third revision*)
IS 1875 : 2025	Steel ingots, billets, blooms, slabs, and bars for forging — Specification (*sixth revision*)
IS 1921 : 2025	Solder wire — Solid and flux cored — Specification (*third revision*)
IS 2591 : 1982	Dimensions for hot rolled bars for threaded components (*second revision*)
IS 3150 : 1982	Specification for hexagonal wire netting for general purposes
IS 4826 : 2023	Hot-dip galvanized coatings on round steel wires requirements (*second revision*)
IS 6528 : 2024	Stainless steel wire — Specification (*second revision*)
IS 6603 : 2024	Stainless steel semi-finished products, bars, wire rods and bright bars — Specification (*second revision*)
IS 7887:1992	Specification for mild steel wire rods for general engineering purposes (*first revision*)
IS 7904 : 2018	High carbon steel wire rods — Specification (*second revision*)
IS 10631 : 1983	Stainless steel for welding electrode core wire
IS/ISO 16124 : 2015/ ISO 16124 : 2015	Steel wire rod — Dimensions and tolerances (*first revision*)

e) Plates and Studs

IS No.	*Title*
IS 1862 : 1975	Specification for studs (*second revision*)
IS 3502 : 2009	Specification for steel chequered plates (*third revision*)

f) Tubes and Tubulars

IS No.	*Title*
IS 1161 : 2014	Specification for steel tubes for structural purposes (*fifth revision*)
IS 4923 : 2017	Hollow steel sections for structural use — Specification (*third revision*)
IS 17875 : 2022	Stainless steel seamless pipes and tubes for general services — Specification
IS 17876 : 2022	Stainless steel welded pipes and tubes for general services — Specification

g) Slotted Sections

IS No.	*Title*
IS 8081 : 1976	Specification for slotted sections

22 STONES

IS No.	*Title*
IS 1121	Methods of test for determination of strength properties of natural building stones:
(Part 1) : 2023	Compressive strength (*third revision*)
(Part 2) : 2023	Transverse strength (*third revision*)
(Part 3) : 2023	Indirect tensile strength (*third revision*)
(Part 4) : 2013	Shear strength (*second revision*)
(Part 5) : 2023	Flexural modulus of elasticity
IS 1122 : 2023	Determination of true specific gravity of natural building stones — Method of test (*second revision*)
IS 1123 : 1975	Method of identification of natural building stones (*first revision*)
IS 1124 : 1974	Method of test for determination of water absorption, apparent specific gravity and porosity of natural building stones (*first revision*)
IS 1125 : 2013	Method of test for determination of weathering of natural building stones (*second revision*)
IS 1126 : 2013	Method of test for determination of durability of natural building stones (*second revision*)
IS 1127 : 1970	Recommendations for dimensions and workmanship of natural building stones for masonry work (*first revision*)
IS 1128 : 1974	Specification for limestone (slab and tiles) (*first revision*)
IS 1129 : 1972	Recommendation for dressing of natural building stones (*first revision*)
IS 1130 : 1969	Specification for marble (blocks, slabs and tiles)

IS No.	*Title*
IS 1706 : 2024	Determination of resistance to wear by abrasion of natural building stones — Method of test (*second revision*)
IS 3316 : 1974	Specification for structural granite (*first revision*)
IS 3620 : 1979	Specification for laterite stone block for masonry (*first revision*)
IS 3622 : 1977	Specification for sand stone (slabs and tiles) (*first revision*)
IS 4121 : 1967	Method of test for determination of water transmission rate by capillary action through natural building stones
IS 4122 : 1967	Method of test for surface softening of natural building stones by exposure to acidic atmospheres
IS 4348 : 2024	Determination of permeability of natural building stones — Methods of test (*second revision*)
IS 5218 : 1969	Method of test for toughness of natural building stones
IS 5640 : 1970	Method of test for determining the aggregate impact value of soft coarse aggregates
IS 6241 : 2024	Determination of stripping value of road aggregates — Method of test (*first revision*)
IS 6250 : 1981	Specification for roofing slate tiles (*first revision*)
IS 6579 : 1981	Specification for coarse aggregate for water bound macadam (*first revision*)
IS 7779	Schedule for properties and availability of stones for construction purposes:
(Part 1)	Gujarat State,
(Sec 1) : 1975	Availability of stones
(Sec 2) : 1975	Engineering properties of building stones
(Sec 3) : 1975	Engineering properties of stone aggregates
(Part 2)	Maharashtra state,
(Sec 1) : 1979	Availability of stones
(Sec 2) : 1979	Engineering properties of building stones
(Sec 3) : 1979	Engineering properties of stone aggregates
(Part 3)	Tamil Nadu state,
(Sec 2) : 1980	Engineering properties of building stones
(Sec 3) : 1980	Engineering properties of stone aggregates
(Part 4/Sec 1 to 3) : 1996	Karnataka state, Sections (1 to 3)
(Part 5)	Andhra Pradesh,
(Sec 1) : 1997	Availability of stones

IS No.	*Title*
(Sec 2) : 1997	Engineering properties of building stones
(Sec 3):1997	Engineering properties of stone aggregates
IS 8759 : 2024	Maintenance and preservation of stone in buildings — Code of practice (*first revision*)
IS 9394 : 2024	Stone lintels — Specification (*first revision*)
IS 14223	Polished building stones specification:
(Part 1) : 2023	Granite and similar stones (*first revision*)
(Part 2) : 2025	Marble and similar stones

23 STRUCTURAL SECTIONS

a) Structural Shapes

IS No.	*Title*
IS 811 : 1987	Specification for cold formed light gauge structural steel sections (*second revision*)
IS 1173 : 2025	Hot rolled and slit steel tee bars — Dimensions and properties (*third revision*)
IS 1863 : 1979/ ISO 657-19	Rolled steel bulb flats (*first revision*)
IS 2314	Steel sheet piling section specification:
(Part 1) : 2023	Hot rolled sheet pile (*second revision*)
(Part 2) : 2023	Cold formed sheet pile (*second revision*)
IS 3443 : 1980	Specification for crane rail sections (*first revision*)
IS 3908 : 2025	Aluminium beam, channel and angle sections — Dimensions and properties (*second revision*)
IS 3964 : 1980	Specification for light rails (*first revision*)
IS 6445 : 1985	Specification for aluminium tee sections (*first revision*)

b) Dimensional Standards

IS No.	*Title*
IS 808 : 2021	Hot rolled steel beam column channel and angle sections — Dimensions and properties (*fourth revision*)
IS 1730 : 1989	Dimensions for steel plates, sheets strips and flats for general engineering purposes (*second revision*)
IS 1732 : 1989	Dimensions for round and square steel bars for structural and general engineering purposes (*second revision*)
IS 1852 : 1985	Rolling and cutting tolerances for hot rolled steel products (*fourth revision*)

IS No.	*Title*
IS 2525 : 1982	Dimensions for wrought aluminium and aluminium alloy wire (*first revision*)
IS 2591 : 1982	Dimensions for hot rolled steel bars for threaded components (*second revision*)
IS 2673 : 2002	Dimensions for wrought aluminium and aluminium alloys, extruded round tube (*second revision*)
IS 2676 : 1981	Dimensions for wrought aluminium and aluminium alloys, sheet and strip (*first revision*)
IS 2677 : 1979	Dimensions for wrought aluminium and aluminium alloys, plates and hot rolled sheets (*first revision*)
IS 2678 : 1987	Dimensions and tolerances for wrought aluminium and aluminium alloys, drawn round tubes (*second revision*)
IS 3577 : 1992	Dimensions and tolerances for wrought aluminium and aluminium alloys rivet, bolt and screw stock (*first revision*)
IS 3954 : 1991	Hot rolled steel channel sections for general engineering purposes — Dimensions (*first revision*)
IS 3965 : 1981	Dimensions for wrought aluminium and aluminium alloys, bar, rod and section (*first revision*)
IS 6477 : 1983	Dimensions for wrought aluminium and aluminium alloys, extruded hollow sections (*first revision*)
IS 12779 : 1989	Rolling and cutting tolerances for hot rolled parallel flange beam and column sections
IS/ISO 16124 : 2015	Steel wire rod — Dimensions and tolerances (*first revision*)
IS/ISO 16160 : 2012	Hot-rolled steel sheet products dimensional and shape tolerances (*first revision*)
IS/ISO 16162 : 2012	Cold-rolled steel sheet products — Dimensional and shape tolerances (*first revision*)
IS/ISO 16163 : 2012	Continuously hot-dipped coated steel sheet products — Dimensional and shape tolerances (*first revision*)
IS 16998 : 2018	Hot-rolled steel plates — Tolerances on dimensions and shape

24 THERMAL INSULATION MATERIALS

IS No.	*Title*
IS 3144 : 2024	Mineral wool thermal insulation materials — Methods of test (*third revision*)
IS 3346 : 1980	Methods for the determination of thermal conductivity of thermal insulation materials (two slab, guarded hot-plate method (*first revision*)

IS No.	*Title*
IS 3677 : 2026	Unbonded rock and slag wool for thermal insulation — Specification (*third revision*)
IS 4671 : 2018	Expanded polystyrene for thermal insulation purposes (*second revision*)
IS 5688 : 2018	Methods of test for preformed block-type and pipe-covering type thermal insulation (*second revision*)
IS 5724 : 2018	Thermal insulating cements — Methods of test (*first revision*)
IS 6598 : 2018	Cellular concrete for thermal insulation — Specification (*first revision*)
IS 7509 : 2024	Thermal insulating cements — Specification (*second revision*)
IS 8154 : 2024	Preformed calcium silicate insulation for temperatures up to 650 °C — Specification (*second revision*)
IS 8183 : 2024	Bonded mineral wool — Specification (*second revision*)
IS 9403 : 2018	Method of test for thermal conductance and transmittance of built-up Section by means of guarded hot box (*first revision*)
IS 9489 : 2018	Method of test for thermal conductivity of thermal insulation materials by means of heat flow meter (*first revision*)
IS 9490 : 2018	Method for determination of thermal conductivity of thermal insulation materials water calorimeter method (*first revision*)
IS 9742 : 2024	Sprayed mineral wool thermal insulation — Specification (*second revision*)
IS 9743 : 2020	Thermal insulation finishing cement — Specification (*second revision*)
IS 9842 : 2024	Preformed fibrous pipe insulation – Specification (*second revision*)
IS 11128 : 2018	Spray applied hydrated calcium silicate thermal insulation (*first revision*)
IS 11129 : 2018	Method of test for tumbling friability of preformed block-type thermal insulation (*first revision*)
IS 11239	Methods of test for rigid cellular thermal insulation materials:
(Part 1) : 2009/ ISO 1923 : 1981	Dimensions (*first revision*)
(Part 2) : 2019/ ISO 845 : 2006	Apparent density (*second revision*)
(Part 3) : 2009/ ISO 2796 : 1986	Dimensional stability (*first revision*)
(Part 4) : 2025/ ISO 1663 : 2023	Water vapour transmission rate (*second revision*)
(Part 5) : 2019/ ISO 4590 : 2016	Volume percent of open and closed cells (*second revision*)
(Part 6) : 1985	Heat distortion temperature
(Part 7) : 1985	Coefficient of linear thermal expansion at low temperatures

IS No.	*Title*
(Part 8) : 2024	Flame height, time of burning and loss of mass (*first revision*)
(Part 9) : 1988	Water absorption
(Part 10) : 1985	Flexural strength
(Part 11) : 2024	Compressive strength (*first revision*)
(Part 12) : 1988	Horizontal burning characteristics
(Part 14) : 1992	Determination of flammability by oxygen index
IS 11307 : 2025	Specification for cellular glass block and pipe thermal insulating (*first revision*)
IS 11308 :2024	Hydraulic setting thermal insulating castables for temperatures up to 1 250 °C — Specification (*first revision*)
IS 12436 : 1988	Specification for preformed rigid polyurethane (PUR) and polyisocyanurate (PIR) foams for thermal insulation
IS 13204 : 2024	Specification for rigid phenolic foams for thermal insulation (*first revision*)
IS 13286 : 2025	Methods of test for surface spread of flame for thermal insulation materials (*first revision*)
IS 14656 : 2026	Ceramic fibre products — Methods of test (*first revision*)

25 THREADED FASTENERS, RIVETS AND NAILS

IS No.	*Title*
IS 207 : 1964	Specification for gate and shutter hooks and eyes (*revised*)
IS 451 : 1999	Specification for technical supply conditions for wood screws (*third revision*)
IS 554 : 1999	Specification for pipe threads where pressure-tide joints are made on the threads — Dimensions, tolerances and designation (*fourth revision*)
IS 723 : 2023	Steel countersunk head wire nails — Specification (*second revision*)
IS 724 : 2023	Mild steel and brass cup, ruler and square hooks and screw eyes — Specification (*second revision*)
IS 725 : 1961	Specification for copper wire nails (*revised*)
IS 730 : 2021	Specification for hook bolts for corrugated sheet roofing (*third revision*)
IS 1120 : 1975	Specification for coach screws (*first revision*)
IS 1363	Hexagon head bolts, screws and nuts of product grade C:
(Part 1) : 2023/ ISO 4016 : 2022	Hexagon head bolts (size range M5 to M64) (*sixth revision*)
(Part 2) : 2023/ ISO 4018 : 2022	Hexagon head screws (size range M5 to M64) (*sixth revision*)

IS No.	*Title*
(Part 3) : 2018/ ISO 4034 : 2012	Style 1 Hexagon nuts (size range M5 to M64) (*fifth revision*)
IS 1364	Hexagon head bolts, screws and nuts of property grades A and B:
(Part 1) : 2023/ ISO 4014 : 2022	Hexagon head bolts (size range M1.6 to M64) (*sixth revision*)
(Part 2) : 2023/ ISO 4017 : 2022	Hexagon head screws (size range M1.6 to M64) (*sixth revision*)
(Part 3) : 2026/ ISO 4032 : 2023	Hexagon nuts, style 1 (size range M5 to M39) (*sixth revision*)
(Part 4) : 2025/ ISO 4035 : 2023	Hexagon nuts, style 0 (size range M1.6 to M64) (*fifth revision*)
(Part 5) : 2002/ ISO 4036 : 1999	Hexagon thin nuts — Product grade B (unchamfered) (size range M 1.6 to M10) (*fourth revision*)
(Part 6) : 2025/ ISO 4033 : 2023	Hexagon nuts, style 2 (Size Range M5 to M39) (*second revision*)
IS 1365 : 2022/ ISO 2009 : 2011	Slotted countersunk flat head screws — Product grade A (*fifth revision*)
IS 1366 : 2022/ ISO 1207 : 2011	Slotted cheese head screws — Product grade A (*fourth revision*)
IS 1367	Technical supply conditions for threaded steel fasteners:
(Part 1) : 2014/ ISO 8992 : 2005	General requirements for bolts, screws, studs and nuts (*fourth revision*)
(Part 2) : 2002/ ISO 4759-1 : 2000	Tolerances for fasteners — Bolts, screws, studs and nuts — Product grades a b and c (*third revision*)
(Part 3) : 2017/ ISO 898-1 : 2013	Mechanical properties of fasteners made of carbon steel and bolts, screws and studs (*fifth revision*)
(Part 5) : 2018 ISO 898-5 : 2012	Mechanical properties of fasteners made of carbon steel and alloy steel — Set screws and similar threaded fasteners with specified hardness classes-Coarse thread and fine pitch thread (*fourth revision*)
(Part 6) : 2025/ ISO 898-2:2022	Mechanical properties of fasteners made of carbon steel and alloy steel — Nuts with specified property classes (*fifth revision*)
(Part 7) : 1980	Mechanical properties and test methods for nuts without specified proof loads (*second revision*)
(Part 8) : 2020/ ISO 2320 : 2015	Prevailing torque type steel nuts functional properties (*fifth revision*)
(Part 9)	Surface discontinuities,
(Sec 1) : 1993/ ISO 6157-1 : 1988	Bolts screws and studs for general applications (*third revision*)

IS No.	*Title*
(Sec 2) : 1993/ ISO 6167-3 : 1988	Bolts screws and studs for special applications (*third revision*)
(Part 10) : 2002/ ISO 6157-2 : 1995	Surface discontinuities — Nuts (*third revision*)
(Part 11) : 2024/ ISO 4042 : 2022	Electroplated coating systems (*fifth revision*)
(Part 12) : 1981	Phosphate coatings on threaded fasteners (*second Revision*)
(Part 13) : 2020/ ISO 10684 : 2004	Hot dip galvanized coatings on threaded fasteners (*third Revision*)
(Part 14)	Mechanical properties of corrosion-resistant stainless steel fasteners,
(Sec 1) : 2023/ ISO 3506-1 : 2020	Bolts screws and studs with specified grades and property classes (*fifth revision*)
(Sec 2) : 2023/ ISO 3506-2 : 2020	Nuts with specified grades and property classes (*fifth revision*)
(Sec 3) : 2018/ ISO 3506-3 : 2009	Set screws and similar fasteners not under tensile stress (*fourth revision*)
(Sec 4) : 2023/ ISO 3506-4 : 2009	Tapping screws
(Part 16) : 2002/ ISO 8991 : 1986	Designation system for fasteners (*third revision*)
(Part 17) : 2023/ ISO 3269 : 2019	Inspections, sampling and acceptance procedure (*fifth revision*)
IS 1367	Industrial fasteners — Threaded steel fasteners — Technical supply conditions:
(Part 18) : 1996	Packaging (*third revision*)
(Part 19) : 1997/ ISO 3800 : 1993	Axial load fatigue testing of bolts screws and studs
(Part 20) : 1996/ ISO 896-7 : 1992	Torsional test and minimum torques for bolts and screws with nominal diameters 1 mm to 10 mm
IS 1929 : 1982	Specification for hot forged steel rivets for hot closing (12 mm to 36 mm diameter) (*first revision*)
IS 2016 : 1967	Specification for plain washers (*first revision*)
IS 2155 : 1982	Specification for cold forged solid steel rivets for hot closing (6 mm to 16 mm diameter) (*first revision*)
IS 2269 : 2006	Hexagon socket head cap screws (*fifth revision*)
IS 2585 : 2006	Square head bolts, screws and square nuts of product Grade C — Specification (*second revision*)

IS No.	*Title*
IS 2609 : 1972	Specification for coach bolts (*first revision*)
IS 2643 : 2005	Pipe threads where pressure-tight joints are not made on the threads — Dimensions, tolerances and designation (*third revision*)
IS 2687 : 1991	Specification for cap nuts (*second revision*)
IS 2769 : 1969	Sizes for squares and square holes for general engineering purposes (*first revision*)
IS 2907 : 1998	Specification for non-ferrous rivets (*first revision*)
IS 2998 : 1982	Specification for cold forged steel rivets for cold closing (1 mm to 16 mm diameter) (*first revision*)
IS 3063 : 1994	Specification for fasteners single coil rectangular section spring lock washers (*second revision*)
IS 3121 : 2023	Rigging screws and stretching screws — Specification (*second revision*)
IS 3468:1991	Specification for pipe nuts (*second revision*)
IS 3640 : 1982	Specification for hexagon fit bolts (*first revision*)
IS 3757 : 1985	Specification for high strength structural bolts (*second revision*)
IS 4206 : 2018/ ISO 888 : 2012	Dimensions for nominal lengths and thread lengths for bolts screws and studs *(second revision)*
IS 4762 : 2002	Fasteners — Worm drive hose clamps for general purposes — Specification (*second revision*)
IS 5370 : 1969	Specification for plain washers with outside diameter ≈ 3 × inside diameter
IS 5372 : 1975	Specification for taper washer for channels (ISMC) (*first revision*)
IS 5373 : 1969	Specification for square washers for wood fastenings
IS 5374 : 1975	Specification for taper washers for l-beam (ISMB) (*first revision*)
IS 5624 : 2021	Foundation bolts – Specification (*second revision*)
IS 6101 : 2018	Slotted pan head screws — Product Grade A (*third revision)*
IS 6113 : 1970	Specification for aluminium fasteners for building purposes
IS 6610 : 1972	Specification for heavy washers for steel structures
IS 6623 : 2004	High strength structural nuts — Specification (*second revision*)
IS 6639 : 1972	Specification for hexagon bolts for steel structures
IS 6649 : 1985	Specification for hardened and tempered washers for high strength structural bolts and nuts (*first revision*)
IS 6733 : 1972	Specification for wall and roofing nails
IS 6736 : 1972	Specification for slotted raised countersunk head wood screws

IS No.	*Title*
IS 6739 : 1972	Specification for slotted round head wood screws
IS 6760 : 1972	Specification for slotted countersunk head wood screws
IS 6761 : 2023	Fasteners — Hexagon socket countersunk head screws with reduced loadability (*third revision*)
IS 7002 : 2018	Prevailing torque type hexagon regular nuts (with non-metallic insert) — Property classes 5,8 and 10 (*third revision*)
IS 7178 : 2018	Heat-Treated steel tapping screws — Mechanical properties (*fourth revision*)
IS 7483 : 2018/ ISO 7045 : 2011	Pan head screws with type H or type Z cross recess — Product grade A (*third revision*)
IS 7485	Countersunk flat head screws (common head style) with Type H or Type Z cross recess — Product grade A:
(Part 1) : 2018/ ISO 7046-1 : 2011	Steel screws of property class 4.8 (*third revision*)
(Part 2) : 2018/ ISO 7046-2 : 2011	Steel screws of property class 8.8, stainless steel screws and non- ferrous metal screws (*third revision*)
IS 7486 : 2018/ ISO 7047 : 2011	Raised countersunk head screws (common head style) with type H or type Z cross recess — Product grade A (*third revision*)
IS 8033 : 1976	Specification for washers with square hole for wood fastenings
IS 8412 : 1977	Specification for slotted countersunk head bolts for steel structures
IS 8536 : 2021/ ISO 225 : 2010	Fasteners — Bolts, screws, studs and nuts — Symbols and descriptions of dimensions (*second revision*)
IS 8822 : 1978	Specification for slotted mushroom head roofing bolts
IS 8869 : 1978	Specification for washers for corrugated sheet roofing
IS 8911 : 2018/ ISO 2010 : 2011	Slotted raised countersunk head screws — Product grade A (*second revision*)
IS 10102 : 1982	Specification for technical supply conditions for rivets
IS 10238 : 2001	Fasteners — Threaded steel fasteners — Step bolts for steel structures — Specification (*first revision*)
IS/ISO 10683 : 2018	Fasteners — Non electrolytically applied zinc flake coating systems
IS 12427 : 2001	Threaded steel fasteners — hexagon head transmission tower bolts — Specification (*first revision*)
IS 13722 : 2025/ ISO 8673 : 2023	Hexagon regular nuts (Style 1) with metric fine pitch thread — Product grades A and B — Specification (*third revision*)
IS 13723 : 2025/ ISO 8674 : 2023	Hexagon high nuts (Style 2) with metric fine pitch thread — Product grades A and B — Specification (*third revision*)
IS 13724 : 2025/ ISO 8675 : 2023	Hexagon thin nuts (Style 0) with metric fine pitch thread — Product grades A and B — Specification (*third revision*)

IS No.	*Title*
IS 13725 : 2023/ ISO 8676 : 2022	Hexagon head screws with metric fine pitch thread –Product grades A and B (*third revision*)
IS 13726 : 2023/ ISO 8765 : 2022	Hexagon head bolts with metric fine pitch thread — Product grades A and B (*third revision*)
IS 14894 : 2023/ ISO 4015 : 2022	Fasteners-Hexagon head bolts of product grade B — Reduced shank (Shank diameter ≈ Pitch diameter) — Specification (*first revision*)
IS 15274 : 2021/ ISO 4759-3 : 2016	Tolerances for fasteners – Washers for bolts, screws and nuts — Product grades A, C and F (*first revision*)
IS 15581 : 2018	Hexagon nuts with flange, style 2 — Coarse thread (*first revision*)
IS 15582 : 2018	Hexagon bolts with flange – Small series — Product grade A with driving feature of product grade B (*first revision*)
IS 15628 : 2022/ ISO 4766 : 2011	Slotted set screws with flat point — Specification (*first revision*)
IS 17445 : 2020/ ISO 15330 : 1999	Fasteners — Preloading test for the detection of hydrogen embrittlement — Parallel bearing surface method
IS 17894 : 2022/ ISO 22081 : 2021	Geometrical product specifications (GPS) –Geometrical tolerancing — General geometrical specifications and general size specifications
IS 18471 : 2025	Fasteners — Drilling screws with tapping screw thread — Specification (*first revision*)
IS 18476 : 2023	Fasteners — Hexagon washer head drilling screws with tapping screw thread
IS 18480 : 2025	Self-tapping screws — Specification (*first revision*)
IS 18507 : 2026	Drywall screws — Specification (*first revision*)
IS 18508 : 2026	Chipboard screws — Specification (*first revision*)
IS 18509 : 2024	Cross recessed countersunk head wood screws — Specification
IS 18741 : 2024	Concrete nails — Specification
IS 19078 : 2025/ ISO 10666 : 1999	Drilling screws with tapping screw thread — Mechanical and functional properties
IS 19406 : 2026/ ISO 10587 : 2000	Metallic and other inorganic coatings — Test for residual embrittlement in both metallic coated and uncoated externally threaded articles and rods — Inclined wedge method

26 TIMBER, BAMBOO AND OTHER LIGNOCELLULOSIC BUILDING MATERIALS

a) Timber and Bamboo

i) *Timber Classification*

IS No.	*Title*
IS 287 : 1993	Permissible moisture content for timber used for different purposes — Recommendations (*third revision*)
IS 399 : 1963	Classification of commercial timbers and their zonal distribution (*revised*)
IS 1150 : 2000	Trade names and abbreviated symbols *for timber species* (*third revision*)
IS 4970 : 1973	Key for identification of commercial timber (*first revision*)

ii) *Timber Conversion and Grading*

IS No.	*Title*
IS 190 : 1991	Specification for coniferous sawn timber (baulks and scantlings) (*fourth revision*)
IS 1326 : 2023	Non-Coniferous sawn timber baulks and scantling — Specification (*third revision*)
IS 1331 : 1971	Specification for cut sizes of timber (*second revision*)
IS 2377 : 1967	Tables for volumes of cut sizes of timber (*first revision*)
IS 3337 : 1978	Specification for ballies for general purposes (*first revision*)
IS 3386 : 1979	Specification for wooden fence posts (*first revision*)
IS 5966 : 2023	Non-coniferous timber in converted form for general purposes — Specification (*second revision*)
IS 14960 : 2001	Specification for preservative treated and seasoned sawn timber from rubberwood (*Hevea brasiliensis*)

iii) *Timber Testing*

IS No.	*Title*
IS 1708	Methods of testing small clear specimens of timber:
(Part 1) : 1986	Determination of moisture content (*second revision*)
(Part 2) : 1986	Determination of specific gravity (*second revision*)
(Part 3) : 1986	Determination of volumetric shrinkage (*second revision*)
(Part 4) : 1986	Determination of radial and tangential shrinkage and fibre saturation point (*second revision*)
(Part 5) : 1986	Determination of static bending strength (*second revision*)
(Part 6) : 1986	Determination of static bending strength under two point loading (*second revision*)

IS No.	*Title*
(Part 7) : 1986	Determination of impact bending strength (*second revision*)
(Part 8) : 1986	Determination of compressive strength parallel to grain (*second revision*)
(Part 9) : 1986	Determination of compressive strength perpendicular to grain (*second revision*)
(Part 10) : 1986	Determination of hardness under static indentation (*second revision*)
(Part 11) : 1986	Determination of shear strength parallel to grain (*second revision*)
(Part 12) : 1986	Determination of tensile strength parallel to grain (*second revision*)
(Part 13) : 1986	Determination of tensile strength perpendicular to grain (*second revision*)
(Part 14) : 1986	Determination of cleavage strength parallel to grain (*second revision*)
(Part 15) : 1986	Determination of nail and screw holding power (*second revision*)
(Part 16) : 1986	Determination of brittleness by izod impact (*second revision*)
(Part 17) : 1986	Determination of brittleness by charpy impact (*second revision*)
(Part 18) : 1986	Determination of torsional strength (*second revision*)
IS 2408 : 1963	Methods of static tests of timbers in structural sizes
IS 2455 : 1990	Method of sampling of model trees and logs for timber testing and their conversion (*second revision*)
IS 2753	Methods for estimation of preservatives in treated timber and treating solutions:
(Part 1) : 1991	Determination of copper, arsenic, chromium, zinc, boron, creosote and fuel oil (*first revision*)
(Part 2) : 2014	Determination of copper in copper organic preservative salt (*second revision*)
IS 4907 : 2004	Method of testing timber connector joints (*first revision*)
IS 8292 : 1992	Methods for evaluation of working quality of timber under different wood operations — Method of test (*first revision*)
IS 8720 : 1978	Methods of sampling of timber scantlings from depots and their conversion for testing
IS 8745 : 1994	Methods of presentation of data of physical and mechanical properties of timber (*first revision*)
IS 10420 : 1982	Method of determination of sound absorption coefficient of timber by standing wave method
IS 10754 : 1983	Method of determination of thermal conductivity of timber
IS 11215 : 1991	Methods for determination of moisture content of timber and timber products (*first revision*)
IS 13621 : 1993	Method of test for determination of dielectric constant of wood under microwave frequencies

iv) *Structural Timber and Test*

IS No.	*Title*
IS 2372 : 2021	Timber for cooling towers — Specification (*third revision*)
IS 3629 : 1986	Specification for structural timber in building (*first revision*)
IS 4891 : 1988	Specification for preferred cut sizes of structural timber (*first revision*)
IS 4924	Method of test for nail jointed timber trusses:
(Part 1) : 1968	Destructive test
(Part 2) : 1968	Proof test

v) *Logs*

IS No.	*Title*
IS 656 : 2023	Logs for plywood — Specification (*fourth revision*)
IS 3364	Method of measurement and evaluation of defects in timber:
(Part 1) : 1976	Logs (*first revision*)
(Part 2) : 1976	Converted timber (*first revision*)
IS 4895:1985	Specification for teak logs (*first revision*)
IS 5246:2000	Specification for coniferous logs (*first revision*)
IS 7308:1999	Specification for non-coniferous logs (*first revision*)

vi) *Bamboo*

IS No.	*Title*
IS 6874 : 2008	Method of tests for bamboos (*first revision*)
IS 8242 : 1976	Methods of tests for split bamboos
IS 17571 : 2021	Flattened bamboo board — Specification
IS 17572 : 2022	BWP grade bamboo mat-veneer composite board — Specification
IS 17573 : 2021	BWP grade bamboo mat board – Specification

(b) Reconstituted Products

i) *Plywood*

IS No.	*Title*
IS 303 : 2024	Plywood for general purposes — Specification (*fourth revision*)
IS 710 : 2024	Marine plywood — Specification (*third revision*)
IS 1328 : 2025	Veneered decorative plywood — Specification (*fourth revision*)

IS No.	*Title*
IS 1734	Methods of test for plywood:
(Part 1) : 1983	Determination of density and moisture content (*second revision*)
(Part 2) : 1983	Determination of resistance of dry heat (*second revision*)
(Part 3) : 1983	Determination of fire resistance (*second revision*)
(Part 4) : 1983	Determination of glue shear strength (*second revision*)
(Part 5) : 1983	Test for adhesion of plies (*second revision*)
(Part 6) : 1983	Determination of water resistance (*second revision*)
(Part 7) : 1983	Mycological test (*second revision*)
(Part 8) : 1983	Determination of *p*H value (*second revision*)
(Part 9) : 1983	Determination of tensile strength (*second revision*)
(Part 10) : 1983	Determination of compressive strength (*second revision*)
(Part 11) : 1983	Determination of static bending strength (*second revision*)
(Part 12) : 1983	Determination of scarf joint strength (*second revision*)
(Part 13) : 1983	Determination of panel shear strength (*second revision*)
(Part 14) : 1983	Determination of plate shear strength (*second revision*)
(Part 15) : 1983	Central loading of plate test (*second revision*)
(Part 16) : 1983	Vibration of plywood plate test (*second revision*)
(Part 17) : 1983	Long time loading test of plywood strips (*second revision*)
(Part 18) : 1983	Impact resistance test on the surface of plywood (*second revision*)
(Part 19) : 1983	Part 19 Determination of nail and screw holding power (*second revision*)
(Part 20) : 1983	Part 20 Acidity and alkalinity resistance test (*second revision*)
IS 4990 : 2024	Plywood for concrete shuttering works — Specification *(fourth revision)*
IS 5509 : 2021	Fire retardant plywood – Specification *(third revision)*
IS 5539:1969	Specification for preservative treated plywood
IS 7316:1974	Specification for decorative plywood using plurality of veneers for decorative faces
IS 10701:2012	Structural plywood — Specification (*first revision*)
IS 13957:1994	Specification for metal faced plywood
IS 15791:2007	Museum plywood — Specification

ii) *Blockboards, Particle Boards and Fibre Boards*

IS No.	*Title*
IS 1658 : 2006	Fibre hardboards — Specification (*third revision*)
IS 1659 : 2004	Block boards — Specification *(fourth revision)*
IS 2380	Methods of test for wood particle boards and boards from other lignocellulosic materials:
(Part 1) : 1977	Preparation and conditioning of test specimens (*first revision*)
(Part 2) : 1977	Accuracy of dimensions of boards (*first revision*)
(Part 3) : 1977	Determination of moisture content and density (*first revision*)
(Part 4) : 1977	Determination of static bending strength (*first revision*)
(Part 5) : 1977	Determination of tensile strength perpendicular to surface (*first revision*)
(Part 6) : 1977	Determination of tensile strength parallel to surface (*first revision*)
(Part 7) : 1977	Determination of compression-perpendicular to plane of the board (*first revision*)
(Part 8) : 1977	Compression parallel to surface test (*first revision*)
(Part 9) : 1977	Determination of resistance to shear in plane of the board (*first revision*)
(Part 10) : 1977	Falling hammer impact test (*first revision*)
(Part 11) : 1977	Surface hardness (*first revision*)
(Part 12) : 1977	Central loading of plate test (*first revision*)
(Part 13) : 1977	Long time loading bending test (*first revision*)
(Part 14) : 1977	Screw and nail withdrawal test (*first revision*)
(Part 15) : 1977	Lateral nail resistance (*first revision*)
(Part 16) : 1977	Determination of water absorption (*first revision*)
(Part 17) : 1977	Determination of swelling in water (*first revision*)
(Part 18) : 1977	Determination of mass and dimensional changes caused by moisture changes (*first revision*)
(Part 19) : 1977	Durability cyclic test for interior use (*first revision*)
(Part 20) : 1977	Accelerated weathering cyclic test for exterior use (*first revision*)
(Part 21) : 1977	Planeness test under uniform moisture content (*first revision*)
(Part 22) : 1981	Determination of surface glueability test
(Part 23) : 1981	Vibration test for particle boards
IS 3087 : 2025	Medium density particle boards of wood and other lignocellulosic materials for general purpose — Specification (*third revision*)

IS No.	*Title*
IS 3097 : 2025	Veneered medium density particle boards from wood and other lignocellulosic material — Specification (*third revision*)
IS 3129 : 1985	Specification for low density particle boards (*first revision*)
IS 3308 : 1981	Specification for wood wool building slabs (*first revision*)
IS 3348 : 1965	Specification for fibre insulation boards
IS 3478 : 1966	Specification for high density wood particle boards
IS 12406 : 2025	Medium density fibre boards of wood and other lignocellulosic materials for general purpose — Specification (*third revision*)
IS 12823 : 2025	Prelaminated medium density particle boards from wood and other lignocellulosic material — Specification (*second revision*)
IS 13745 : 2020	Method for determination of formaldehyde content in wood-based panels by extraction method called perforator method (*first revision*)
IS 14276 : 2016	Cement bonded particle boards — Specification (*first revision*)
IS 14587 : 2025	Prelaminated medium density fibre boards of wood and other lignocellulosic materials — Specification (*second revision*)
IS 15786 : 2008	Prelaminated cement bonded particle boards — Specification
IS 19267 : 2025	Oriented strand boards — Specification

iii) *Wood-Based Laminates and Lumber*

IS No.	*Title*
IS 3513	Specification for resin treated compressed wood laminates (compregs):
(Part 3) : 1989	For General Purposes (*first revision*)
(Part 4) : 1966	Sampling and tests
IS 7638 : 1999	Methods of sampling for wood/lignocellulosic based panel products
IS 9307	Methods of tests for wood-based structural sandwich construction:
(Part 1) : 1979	Flexure test
(Part 2) : 1979	Edgewise compression test
(Part 3) : 1979	Flatwise compression test
(Part 4) : 1979	Shear test
(Part 5) : 1979	Flatwise tension test
(Part 6) : 1979	Flexure creep test
(Part 7) : 1979	Cantilever vibration test
(Part 8) : 1979	Weathering test

IS No.	*Title*
IS 14315 : 1995	Specification for commercial veneers
IS 14616 : 1999	Specification for laminated veneer lumber
IS 16171 : 2014	Veneer laminated lumber – Specification

iv) *Bamboo and Coir Board Products*

IS No.	*Title*
IS 13958 : 1994	Specification for bamboo mat board for general purposes
IS 14588 : 1999	Specification for bamboo mat veneer composite for general purposes
IS 14842 : 2000	Specification for coir veneer board for general purposes
IS 15476 : 2004	Specification for bamboo mat corrugated sheets
IS 15491 : 2004	Specification for medium density coir boards for general purposes
IS 15877 : 2010	Coir faced block boards — Specification
IS 15878 : 2010	Coir hardboard for general purposes — Specification
IS 15972 : 2012	Bamboo-jute corrugated and semi-corrugated sheets — Specification

v) *Adhesives*

IS No.	*Title*
IS 848 : 2025	Synthetic resin adhesives for plywood (phenolic, aminoplastic and bio-materials based) — Specification (*third revision*)
IS 851 : 1978	Specification for synthetic resin adhesives for construction work (non-structural) in wood (*first revision*)
IS 852 : 1994	Animal glue for general wood-working purposes Specification (*second revision*)
IS 1508 : 1972	Specification for extenders for use in synthetic resin adhesives (urea-formaldehyde) for plywood (*first revision*)
IS 4835 : 1979	Specification for polyvinyl acetate dispersion-based adhesives for wood (*first revision*)
IS 9188 : 1979	Performance requirements for adhesive for structural laminated wood products for use under exterior exposure condition

27 UNIT WEIGHTS OF BUILDING MATERIALS

IS No.	*Title*
IS 875 (Part 1) : 1987	Code of practice for design loads (other than earthquake) for buildings and structures: Part 1 Dead loads — Unit weights of building material and stored materials (*second revision*)

28 WATERPROOFING AND DAMP-PROOFING MATERIALS

IS No.	*Title*
IS 1322 : 1993	Specification for bitumen felts for waterproofing and damp-proofing (*fourth revision*)
IS 1580 : 1991	Specification for bituminous compound for waterproofing and caulking purposes (*second revision*)
IS 3037 : 1986	Specification for bitumen mastic for use in waterproofing of roofs (*first revision*)
IS 3384 : 1986	Specification for bitumen primer for use in waterproofing and damp-proofing (*first revision*)
IS 5871 : 1987	Specification for bitumen mastic for tanking and damp-proofing (*first revision*)
IS 7193 : 2013	Glass fibre base bitumen felts — Specification (*second revision*)
IS 12027 : 1987	Silicone-based water repellents — Specification
IS 12027 (Part 2) : 2025	Water repellents — Specification: Part 2 Silane based (*first revision*)
IS 13435	Acrylic based polymer waterproofing material — Method of tests:
(Part 1) : 2021	Determination of solid content (*first revision*)
(Part 2) : 1992	Determination of coarse particles
(Part 3) : 1992	Determination of capillary water take-up
(Part 4) : 1992	Determination of *p*H value
IS 13826	Bitumen based felts — Method of test:
(Part 1) : 1993	Breaking strength test
(Part 2) : 2022	Pliability test (*first revision*)
(Part 3) : 1993	Storage sticking test
(Part 4) : 1993	Pressure head test
(Part 5) : 1994	Heat resistance test
(Part 6) : 1993	Water absorption test
(Part 7) : 1993	Determination of binder content
IS 14695 : 1999	Glass fibre base coal tar pitch outer wrap — Specification
IS 16525 : 2017	Styrene butadiene styrene (SBS) modified bituminous waterproofing and damp-proofing membrane with polyester reinforcement — Specification
IS 16526 : 2017	Atactic polypropylene (APP) modified bituminous waterproofing and damp-proofing membrane with glass fibre reinforcement — Specification

IS No.	*Title*
IS 16532 : 2017	APP modified bituminous waterproofing and damp-proofing membrane with polyester reinforcement — Specification
IS 16540 : 2017	Atactic polypropylene (APP) modified high molecular high density polyethylene (HMHDPE) bituminous waterproofing and damp-proofing membrane — Specification
IS 17856 : 2022	Vulcanized single layer rubber sheets for use as membrane — Specification

29 WELDING ELECTRODES AND WIRES

IS No.	*Title*
IS 814 : 2004	Covered electrodes for manual metal arc welding of carbon and carbon manganese steel — Specification (*sixth revision*)
IS 1278 : 1972	Specification for filler rods and wires for gas welding (*second revision*)
IS 1395 : 1982	Specification for low and medium alloy steel covered electrodes for manual metal arc welding (*third revision*)
IS 2879 : 1998	Mild steel for metal arc welding electrodes (*third revision*)
IS 4972	Resistance spot welding:
(Part 1) : 2022/ ISO 8430-1 : 2016	Electrode holders — Taper fixing 1 : 10 (*first revision*)
(Part 2) : 2022/ ISO 8430-2 : 2016	Electrode holders — Morse taper fixing (*first revision*)
(Part 3) : 2022/ ISO 8430-3 : 2016	Electrode holders parallel shank fixing for end thrust *(first revision)*
(Part 4) : 2022/ ISO 5183 – 1 : 1998	Electrode adaptors, male taper 1 : 10 — Conical fixing, taper 1 : 10 (*first revision*)
(Part 5) : 2022/ ISO 5183-2 : 2000	Electrode adaptors, male taper 1 : 10 — Parallel shank fixing for end-thrust electrodes (*first revision*)
(Part 6) : 2022/ ISO 5184 : 1979	Straight resistance spot welding electrodes (*first revision*)
(Part 7) : 2022/ ISO 1089 : 2023	Electrode taper fits for spot welding equipment — Dimensions (*second revision*)
(Part 8) : 2022/ ISO 5182 : 2016	Materials for electrodes and ancillary equipment (*first revision*)
IS 5206 : 1983	Covered electrodes for manual arc welding of stainless steel and other similar high alloy steels (*first revision*)
IS 5511 : 1991	Specification for covered electrodes for manual metal arc welding of cast iron (*first revision*)
IS 5856 : 2022/ ISO 14343 : 2017	Welding consumables — Wire electrodes, strip electrodes, wires and rods for arc welding of stainless and heat resisting steels — Classification (*third revision*)

IS No.	*Title*
IS 5897 : 2026	Welding consumables — Wire electrodes, wires and rods for welding of aluminium and aluminium alloys — Specification (*second revision*)
IS 5898 : 1970	Specification for copper and copper alloy bare solid welding rods and electrodes
IS 6419 : 1996	Specification for welding rods and bare electrodes for gas shielded arc welding of structural steel (*first revision*)
IS 6560 : 2017/ ISO 21952 : 2012	Welding consumables — Wire electrodes, wires, rods and deposits for gas shielded arc welding of creep-resisting steels — Classification (*second revision*)
IS 8363 : 1976	Specification for bare wire electrodes for electroslag welding of steels
IS 10631 : 1983	Stainless steel for welding electrode core wire
IS 13007 : 2018	Arc welding and cutting — Non consumable tungsten electrodes — Classification (*first revision*)
IS 15977 : 2013	Classification and acceptance tests for bare solid wire electrodes and wire flux combination for submerged arc welding of structural steel — Specification
IS 18641 : 2024/ ISO 544 : 2017	Welding consumables — Technical delivery conditions for filler materials and fluxes — Type of product, dimensions, tolerances and markings
IS 18734 : 2024/ ISO 6847 : 2020	Welding consumables — Deposition of a weld metal pad for chemical analysis
IS 18738	Welding consumables — Methods of test:
(Part 1) : 2024/ ISO 15792-1 : 2020	Preparation of all-weld metal test pieces and specimens in steel, nickel and nickel alloys
(Part 2) : 2024/ ISO 15792-2 : 2020	Preparation of single-run and two-run technique test pieces and specimens in steel
(Part 3) : 2024/ ISO 15792-3 : 2011	Classification testing of positional capacity and root penetration of welding consumables in a fillet weld
IS 18783 : 2024/ ISO 14175 : 2008	Welding consumables — Gases and gas mixtures for fusion welding and allied processes
IS 8666 : 1977	Specification for copper and copper alloy covered electrodes for manual metal arc welding

30 WIRE ROPES AND WIRE PRODUCTS (Including wire for fencing)

IS No.	*Title*
IS 278 : 2009	Galvanized steel barbed wire for fencing — Specification (*fourth revision*)
IS 1755 : 2018	Metallic materials — Wire-wrapping test (*second revision*)
IS 2140 : 2022	Specification for stranded galvanized steel wire for fencing (*second revision*)
IS 2266 : 2024	Steel wire ropes for general engineering purpose — Specification (*sixth revision*)

IS No.	*Title*
IS 2315 : 2023	Thimbles for wire ropes — Specification (*second revision*)
IS 2365 : 2024/ ISO 4344 : 2022	Steel wire ropes for lifts — Minimum requirements (*third revision*)
IS/ISO 2408 : 2017	Steel wire ropes — Requirements
IS 2485 : 2022	Drop forged sockets for wire ropes for general engineering purposes — Specification (*second revision*)
IS 2721 : 2025	Galvanized polyvinyl chloride (PVC), polyolefin and other polymer-coated steel chain link fence fabric — Specification (*third revision*)
IS 6594 : 2024	Technical supply conditions for steel wire ropes and strands (*fourth revision*)
IS 13902	Sockets for wire ropes for general purposes:
(Part 1) : 2022	General characteristics and conditions of acceptance (*first revision*)
(Part 2) : 2022	Special requirements for sockets produced by forging or machined from the solid (*first revision*)
IS 16013 : 2018	Welded wire gabions (metallic-coated or metallic-coated with PVC coating) — Specification (*first revision*)
IS 16014 : 2024	Mechanically woven, Double-Twisted, hexagonal wire mesh gabions, revet mattresses, rock fall netting and other products for civil engineering purposes (galvanized steel wire or galvanized steel wire with polymer coating) — Specification (*second revision*)
IS/ISO 17745 : 2016	Steel wire ring net panels — Definitions and specifications
IS/ISO 17746 : 2016	Steel wire rope net panels and rolls — Definitions and specifications
IS 17929	Fibre ropes for offshore station keeping:
(Part 1) : 2022/ ISO 18692-1 : 2018	General specification
(Part 2) : 2022/ ISO 18692-2 : 2019	Polyester
(Part 3) : 2022/ ISO 18692-3 : 2020	High modulus polyethylene (HMPE)
(Part 4) : 2024/ ISO 18692-4 : 2023	Polyarylate
(Part 5) : 2024/ ISO 18692-5 : 2024	Aramid
IS 18759 : 2024/ ISO 10325 : 2018	Fibre ropes — High modulus polyethylene — 8-Strand braided ropes, 12-Strand braided ropes and covered ropes
IS 19363 : 2025	Metallic or polymer coated — Welded wire mesh fencing — Specification

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NATIONAL BUILDING CONSTRUCTION STANDARDS

PART C STRUCTURAL DESIGN

SECTION 1 LOADS AND LOAD EFFECTS

BUREAU OF INDIAN STANDARDS

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FOREWORD

This NBCS (Part C/Section 1) covers the various loads, forces and effects which are to be taken into account for structural design of buildings. The various loads that are covered under this Section are dead load, imposed load, wind load, seismic force, snow load, special loads and load combinations.

This Section was first published in 1970 and subsequently revised in 1983, 2005 and 2016 as a chapter of the National Building Code of India. The first revision of this Section was modified in 1987 through Amendment No. 2 to the 1983 version to bring this Section in line with the latest revised loading code. Thereafter, in view of the revision of an important Indian Standard related to earthquake resistant design of structures, that is IS 1893, a need arose to revise this part of NBC. Therefore, the second revision of 2005 was formulated to consider the revised standard, IS 1893 (Part 1) : 2002 ‘Criteria for earthquake resistant design of structures: Part 1 General provisions and buildings (*fifth revision*)’ and to incorporate latest information on additional loads, forces and effects and the details regarding multi-hazard risk in various districts of India.

The significant changes incorporated in the second revision of 2005 included: the revision of the seismic zone map providing only four zones, instead of five, with erstwhile Zone I being merged into Zone II; changing of the values of seismic zone factors to reflect more realistic values of effective peak ground acceleration considering maximum considered earthquake (MCE) and service life of structure in each seismic zone; specifying of response spectra for three types of founding strata, namely rock and hard soil, medium soil and soft soil; the revision of empirical expression for estimating the fundamental natural period T_a of multi-storeyed buildings with regular moment resisting frames; adoption of the procedure of first calculating the actual force that may be experienced by the structure during the probable maximum earthquake, if it were to remain elastic, also bringing in the concept of response reduction due to ductile deformation and associated energy dissipation by introducing the ‘response reduction factor’ in place of the earlier performance factor; specifying a lower bound for the design base shear of buildings, based on empirical estimate of the fundamental natural period T_a; deletion of the soil-foundation system factor and instead, introduction of a clause to restrict the use of foundations vulnerable to differential settlements in severe seismic zones; revision of torsional eccentricity values upwards in view of serious damages observed in buildings with irregular plans; revision of modal combination rule in dynamic analysis of buildings; inclusion of a new clause on multi-hazard risk in various districts of India and a list of districts identified as multi-hazard prone districts; incorporation of latest amendments issued to IS 875 introduction of a clause on vibration in buildings for general guidance; and inclusion of reference to the Indian Standards on landslide control and design of retaining walls which were formulated after the first revision of the Section.

The significant changes incorporated in the third revision of 2016 included: enhanced provisions for parapets and balustrades, incorporating concentrated horizontal loads and adjustments in horizontal load per unit length; new areas of application, such as appurtenances fixed to structures; aerodynamic roughness heights for different terrain categories were explicitly addressed, aiding in the determination of turbulence intensity and wind speed profiles; a new modification factor k_4 was introduced for cyclonic regions; simplified empirical expressions for variations in hourly mean wind speed and turbulence intensity across different terrains were suggested, along with provisions for directionality, area averaging and correlation of pressures for design wind pressure; wind-induced interference for both tall and low-rise buildings was accounted for, with recommendations for wind tunnel or CFD studies for final designs of critical structures; updates to the wind speed map of India were included; and new provisions for design loads for helipads, emergency vehicles and collisions with structural elements in parking areas. For earthquake effects, the design spectra was defined for natural periods up to 6 s, applicable to all buildings regardless of construction material; temporary structures and buildings with flat slabs were brought under the scope of the standard (though with some conditions), with guidelines for addressing structural irregularities and estimating the in-plane stiffness of masonry infill walls; additional revisions including simplified torsional provisions, methods for computing natural periods in various structures, new provisions for evaluating liquefaction potential and blast loads; and inputs were also derived from the Heliport Manual, 1995 of the International Civil Aviation Organization for the design of roof top helipad, etc.

In the current revision, this publication has been renamed as National Building Construction Standards (NBCS).

In this revision of this Part C/Section 1, load provisions have been updated in alignment with the existing IS 875 series and IS 4991. The IS 875 framework continues and the changes may be seen as its evolution. The present deterministic approach with safety margins will gradually be replaced by a unified approach of load classification and quantification. Loads will be grouped as natural or man-made and further as force-based or displacement-based. For natural hazards, return period–based probabilistic treatment will apply, while man-made loads will be based on statistical measures such as mean and standard deviation. This philosophy may, in due course, be reflected in future revisions of various Indian Standards on loading, following which their safety factors may also be recalibrated.

Further, considering the recent developments and R&D efforts nationally and internationally, the following significant modifications and inclusions have been made:

1) The provision relating to structural design basis report (SDBR) is introduced.

Dead Loads:

2) Unit weights of construction materials and stored materials have been included in Annex A.
3) Provisions relating to dead load for gardening and landscaping have been introduced.

Imposed Loads:

4) Imposed loads for dwelling units planned and executed in accordance with IS 8888 : 2020 'Requirements of low income housing for Urban areas guide (*second revision*)' have been brought at par with other residential buildings.
5) Imposed loads for datacenters have been included.
6) Imposed loads for roof top solar panels (with or without frames and with anchor blocks) and roof top HVAC equipment, have been included.
7) Imposed load for garage floors with and without stack parking have been updated.
8) Imposed load for refuge area and disaster shelter have been provided.

Wind Loads:

9) Provision relating to testing of building fabrics against wind borne debris has been included.
10) Table of basic wind speed for various cities of India has been updated.

Snow Loads:

11) A new term 'characteristic ground snow load' has been introduced and defined.
12) Characteristic ground snow load maps for union territory of Jammu and Kashmir, union territory of Ladakh and states of Himachal Pradesh, Uttarakhand and Sikkim have been introduced, resulting from studies conducted by Defence Geoinformatics Research Establishment (DRDO), Chandigarh.
13) Equation for calculation of characteristic ground snow load has been suggested in Annex H.
14) Clause relating to partial loading due to melting, sliding, snow redistribution and snow removal has been included.
15) Clause relating to ponding instability has been included.

Earthquake loads:

16) The Indian Standard IS 1893, on which the clause of earthquake load is largely based, is under revision at the time of publication of this NBCS. Major changes have been envisaged in the revision of IS 1893 which include apart from others, the introduction of probabilistic seismic hazard map of India having updated seismic zones. In the absence of availability of finalized version of revised IS 1893 at the time of revision of this Section, in this revision of the NBCS, the provisions of design as per existing IS 1893 (Part 1) : 2016 'Criteria for earthquake resistant design of structures: Part 1 General provisions and buildings' have been continued through app ropriate reference to the same.

Blast Loads:

17) Detailed provisions relating to design for blast loads have been included in Annex L. This annex provides prescriptive requirements for estimation of blast loads and simplified methods for structural analysis.
18) General requirements for blast-protection and categorization of structures have been provided.
19) Threat assessment requirements for determination of design explosive charge mass and scaled distance have been given.
20) Blast load estimation methods due to above-ground explosion of high-explosive under three different detonation scenarios: surface burst, free-air burst and air burst have been specified.
21) Evaluation of blast loads effects on structures of regular geometry and shape has been specified.
22) Prescriptive simplified single degree of freedom (SDOF) analysis procedure for peak response evaluation of structural elements based on flexural mode has been provided.
23) Guidelines for the application of multi-degree of freedom (MDOF) and detailed finite element analysis have been provided.

The provisions outlined in this Chapter are intended to assist structural designers in making informed engineering decisions when dealing with diverse loading scenarios, including special loads and unique load combinations that may arise in practical applications. It is expected that this Chapter will enable designers to adopt a rational and scientific approach in assessing structural loads and their combinations, thereby enhancing the resilience of structures against various external forces and ensuring their long-term performance. The Chapter serves as a fundamental reference for structural engineers, ensuring that the design approach aligns with safety requirements, reliability principles and advancements in engineering practices. It integrates knowledge from past experiences, research developments and international best practices while considering the specific conditions prevalent in India.

Structures are subjected to various loads, environmental effects and material degradation over time, which can impact their performance and safety. Hence, monitoring of structures has been gaining attention. Monitoring of structures is seen now along three directions, namely health monitoring, performance monitoring and safety monitoring. Structural health monitoring (SHM) involves monitoring of the condition of the materials of the structure, structural performance monitoring (SPM) involves monitoring of the response of the structure (without any damage induced in it) to daily loads the structure, such as vibrations of the structure under wind loads and structural safety monitoring involves monitoring the response of the structure when subjected to loads that damage the structure, such as, strong ground shaking of the structure during an earthquake, or air pressure induced under blast. In all cases, the engineer needs to assess the structure to identify actions needed towards repairing, correcting, protecting or retrofitting the structure, as the case be.

Monitoring of structures is a crucial process that enables the continuous or periodic assessment of structural integrity, ensuring early detection of potential damage and preventing catastrophic failures. It provides real-time insights into the behaviour of buildings and infrastructure under different conditions by utilizing advanced sensors, data acquisition systems and analytical models. The need for monitoring the structures arises from the increasing complexity of modern structures, aging infrastructure and the demand for enhanced safety and serviceability. It helps in identifying structural anomalies, degradation patterns and potential failure modes before they become critical. The system of monitoring of structures should be adopted to validate analytical models and evaluate techniques to ensure accurate assessment and decision-making. Implementing monitoring systems in buildings and structures where necessary enhances durability, reduces maintenance costs and supports proactive intervention strategies, ultimately improving structural resilience and public safety.

There has been a growing awareness among the consultants, academicians, researchers and practice engineers for design and construction of wind sensitive structures. In order to augment the available limited good quality meteorological wind data and structural response data, it is necessary to conduct full scale measurements in the field. Thus, as emphasized in the previous revision, all individuals and organizations responsible for putting-up of tall structures are encouraged to provide instrumentation in their existing and new structures at different elevations (at least at two levels) to continuously measure and monitor wind data. The instruments are required to collect data on wind direction, wind speed and structural response of the structure due to wind (with the help of accelerometer, strain gauges, etc). Such instrumentation in tall structures shall not in any way affect or alter the functional behaviour of such structures. The data so collected shall be very valuable in evolving more accurate wind loading of structures.

The information contained in this Section is largely based on the following Indian Standards:

IS 875	Code of practice for design loads (other than earthquake) for buildings and structures:
Part 1 : 2026	Dead loads-unit weights of building material and stored materials (*third revision*) (*under preparation*)
Part 2 : 1987	Imposed loads (*second revision*)
Part 3 : 2015	Wind loads (*third revision*)
Part 4 : 2021	Snow loads (*third revision*)
Part 5 : 1987	Special loads and load combinations (*second revision*)
IS 4991 (Part 1) : 2024	Criteria for blast resistant design of structures: Part 1 Above-ground explosions (*first revision*)

This Section shall be read together with Sections 2 to 8 of Part C ‘Structural Design’ of this NBCS.

A special publication, SP 64 (S&T) : 2001 ‘Explanatory Handbook on Indian Standard Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures IS 875 (Part 3) : 1987’ is also available. This publication gives detailed background information on the provisions for wind loads and the use of these provisions for arriving at the wind loads on buildings and structures while evaluating their structural safety. But, in view of revision of IS 875 (Part 3) in 2015, applicability of this revised standard and this Section of the NBCS shall be taken as final in case of conflict of provisions with SP 64.

Reference may also be made to the Vulnerability Atlas of India, 2011 and Landslide Hazard Zonation Map of India, 2003, published by Building Materials and Technology Promotion Council, Ministry of Urban Development and Poverty Alleviation, Government of India. The Vulnerability Atlas contains information pertaining to each State and Union Territory of India, on (a) seismic hazard map, (b) cyclone and wind map, (c) flood prone area map and (d) housing stock vulnerability table for each district indicating for each house type the level of risk to which it could be subjected. The Atlas can be used to identify areas in each district of the country which are prone to high risk from more than one hazard. The information will be useful in establishing the need of developing housing designs to resist the combination of such hazards.

All standards, whether given herein above or cross-referred to in the main text of this Section, are subject to revision. The parties to agreement based on this Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

As the regulation of land development and buildings is a State subject and is dealt by the States and local bodies such as urban local bodies within their jurisdiction through building regulatory documents like building regulations, building byelaws and fire regulations, this document is voluntary in nature and is non-binding. The implementation depends on adoption by concerned parties or stipulations in a contract or by appropriate adoption by the concerned authorities.

For the purpose of deciding whether a particular requirement of this section is complied with, the final value observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 ‘Rules for rounding of numerical values (*second revision*)’. The number of significant places retained in the rounded off value should be the same as that of the specified value in this section.

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Important Explanatory Note for Users of the NBCS

In any Part/Section of this NBCS, where reference is made to **'good practice'** in relation to design, constructional procedures or other related information and where reference is made to **"accepted standard"** in relation to material specification, testing, or other related information, the Indian Standards listed at the end of the Part/Section shall be used as a guide to the interpretation.

At the time of publication, the editions indicated in the standards were valid. All standards are subject to revision and parties to agreements based on any Part/ Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

In the list of standards given at the end of a Part/Section, the number appearing within parentheses in the first column indicates the number of the reference of the standard in the Part/Section. For example:

a) Good practices [C-1(1)] refers to the Indian Standard(s) give at serial number (1) of the list of standards given at the end of this Part/Section 1, that is, 8888 : 2020 'Requirements of low income housing for urban areas — Guide (second revision)'

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART C STRUCTURAL DESIGN

SECTION 1 LOADS AND LOAD EFFECTS

1 SCOPE

This NBCS (Part C/Section 1) covers basic design loads to be assumed in the design of buildings. The loads specified in this section are minimum loads to be considered for design purposes in the design of buildings.

2 DEAD LOAD

2.1 Assessment of Dead Load

The dead load in a building shall comprise the weight of all walls, partitions, floors and roofs and shall include the weights of all other permanent constructions (including built-in partitions, finishes, cladding and other similarly incorporated architectural and structural items, weight of fixed service equipment) in the building.

2.2 The list of dead loads of various construction materials and stored materials are given in Annex A.

2.3 Gardening and Landscaping

Elements on roof gardening or landscaping, including soil, plants and drainage layers, along with other features like walkways, fences and walls, are fixed in place and thus classified as dead loads. While the weight of walkways, fences and walls remains constant. The weight of soil and drainage layers, which support plant growth, can vary significantly due to their ability to absorb and retain water. For load calculations, when the weight adds to other structural loads, the dead load should be based on fully saturated soil and drainage layers to account for maximum weight. If the weight is used to counteract uplift forces, calculations should assume the dry weight of soil and drainage layers. Vegetative or landscaped roof areas may retain even more water than fully saturated soil, either from rainfall or irrigation. This additional water retention should be included in the design to accurately assess load variations.

In the design calculation of overturning, uplifting and sliding effects, the beneficial effects of soil shall not be considered. When the soil is used as dead weight and locked permanently, the same may be considered.

3 IMPOSED LOAD

3.1 This clause covers imposed loads to be assumed in the design of buildings. The imposed loads specified herein are minimum loads which should be taken into consideration for the purpose of structural safety of buildings.

NOTE — This Section does not cover detailed provisions for loads incidental to construction and special cases of vibration, such as moving machinery, heavy acceleration from cranes, hoists and the like. Such loads shall be dealt with individually in each case.

3.2 Terminology

3.2.1 For the purpose of imposed loads specified herein, the following definitions shall apply:

3.2.1.1 *Assembly buildings* — These shall include any building or part of a building where groups of people congregate or gather for amusement, recreation, social, religious, patriotic, civil, travel and similar purposes; for example, theatres, motion picture houses, assembly halls, conference/meeting halls, city halls, marriage halls, town halls, auditoria, exhibition halls, museums, skating rinks, gymnasiums, restaurants (also used as assembly halls), place of worship, dance halls, club rooms, passenger stations and terminals of air, surface and other public transportation services, recreation piers and stadia, etc.

3.2.1.2 *Business buildings* — These shall include any building or part of a building, which is used for transaction of business (other than that covered by mercantile buildings); for keeping of accounts and records for similar purposes; offices, banks, professional establishments, court houses and libraries shall be classified in this group so far as principal function of these is transaction of public business and the keeping of books and records.

NOTE — The office buildings are the buildings primarily to be used as an office or for office purposes; 'office purposes' include the purpose of administration, clerical work, handling money, telephone and telegraph operating and operating computers, calculating machines, 'clerical work' includes writing, book-keeping, sorting papers, typing, filing, duplicating, drawing of matter for publication and the editorial preparation of matter for publication, etc.

3.2.1.3 *Dwellings* — These shall include any building or part occupied by members of single/multi-family units with independent cooking facilities. These shall also include apartment houses (flats).

3.2.1.4 *Educational buildings* — These shall include any building used for school, college or day-care purposes involving assembly for instruction, education or recreation and which is not covered by assembly buildings.

3.2.1.5 *Imposed load* — The load assumed to be produced by the intended use or occupancy of a building including the weight of movable partitions, distributed and concentrated loads, loads due to impact and vibration and dust loads but excluding wind, seismic, snow and other loads due to temperature changes, creep, shrinkage, differential settlement, etc.

3.2.1.6 *Industrial buildings* — These shall include any building or a part of a building or structure, in which products or materials of various kinds and properties are fabricated, assembled, manufactured or processed, for example, assembly plants, industrial laboratories, dry cleaning plants, power plants, generating units, pumping stations, fumigation chambers, laundries, buildings or structures in gas plants, refineries, dairies and saw-mills, etc.

3.2.1.7 *Institutional buildings* — These shall include any building or a part thereof, which is used for purposes such as medical or other treatment in case of persons suffering from physical and mental illness, disease or infirmity; care of infants, convalescents or aged persons and for penal or correctional detention in which the liberty of the inmates is restricted. Institutional buildings ordinarily provide sleeping accommodation for the occupants. It includes hospitals, sanatoria, custodial institutions or penal institutions like jails, prisons and reformatories.

3.2.1.8 *Occupancy or use group* — The principal occupancy for which a building or part of a building is used or intended to be used; for the purpose of classification of a building according to occupancy, an occupancy shall be deemed to include subsidiary occupancies which are contingent upon it.

3.2.1.9 *Mercantile buildings* — These shall include any building or a part of a building which is used as shops, stores, market for display and sale of merchandize either wholesale or retail. Office, storage and service and facilities incidental to the sale of merchandize and located in the same building shall be included under this group.

3.2.1.10 *Residential buildings* — These shall include any building in which sleeping accommodation is provided for normal residential purposes with or without cooking or dining or both facilities (except buildings under institutional buildings). It includes lodging or rooming houses, one or two-family private dwellings, dormitories, apartment houses (flats) and hotels.

3.2.1.11 *Storage buildings* — These shall include any building or part of a building used primarily for the storage or sheltering of goods, wares or merchandize, like warehouses, cold storages, freight depots, transit sheds, store houses, garages, hangers, truck terminals, grain elevators, barns and stables.

3.3 Imposed Loads on Floors Due to Use and Occupancy

3.3.1 *Imposed Loads*

The imposed loads to be assumed in the design of buildings shall be the greatest loads that probably will be produced by the intended use or occupancy, but shall not be less than the equivalent minimum loads specified in Table 1 subject to any reductions permitted in **3.3.2**.

Floors shall be investigated for both the uniformly distributed load (UDL) and the corresponding concentrated load specified in Table 1 and designed for the most adverse effects but they shall not be considered to act simultaneously. The concentrated loads specified in Table 1 may be assumed to act over an area of 0.3 m × 0.3 m. However, the concentrated loads need not be considered where the floors are capable of effective lateral distribution of this load.

All other structural elements shall be investigated for the effects of uniformly distributed loads on the floors specified in Table 1.

NOTES

1 Where, in Table 1, no values are given for concentrated load, it may be assumed that the tabulated distributed load is adequate for design purposes.

2 The loads specified in Table 1 are equivalent uniformly distributed loads on the plan area and provide for normal effects of impact and acceleration. They do not take into consideration special concentrated loads and other loads.

3 Where the use of an area or floor is not provided in Table 1, the imposed load due to the use and occupancy of such an area shall be determined from the analysis of loads resulting from:

a) weight of the probable assembly of persons;

b) weight of the probable accumulation of equipment and furnishing;

c) weight of the probable storage materials; and

d) impact factor, if any.

4 While selecting a particular loading, the possible change in use or occupancy of the building should be kept in view. Designers should not necessarily select in every case the lower loading appropriate to the first occupancy. In doing this they might introduce considerable restrictions in the use of the building at a later date and thereby reduce its utility.

5 The loads specified herein, which are based on estimations, may be considered as the characteristic loads for the purpose of limit state method of design till such time statistical data are established based on load surveys to be conducted in the country.

6 When an existing building is altered by an extension in height or area, all existing structural parts affected by the addition shall be strengthened where necessary and all new structural parts shall be designed to meet the requirements for building hereafter erected.

7 The loads specified in the Section does not include loads incidental to construction. Therefore, close supervision during construction is essential to ensure that overloading of the building due to loads by way of stacking of building materials or use of equipment (for example, cranes and trucks) during construction or loads which may be induced by floor to floor propping in multi-storeyed construction, does not occur. However, if construction loads were of short duration, permissible increase in stresses in the case of working stress method or permissible decrease in load factors in limit state method, as applicable to relevant design codes, may be allowed for.

8 The loads in Table 1 are grouped together as applicable to buildings having separate principal occupancy or use. For a building with multiple occupancies, the loads appropriate to the occupancy with comparable use shall be chosen from other occupancies.

9 Regarding loading on lift machine rooms including storage space used for repairing lift machines, designers should go by the recommendations of lift manufacturers for the present. Regarding loading due to false ceiling, the same should be considered as imposed loads on the roof/floor to which it is fixed.

Table 1 Imposed Floor Loads for Different Occupancies

(*Clauses* 3.3.1, 3.3.1.1 *and* 3.4.1)

Sl No.	Occupancy Classification	Uniformly Distributed Load (UDL) kN/m^2	Concentrated Load kN
(1)	(2)	(3)	(4)
i)	*Residential Buildings*		
	a) Dwelling houses:		
	1) All rooms and kitchens	2.0	1.8
	2) Toilets and bath rooms	2.0	–
	3) Corridors, passages, staircases including fire escapes and store rooms	3.0	4.5
	4) Balconies	3.0	1.5 per metre run concentrated at the outer edge
	b) Dwelling units planned and executed in accordance with the accepted standard [C-1(1)] only:		
	1) Habitable rooms, kitchens and toilets and bath rooms	2.0	1.8
	2) Corridors, passages and staircases including fire escapes	3.0	4.5
	3) Balconies	3.0	1.5 per metre run concentrated at the outer edge
	c) Hotels, hostels, boarding houses, lodging houses, dormitories and residential clubs:		
	1) Living rooms, bed rooms and dormitories	2.0	1.8
	2) Kitchen and laundries	3.0	4.5

Table 1 (*Continued*)

Sl No.	Occupancy Classification	Uniformly Distributed Load (UDL) kN/m^2	Concentrated Load kN
(1)	(2)	(3)	(4)
	3) Billiards room and public lounges	3.0	2.7
	4) Store rooms	5.0	4.5
	5) Dining rooms, cafeterias and restaurants	4.0	2.7
	6) Office rooms	2.5	2.7
	7) Rooms for indoor games	3.0	1.8
	8) Baths and toilets	2.0	–
	9) Corridors, passages staircases including fire escapes and lobbies – as per the floor serviced (excluding stores and the like) but not less than	3.0	4.5
	10) Balconies	Same as rooms to which they give access but with a minimum of 4.0	1.5 per metre run concentrated at the outer edge
	d) Boiler rooms and plant rooms – to be calculated but not less than	5.0	6.7
	e) Garages:		
	1) Garage floors (including parking area and repair workshops) for passenger cars and vehicles not exceeding 2.5 tonne gross weight, including access ways and ramps – to be calculated but not less than	2.5	9.0

Table 1 (*Continued*)

Sl No.	Occupancy Classification	Uniformly Distributed Load (UDL) kN/m^2	Concentrated Load kN
(1)	(2)	(3)	(4)
	i) Without stack	5.0	9.0
	ii) With 2 level stack		
	2) Garage floors for vehicles not exceeding 4.0 tonne gross weight (including access ways and ramps) – to be calculated but not less than	5.0	9.0
	f) Roof top solar panels (with or without frames and with anchor blocks)	1.75	1.75
	g) Roof top HVAC loading	9.0	9.0
ii)	*Educational Buildings*		
	a) Class rooms and lecture rooms (not used for assembly purposes)	3.0	2.7
	b) Dining rooms, cafeterias and restaurants	3.0$^{1)}$	2.7
	c) Offices, lounges and staff rooms	2.5	2.7
	d) Dormitories	2.0	2.7
	e) Projection rooms (with audio-visual facilities)	5.0	–
	f) Kitchens	3.0	4.5
	g) Toilets and bath rooms	2.0	–
	h) Store rooms	5.0	4.5
	j) Libraries and archives:		
	1) Stack room/stack area	6.0 kN/m^2 for a minimum height of 2.2 m + 2.0 kN/m^2 per metre height beyond 2.2 m	4.5
	2) Reading rooms (without separate storage)	4.0	4.5
	3) Reading rooms (with separate storage)	3.0	4.5
	k) Boiler rooms and plant rooms – to be	4.0	4.5

Table 1 (*Continued*)

Sl No. (1)	**Occupancy Classification** (2)	**Uniformly Distributed Load (UDL)** kN/m² (3)	**Concentrated Load** kN (4)
	calculated but not less than		
	m) Corridors, passages, lobbies, staircases including fire escapes – as per the floor serviced (without accounting for storage and projection rooms) but not less than	4.0	4.5
	n) Balconies	Same as rooms to which they give access but with a minimum of 4.0	1.5 per metre run concentrated at the outer edge
iii)	*Institutional Buildings*		
	a) Bed rooms, wards, dressing rooms, dormitories and lounges	2.0	1.8
	b) Kitchens, laundries and laboratories	3.0	4.5
	c) Dining rooms, cafeterias and restaurants	3.0[1]	2.7
	d) Toilets and bathrooms	2.0	–
	e) X-ray rooms, operating rooms and general storage areas – to be calculated but not less than	3.0	4.5
	f) Office rooms and O.P.D. rooms	2.5	2.7
	g) Corridors, passages, lobbies, staircases including fire escapes – as per the floor serviced (without accounting for storage and projection rooms) but not less than	4.0	4.5
	j) Boiler rooms and plant rooms – to be	5.0	4.5

Table 1 (*Continued*)

Sl No.	Occupancy Classification	Uniformly Distributed Load (UDL) kN/m²	Concentrated Load kN
(1)	(2)	(3)	(4)
	calculated but not less than		
	k) Balconies	Same as rooms to which they give access but with a minimum of 4.0	1.5 per metre run concentrated at the outer edge
iv)	*Assembly Buildings*		
	a) Assembly areas :		
	1) With fixed seats[2]	4.0	–
	2) Without fixed seats	5.0	3.6
	c) Restaurants (subject to assembly), museums and art galleries and gymnasia	4.0	4.5
	d) Projection rooms (with audio-visual facilities)	5.0	–
	e) Stages	5.0	4.5
	f) Office rooms, kitchens and laundries	3.0	4.5
	g) Dressing rooms	2.0	1.8
	h) Lounges and billiards rooms	2.0	2.7
	j) Toilets and bathrooms	2.0	–
	k) Corridors, passages and staircases including fire escapes	4.0	4.5
	m) Balconies	Same as rooms to which they give access but with a minimum of 4.0	1.5 per metre run concentrated at the outer edge
	n) Boiler rooms and plant rooms including weight of machinery	7.5	4.5
	p) Corridors, passages, subject to loads greater than from crowds, such as wheeled vehicles, trolleys and the like corridors, staircases and passages in grandstands	5.0	4.5

Table 1 (*Continued*)

Sl No. (1)	Occupancy Classification (2)	Uniformly Distributed Load (UDL) kN/m^2 (3)	Concentrated Load kN (4)
v)	*Business and Office Buildings* (*see also* 3.2.1)		
	a) Rooms for general use with separate storage	2.5	2.7
	b) Rooms without separate storage	4.0	4.5
	c) Banking halls	3.0	2.7
	d) Business computing machine rooms (with fixed computers or similar	3.0	4.0
	e) equipment)		
	f) UPS, server and electrical panel	5.0	4.5
	g) Records/files store rooms and storage space	5.0	4.5
	h) Vaults and strong rooms – to be calculated but not less than	5.0	4.5
	j) Cafeterias and dining rooms	3.0[1)]	2.7
	k) Kitchens	3.0	2.7
	m) Corridors, passages, lobbies, staircases including fire escapes – as per the floor serviced (excluding stores) but not less than	4.0	4.5
	n) Bath and toilets rooms	2.0	–
	p) Balconies	Same as rooms to which they give access but with a minimum of 4.0	1.5 per metre run concentrated at the outer edge
	q) Stationary stores	4.0 for each metre of storage height	9.0
	r) Boiler rooms and plant rooms – to be calculated but not less than	5.0	6.7
	s) Libraries	*See* Sl No. (ii)	

Table 1 (*Continued*)

Sl No.	**Occupancy Classification**	**Uniformly Distributed Load (UDL)** kN/m^2	**Concentrated Load** kN
(1)	(2)	(3)	(4)
vi)	*Mercantile Buildings*		
	a) Retail shops	4.0	3.6
	b) Wholesale shops – to be calculated but not less than	6.0	4.5
	c) Office rooms	2.5	2.7
	d) Dining rooms, restaurants and cafeterias	3.0[1)]	2.7
	e) Toilets	2.0	–
	f) Kitchens and laundries	3.0	4.5
	g) Boiler rooms and plant rooms – to be calculated but not less than	5.0	6.7
	h) Corridors, passages, stair-cases including fire escapes and lobbies	4.0	4.5
	j) Corridors, passages, staircases subject to loads greater than from crowds, such as wheeled vehicles, trolleys and the like	5.0	4.5
	k) Balconies	Same as rooms to which they give access but with a minimum of 4.0	1.5 per metre run concentrated at the outer edge
vii)	*Industrial Buildings*[3)]		
	a) Work areas without machinery/ equipment	2.5	4.5
	a) Work areas with machinery/equipment[4)] (To be calculated but not less than)		
	1) Light duty	5.0	4.5
	2) Medium duty	7.0	4.5
	3) Heavy duty	10.0	4.5

Table 1 (*Continued*)

Sl No. (1)	Occupancy Classification (2)	Uniformly Distributed Load (UDL) kN/m^2 (3)	Concentrated Load kN (4)
	b) Boiler rooms and plant rooms – to be calculated but not less than	5.0	6.7
	c) Cafeterias and dining rooms	3.0$^{1)}$	2.7
	d) Corridors, passages, stair cases including fire escapes	4.0	4.5
	e) Corridors, passages, lobbies, staircases subject to machine loads and wheeled vehicles – to be calculated but not less than	5.0	4.5
	f) Kitchens	3.0	4.5
	g) Toilets and bathrooms	2.0	–
viii)	*Storage Buildings*$^{4)}$		
	a) Storage rooms (other than cold storage) and warehouses – to be calculated based on the bulk density of materials stored but not less than	2.4 kN/m^2 per metre of storage height with a minimum of 7.5 kN/m^2	7.0
	b) Cold storage – to be calculated but not less than	5.0 kN/m^2 per metre of storage height with a minimum of 15 kN/m^2	9.0
	c) Corridors, passages, staircases including fire escapes – as per the floor serviced but not less than	4.0	4.5
	d) Corridors, passages subject to loads greater than from crowds, such as wheeled vehicles, trolleys and the like	5.0	4.5
	e) Boiler rooms and plant rooms	7.5	4.5
ix)	Refuge area and disaster shelter	3.0	-

Table 1 (*Concluded*)

Sl No. (1)	**Occupancy Classification** (2)	**Uniformly Distributed Load (UDL)** kN/m^2 (3)	**Concentrated Load** kN (4)
x)	Datacentres		
	a) Data hall Load (With or without base isolation)		
	1) Tier 1	7.2	
	2) Tier 2	8.4	
	3) Tier 3	12	
	4) Tier 4	12	
	b) Data hall floor Hanging load (With or without base isolation)		
	1) Tier 1	1.2	
	2) Tier 2	1.2	
	3) Tier 3	2.4	
	4) Tier 4	2.4	

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[1] Where unrestricted assembly of persons is anticipated, the value of UDL should be increased to 4.0 kN/m^2.

[2] With fixed seats implies that the removal of the seating and the use of the space for other purposes is improbable. The maximum likely load in this case is, therefore, closely controlled.

[3] The loading in industrial buildings (workshops and factories) varies considerably and so three loadings under the terms 'light', 'medium' and 'heavy' are introduced in order to allow for more economical designs but the terms have no special meaning in themselves other than the imposed load for which the relevant floor is designed. It is, however important particularly in the case of heavy weight loads, to assess the actual loads to ensure that they are not in excess of 10 kN/m^2; in case where they are in excess, the design shall be based on the actual loadings.

[4] For various mechanical handling equipment which are used to transport goods, as in warehouses, workshops, store rooms, etc, the actual load coming from the use of such equipment shall be ascertained and design should cater to such loads.

3.3.1.1 *Load application*

The uniformly distributed loads specified in Table 1 shall be applied as static loads over the entire floor area under consideration or a portion of the floor area, whichever arrangement produces critical effects on the structural elements as provided in respective design codes.

In the design of floors, the concentrated loads are considered to be applied in the positions which produce the maximum stresses and where deflection is the main criterion in the positions which produce the maximum deflections. Concentrated load, when used for the calculation of bending and shear, are assumed to act at a point. When used for the calculation of local effects such as crushing or punching, they are assumed to act over an actual area of application of 0.3 m × 0.3 m.

3.3.1.2 *Loads due to light partitions*

In office and other buildings, where actual loads due to light partitions cannot be assessed at the time of planning the floors and the supporting structural members shall be designed to carry, in addition to other loads, uniformly distributed loads per square metre of not less than 33.33 percent of weight per metre run of finished partitions, subject to a minimum of 1 kN/m^2, provided total weight of partition walls per m^2 of the wall area does not exceed 1.5 kN/m^2 and the total weight per metre length is not greater than 4.0 kN.

3.3.2 *Reduction in Imposed Loads on Floors*

3.3.2.1 *For members supporting floors*

Except as provided for in 3.3.2.1(a), the following reductions in assumed total imposed loads on the floors may be made in designing columns, load bearing walls, piers, their supports and foundations:

a) No reduction shall be made for any plant or machinery which is specifically allowed for, or for buildings for storage purposes, warehouses and garages. But, for other buildings, where the floor is designed for an imposed floor load of 5.0 kN/m^2 or more, the reductions shown in **3.3.2.1** may be taken provided that the loading assumed is not less than it would have been, if all the floors had been designed for 5.0 kN/m^2 with no reductions; and

NOTE — In case, if the reduced load in the lower floor is lesser than the reduced load in the upper floor, then the reduced load of the upper floor will be adopted.

b) An example is given in Annex B illustrating the reduction of imposed loads in a multi-storeyed building in the design of column members.

Number of Floors (Including the Roof) to be Carried by Member Under Consideration	*Reduction in Total Distributed Imposed Load on All Floors to be Carried by the Member Under Consideration* Percent
1	0
2	10
3	20
4	30
5 to 10	40
Over 10	50

3.3.2.2 *For beams in each floor level*

Where a single span of beam, girder or truss supports not less than 50 m^2 of floor at one general level, the imposed floor load may be reduced in the design of the beams, girders or trusses by 5 percent for each 50 m^2 area supported subject to a maximum reduction of 25 percent. But, no reduction shall be made in any of the following types of loads:

a) Any superimposed moving load;

b) Any actual load due to machinery or similar concentrated loads;

c) The additional load in respect of partition walls; and

d) Any impact or vibration.

NOTE — The above reduction does not apply to beams, girders or trusses supporting roof loads.

3.3.3 *Posting of Floor Capacities*

Where a floor or part of a floor of a building has been designed to sustain a uniformly distributed load exceeding 3.0 kN/m^2 and in assembly, business, mercantile, industrial or storage buildings, a permanent notice in the form shown below indicating the actual uniformly distributed and/or concentrated loadings for which the floor has been structurally designed shall be posted in a conspicuous place in a position adjacent to such floor or on such part of a floor.

NOTES

1 The lettering of such notice shall be embossed or cast suitably on a tablet whose least dimension shall not be less than 0.25 m and located not less than 1.5 m above floor level with lettering of a minimum size of 25 mm.

2 If a concentrated load or a bulk load has to occupy a definite position on the floor, the same could also be indicated in the table.

DESIGNED IMPOSED FLOOR LOADING

Distributed……………..kN/m^2

Concentrated…………kN

Label Indicating Designed Imposed Floor Loading

3.4 Imposed Loads on Roofs

3.4.1 *Imposed Loads on Various Types of Roofs*

On flat roofs, sloping roofs and curved roofs, the imposed loads due to use and occupancy of the buildings and the geometry of the types of roofs shall be as given in Table 2.

Table 2 Imposed Loads on Various Types of Roofs

(*Clauses* 3.4.1 *and* 3.4.3)

Sl No. (1)	Type of Roof (2)	Imposed Load Measured on Plan Area (3)	Minimum Imposed Load Measured on Plan (4)
i)	Flat, sloping or curved roof with slopes up to and including 10 degrees		
	a) Access provided	1.5 kN/m^2	3.75 kN uniformly distributed over any span of one metre width of the roof slab and 9 kN uniformly distributed over the span of any beam or truss or wall
	b) Access not provided except for maintenance	0.75 kN/m^2	1.9 kN uniformly distributed over any span of one metre width of the roof slab and 4.5 kN uniformly distributed over the span of any beam or truss or wall
ii)	Sloping roof with slope greater than 10 degrees	For roof membrane sheets or purlins – 0.75 kN/m^2 less 0.02 kN/m^2 for every degree increase in slope over 10 degrees	Subject to a minimum of 0.4 kN/m^2
iii)	Curved roof with slope of line obtained by joining springing point to the crown with the horizontal, greater than 10 degrees	$(0.75 - 0.52\alpha^2)$ kN/m^2 where $\alpha = h/l$	Subject to a minimum of 0.4 kN/m^2

Table 2 (*Concluded*)

Sl No.	Type of Roof	Imposed Load Measured on Plan Area	Minimum Imposed Load Measured on Plan
(1)	(2)	(3)	(4)
		h = height of the highest point of the structure measured from its springing; and l = chord width of the roof if singly curved and shorter of the two sides if doubly curved. Alternatively, where structural analysis can be carried out for curved roofs of all slopes in a simple manner applying the laws of statistics, the curved roofs shall be divided into minimum 6 equal segments and for each segment imposed load shall be calculated appropriate to the slope of the chord of each segment as given in (i) and (ii).	

NOTES

1 The loads given above do not include loads due to snow, rain, dust collection, etc. The roof shall be designed for imposed loads given above or for snow/rain load, whichever is greater.

2 For special types of roofs with highly permeable and absorbent material, the contingency of roof material increasing in weight due to absorption of moisture shall be provided for.

Roofs of buildings used for promenade or incidental to assembly purposes shall be designed for the appropriate imposed floor loads given in Table 1 for the occupancy.

3.4.2 *Concentrated Load on Roof Coverings*

To provide for loads incidental to maintenance, unless otherwise specified by the Engineer-in-Charge, all roof coverings (other than glass or transparent sheets made of fibre glass) shall be capable of carrying an incidental load of 0.90 kN concentrated on an area of 1 250 mm^2 so placed as to produce maximum stresses in the covering. The intensity of the concentrated load may be reduced with the approval of the Engineer-in-Charge, where it is ensured that the roof coverings would not be traversed without suitable aids. In any case, the roof coverings shall be capable of carrying the loads in accordance with **3.4.1**, **3.4.3** and **3.4.4** and wind load.

3.4.3 *Loads Due to Rain*

On surfaces whose positioning, shape and drainage system are such as to make accumulation of rain water possible, loads due to such accumulation of water and the imposed loads for the roof as given in Table 2 shall be considered separately and the more critical of the two shall be adopted in the design.

3.4.4 *Dust Loads*

In areas prone to settlement of dust on roofs (example, steel plants, cement plants), provision for dust load equivalent to probable thickness of accumulation of dust may be made.

3.4.5 *Loads on Members Supporting Roof Coverings*

Every member of the supporting structure which is directly supporting the roof covering(s) shall be designed to carry the more severe of the following loads except as provided in **3.4.5.1**:

a) The load transmitted to the members from the roof covering(s) in accordance with **3.4.1**, **3.4.3** and **3.4.4**; and

b) An incidental concentrated load of 0.90 kN concentrated over a length of 125 mm placed at the most critical positions on the member.

NOTE — Where it is ensured that the roofs would be traversed only with the aid of planks and ladders capable of distributing the loads on them to two or more supporting members, the intensity of concentrated load indicated in **3.4.5**(**b**) may be reduced to 0.5 kN with the approval of the Engineer-in-Charge.

3.4.5.1 In case of sloping roofs with slope greater than 10º, members supporting the roof purlins, such as trusses, beams, girders, etc, may be designed for two-thirds of the imposed load on purlin or roofing sheets.

3.5 Imposed Horizontal Loads on Parapets, Balustrades and Other Appurtenances Fixed to Structure and on Grandstands

3.5.1 *Parapets, Parapet Walls, Balustrades and other Appurtenances Fixed to the Structure such as Grab Bars, Fixed Ladders and Guardrails in Stilt Parking*

Parapets, parapet walls, balustrades and other appurtenances fixed to the structure such as grab bars, fixed ladders and guardrails in stilt parking, together with the members which give them structural support, shall be designed for the minimum loads given in Table 3. These are expressed as horizontal forces acting at handrail or coping level. These loads shall be considered to act vertically also but not simultaneously with the horizontal forces. The values given in Table 3 are minimum values and where values for actual loadings are available, they shall be used instead.

Table 3 Horizontal Loads on Parapets, Parapet Walls and Balustrades

(*Clause* 3.5.1)

Sl No. (1)	**Usage Area** (2)	**Intensity of Horizontal Load** kN/m Run (3)	**Concentrated Load (For each 3 m Length)** kN (4)
i)	Light access stairs, gangways and like, not more than 600 mm wide	0.25	—
ii)	Light access stairs, gangways and like, more than 600 mm wide; stairways, landings, balconies and parapet walls (private and part of dwellings)	0.35	—
iii)	a) All other stairways, landings and balconies and all parapets and handrails to roofs [except those subject to overcrowding covered under (iv)]	0.75	0.89
	b) Panel fillers	0.20	0.22

Table 3 (*Concluded*)

Sl No. (1)	Usage Area (2)	**Intensity of Horizontal Load** kN/m Run (3)	**Concentrated Load (For each 3 m Length)** kN (4)
iv)	Parapets and balustrades:		
	a) In places of assembly, such as restaurants and bars, retail and public areas, not likely to be overcrowded	1.5	1.5
	b) In places of assembly, such as retail areas, theatres, cinemas, bars, auditoria, shopping malls, discothèques, places of worship, likely to be overcrowded	3.0	1.5
v)	Grab bars	—	1.11
vi)	Fixed ladders	—	1.33
vii)	Guardrail systems and handrail assemblies	0.73	0.89

NOTE — In the case of guard parapets on a floor of multi-storeyed car park or crash barriers provided in certain buildings for fire escape, the value of imposed horizontal load (together with impact load) may be determined. For (vii), this load need not be considered for (a) one- and two- family dwellings and (b) factory, industrial and storage occupancies, in areas that serve occupant load not greater than 22 kN.

3.5.2 *Grandstands and the Like*

Grandstands, stadia, assembly platforms, reviewing stands and the like shall be designed to resist a horizontal force applied to seats of 0.35 kN per linear metre along the line of seats and 0.15 kN per linear metre perpendicular to the line of the seats. These loadings need not be applied simultaneously. Platforms without seats shall be designed to resist a minimum horizontal force of 0.25 kN/m^2 of plan area.

3.6 Loading Effects Due to Impact and Vibration

The crane loads to be considered under imposed loads shall include the vertical loads, eccentricity effects induced by vertical loads, impact factors, lateral and longitudinal braking forces acting across and along the crane rails, respectively.

3.6.1 *Impact Allowance for Lifts, Hoists and Machinery*

The imposed loads specified in 3.3.1 shall be assumed to include adequate allowance for ordinary impact conditions. However, for structures carrying loads which induce impact or vibration, as far as possible, calculations shall be made for increase in the imposed load due to impact or vibration. In the absence of sufficient data for such calculation, the increase in the imposed loads shall be as follows:

	Structures	*Impact Allowance* Percent *Min*
a)	For frames supporting lifts and hoists	100
b)	For foundations, footings and piers supporting lifts and hoisting apparatus	40
c)	For supporting structures and foundations for light machinery, shaft or motor units	20
d)	For supporting structures and foundations for reciprocating machinery or power units	50

3.6.2 *Concentrated Imposed Loads with Impact and Vibration*

3.6.2.1 Concentrated imposed loads with impact and vibration which may be due to installed machinery shall be considered and provided for in the design. The impact factor shall not be less than 20 percent which is the amount allowable for light machinery.

3.6.2.2 Provision shall also be made for carrying any concentrated equipment loads while the equipment is being installed or moved for servicing and repairing.

3.6.3 *Impact Allowance for Crane Girders*

For crane gantry girders and supporting columns, the impact allowances (given below) shall be deemed to cover all forces set up by vibration, shock from slipping of slings, kinetic action of acceleration and retardation and impact of wheel loads.

	Type of Load	*Additional Load*
a)	Vertical loads for electric overhead cranes	25 percent of maximum static loads for crane girders for all class of cranes 25 percent for columns supporting Class III and Class IV cranes 10 percent for columns supporting Class I and Class II cranes No additional load for design of foundations
b)	Vertical loads for hand operated cranes	10 percent of maximum wheel loads for crane girders only
c)	Horizontal forces transverse to rails:	
	1) For electric overhead cranes with trolley having rigid mast for suspension of lifted weight (such as soaker crane, stripper crane, etc)	10 percent of weight of crab and the weight lifted by the cranes, acting on any one crane track rail, acting in either direction and equally distributed amongst all the wheels on one side of rail track For frame analysis, this force, calculated as above, shall be applied on one side of the frame at a time in either direction
	2) For all other electric overhead cranes and hand operated cranes	5 percent of weight of crab and the weight lifted by the cranes, acting on any one crane track rail, acting in either direction and equally distributed amongst the wheels on one side of rail track For the frame analysis, the force, calculated as above, shall be applied on one side of the frame at a time in either direction

	Type of Load	*Additional Load*
d)	Horizontal traction forces along the rails for overhead cranes, either electrically operated or hand operated	5 percent of all static wheel loads

Forces specified in (c) and (d) shall be considered as acting at the rail level and being appropriately transmitted to the supporting system. Gantry girders and their vertical supports shall be designed on the assumption that either of the horizontal forces in (c) and (d) may act at the same time as the vertical load.

NOTE — *See* as per good practice [C-1(2)] for classification (Class I to Class IV) of cranes.

3.6.3.1 *Overloading factors in crane supporting structures*

For all ladle cranes and charging cranes where there is possibility of overloading from production considerations, an overloading factor of 10 percent of the maximum wheel loading shall be taken.

3.6.4 *Crane Load Combinations*

In the absence of any specific indications, the load combinations shall be as indicated below.

3.6.4.1 *Vertical loads*

In an aisle, where more than one crane is in operation or has provision for more than one crane in future, the following load combinations shall be taken for vertical loading:

a) two adjacent cranes working in tandem with full load and with overloading according to **3.6.3.1**; and

b) for long span gantries, where more than one crane can come in the span, the girder shall be designed for one crane fully loaded with overloading according to **3.6.3.1** plus as many loaded cranes as can be accommodated on the span but without taking into account overloading according to **3.6.3**(**a**) to give the maximum effect.

3.6.4.2 *Lateral surge*

For design of columns and foundations, supporting crane girders, the following crane combinations shall be considered:

a) *For single bay frames* — Effect of one crane in the bay giving the worst effect shall be considered for calculation of surge force; and

b) *For multi-bay frames* — Effect of two cranes working, one each in any of two bays in the cross section to give the worst effect shall be considered for calculation of surge force.

3.6.4.3 *Tractive force*

3.6.4.3.1 Where one crane is in operation with no provision for future crane, tractive force from only one crane shall be taken.

3.6.4.3.2 Where more than one crane is in operation or there is provision for future crane, tractive force from two cranes giving maximum effect shall be considered.

NOTE — Lateral surge force and longitudinal tractive force acting across and along the crane rail respectively shall not be assumed to act simultaneously. However, if there is only one crane in the bay, the lateral and longitudinal forces may act together simultaneously with vertical loads.

3.7 Rooftop Helipad

Elevated helipad structures shall be designed as per the latest guidelines of Directorate General of Civil Aviation and International Civil Aviation Organization’s Heliport Manual.

3.7.1 *Structural Design*

Elevated helipads may be designed for a specific helicopter type though greater operational flexibility will be obtained from a classification system of design. The final approach and take-off area (FATO) should be designed for the largest or heaviest type of helicopter that is anticipated to use the helipad and account taken of other types of loading such as personnel, freight, snow, refueling equipment, etc. For the purpose of design, it is to be assumed that the helicopter will land on two main wheels, irrespective of the actual number of wheels in the undercarriage, or on two skids, if they are fitted. The loads imposed on the structure should be taken as point loads at the wheel centres as shown below:

Sl No.	*Helicopter Category*	*Maximum Take-off Mass*		*Point Load for Each Wheel*	*Under-Carriage Wheel Centres*	*Super-imposed Load* S_{Ha}	*Super-imposed Load* S_{Hb}
		kg	kN	kN	M	kN/m^2	kN/m^2
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	1	Up to 2300	Up to 22.6	12.0	1.75	0.5	1.5
ii)	2	2 301 to 5000	22.6 to 49.2	25.0	2.0	0.5	2.0
iii)	3	5001 to 9000	49.2 to 88.5	45.0	2.5	0.5	2.5
iv)	4	9001 to 13500	88.5 to 133.0	67.0	3.0	0.5	3.0
v)	5	13501 to 19500	133.0 to 192.0	96.0	3.5	0.5	3.0
vi)	6	19501 to 27000	192.0 to 266.0	133.0	4.5	0.5	3.0

3.7.2 The FATO should be designed for the worse condition derived from consideration of the following two cases.

3.7.3 *Case A — Helicopter on Landing*

When designing a FATO on an elevated helipad and in order to cover the bending and shear stresses that result from a helicopter touching down, the following should be taken into account:

a) *Dynamic load due to impact on touchdown* — This should cover the normal touchdown, with a rate of descent of 1.8 m/s, which equates to the serviceability limit state. The impact load is then equal to 1.55 times the maximum take-off mass of the helicopter;

   The emergency touchdown should also be covered at a rate of descent of 3.6m/s (12 ft/s), which equates to the ultimate limit state. The partial safety factor in this case should be taken as 1.66. Therefore,
   Ultimate design load = 1.66 × service load

   = (1.66 × 1.5) maximum take-off mass

   = 2.5 maximum take-off mass

   The sympathetic response factor discussed at 3.7.3(b) below should be applied.

b) *Sympathetic response on the FATO* — The dynamic load should be increased by a structural response factor dependent upon the natural frequency of the platform slab when considering the design of supporting beams and columns. This increase in loading will usually apply only to slabs with one or more freely supported edges. It is recommended that the average structural response factor (R) of 1.3 should be used in determining the ultimate design load;

c) *Over-all superimposed load on the FATO* (S_{Ha}) — To allow for snow load, personnel, freight and equipment loads, etc, in addition to wheel loads, an allowance of 0.5 KN/m^2 should be included in the design;

d) *Lateral load on the platform supports* — The supports of the platform should be designed to resist a horizontal point load equivalent to 0.5 maximum take-off mass of the helicopter, together with the wind loading [*see* (*f*)], applied in the direction which will provide the greater bending moments;

e) *Dead load of structural members* — The partial safety factor to be used for the dead load should be taken as 1.4;

f) *Wind loading* — Shall be as per 4; and

g) *Punching shear* — Check for the punching shear of an undercarriage wheel or skid using the ultimate design load with a contact area of 64.5×10^3 mm^2.

3.7.4 *Case B — Helicopter at Rest*

When designing a FATO on an elevated helipad and in order to cover the bending and shear stresses from a helicopter at rest, the following should be taken into account:

a) *Dead load of the helicopter* — Each structural element must be designed to carry the point load, in accordance with the table under 3.7.1, from the two main wheels or skids applied simultaneously in any position on the FATO so as to produce the worst effect from both bending and shear;

b) *Over-all superimposed load* (S_{Hb}) — In addition to wheel loads, an allowance for over-all superimposed load given in the table under 3.7.1, over the area of the FATO, should be included in the design; and

c) *Dead load on structural members and wind loading* — The same factors should be included in the design for these items as given for Case A.

NOTE — The above design loads for helicopters at rest are summarized below:

Design Load for Helicopter on Landing — Case A

i) *Superimposed loads*	
a) Helicopter	2.5 L_H distributed as two point loads at the wheel centres for the helicopter category given in the informal table under 3.7.1. Average value for R = 1.3.
b) Lateral load	$1.6\ \frac{L_H}{2}$ applied horizontally in any direction.
c) Over-all superimposed load	Load at platform level together with the maximum wind loading. 1.4 S_{Ha} over the whole area of the platform (S_{Ha} given in the informal table under 3.7.1).
ii) Dead load	$1.4G$
iii) Wind loading	$1.4W$
iv) Punching shear check	2.5 $L_H R$ load over tyre skid contact area of 64.5×10^3 mm^2.

Design Load For Helicopter at Rest — Case B

i) *Superimposed loads*	
a) Helicopter	1.6 L_H distributed as two point loads at the wheel centres for the helicopter category given in the informal table under **3.7.1**.
b) Over-all superimposed load (Personnel, freight, etc)	1.6 S_{Hb} over the whole area of the platform. S_{Hb} given in the informal table under **3.7.1**.
ii) Shear check	Check as appropriate

Symbol	*Meaning*
L_H	Maximum take-off mass of helicopter
G	Dead load of structure
W	Wind loading
R	Structural response factor
S_{Ha}	Superimposed load — Case A
S_{Hb}	Superimposed load — Case B

Load Type	*Partial Load Factors*
Dynamic load (ultimate design load)	2.5
Imposed load	1.6
Dead load	1.4
Wind loading	1.4

3.7.5 Normally, the upper load limit of the selected helicopter category should be used for design purposes; however, to avoid over-design, the upper limit in any band may be exceeded by up to 10 percent if the maximum take-off mass of a helicopter falls just into the next higher category.

3.8 Fire Tenders and Emergency Vehicles

Where a structure or portions of a structure are accessed and loaded by fire department access vehicles and other similar emergency vehicles, the structure shall be designed for the greater of the following loads:

a) the actual operational loads, including outrigger reactions and contact areas of the vehicles as stipulated and provided by the building official;

b) the contact area of wheel dimensions to be used considering 45° distribution at the reinforcement of slab considering the bear coat on the slab and any soil filling.

or

in absence of any data, the bare slab loading may be considered as 15 kN/m^2 to 20 kN/m^2.

c) when the fire tender load is combined with gravity loads and the same can be considered as accidental load with the partial load factor of 1.05; and

d) fire tender load need not be combined with lateral loads.

4 WIND LOAD

4.1 General

4.1.1 This clause gives wind forces and their effects (static and dynamic) that should be taken into account when designing buildings, structures and components thereof.

4.1.2 Wind speeds vary randomly both in time and space and hence assessment of wind loads and response predictions are very important in the design of several buildings and structures. A large majority of structures met with in practice do not however, suffer wind induced oscillations and generally do not require to be examined for the dynamic effects of wind. For such normal, short and heavy structures, estimation of loads using static wind analysis has proved to be satisfactory. The details of this method involving important wind characteristics such as the basic wind speeds, terrain categories, modification factors, wind pressure and force coefficients, etc, are given in **4.4** and **4.5**.

4.1.3 Nevertheless, there are various types of structures or their components such as some tall buildings which require investigation of wind induced oscillations. The influence of dynamic velocity fluctuations on the along wind loads (drag loads) for these structures shall be determined using Gust Factor Method, included in **4.8**. A method for calculation of across wind response of tall buildings is included in **4.8.3**.

4.1.4 This Section also applies to buildings or other structures during erection/construction and the same shall be considered carefully during various stages of erection/construction. In locations where the strongest winds and icing may occur simultaneously, loads on structural members, cables and ropes shall be calculated by assuming an ice covering based on climatic and local experience.

4.1.5 Wind is air in motion relative to the surface of the earth. The primary cause of wind is traced to earth's rotation and differences in terrestrial radiation. The radiation effects are primarily responsible for convection either upwards or downwards. The wind generally blows horizontal to the ground at high wind speeds. Since vertical components of atmospheric motion are relatively small, the term ‘wind’ denotes almost exclusively the horizontal wind; vertical winds are always identified as such. The wind speeds are assessed with the aid of anemometers or anemographs which are installed at meteorological observatories at heights generally varying from 10 m to 30 m above ground.

4.1.6 Very strong winds (more than 80 km/h) are generally associated with cyclonic storms, thunderstorms, dust storms or vigorous monsoons. A feature of the cyclonic storms over the Indian area is that they rapidly weaken after crossing the coasts and move as depressions/lows inland. The influence of a severe storm after striking the coast does not; in general exceed about 60 km, though sometimes, it may extend even up to 120 km. Very short duration hurricanes of very high wind speeds called Kal Baisaki or Norwesters occur fairly frequently during summer months over North East India.

4.1.7 The wind speeds recorded at any locality are extremely variable and in addition to steady wind at any time, there are effects of gusts which may last for a few seconds. These gusts cause increase in air pressure but their effect on stability of the building may not be so important; often, gusts affect only part of the building and the increased local pressures may be more than balanced by a momentary reduction in the pressure elsewhere. Because of the inertia of the building, short period gusts may not cause any appreciable increase in stress in main components of the building although the walls, roof sheeting and individual cladding units (glass panels) and their supporting members such as purlins, sheeting rails and glazing bars may be more seriously affected. Gusts can also be extremely important for design of structures with high slenderness ratios.

4.1.8 The liability of a building to high wind pressures depends not only upon the geographical location and proximity of other obstructions to air flow but also upon the characteristics of the structure itself.

4.1.9 The effect of wind on the structure as a whole is determined by the combined action of external and internal pressures acting upon it. In all cases, the calculated wind loads act normal to the surface to which they apply.

4.1.10 The stability calculations as a whole shall be done considering the combined effect, as well as separate effects of imposed loads and wind loads on vertical surfaces, roofs and other part of the building above general roof level.

4.1.11 Buildings shall also be designed with due attention to the effects of wind on the comfort of people inside and outside the buildings.

4.1.12 Wind borne debris present in cyclone or high speed wind has been causing a significant amount of damage to building envelopes. The actual in-service performance of fenestration assemblies and impact protective systems in areas prone to severe high speed wind depends on many factors. The main factors that affect the actual loading on building surfaces during a severe windstorm include varying wind direction, duration of the wind event, height above ground, building shape, terrain and surrounding structures. The resistance of fenestration or protective systems assemblies to wind loading after impact depends upon the product design, installation, load magnitude, duration and repetition. The method for determination of performance relating to safety of external building envelope like glazed curtain walls, exterior doors, exterior windows, impact protective systems (shutters, screens), skylight, wall cladding system, etc, impacted by wind borne debris, for buildings and other structures located in geographic regions that are prone to cyclone or extreme wind events shall be in accordance with [C-1(3)].

NOTES

1 This Section does not apply to buildings or structures with unconventional shapes, unusual locations and abnormal environmental conditions that have not been covered in this NBCS. Special investigations are necessary in such cases to establish wind loads and their effects. Wind tunnel studies may also be required in such situations.

2 In the case of tall structures with unsymmetrical geometry, the designs may have to be checked for torsional effects due to wind pressure.

3 The provisions given in good practice [C-1(4)] may be suitably referred by the design engineer/planner for reference.

4.2 Notations

The notations to be followed unless otherwise specified in relevant clauses under wind loads are given in **C-1**.

4.3 Terminology

4.3.1 For the purpose of wind loads, the following definitions shall apply.

4.3.1.1 *Angle of attack* — An angle between the direction of wind and a reference axis of the structure.

4.3.1.2 *Breadth* — It means horizontal dimension of the building measured normal to the direction of wind.

4.3.1.3 *Depth* — It means the horizontal dimension of the building measured in the direction of the wind.

NOTE — Breadth and depth are dimensions measured in relation to the direction of wind, whereas length and width are dimensions related to the plan.

4.3.1.4 *Developed height* — It is the height of upward penetration of the velocity profile in a new terrain. At large fetch lengths, such penetration reaches the gradient height, above which the wind speed may be taken to be constant. At lesser fetch lengths, a velocity profile of a smaller height but similar to that of the fully developed profile of that terrain category has to be taken, with the additional provision that the velocity at the top of this shorter profile equal to that of the un-penetrated earlier velocity profile at that height.

4.3.1.5 *Effective frontal area* — The projected area of the structure normal to the direction of wind.

4.3.1.6 *Element of surface area* — The area of surface over which the pressure coefficient is taken to be constant.

4.3.1.7 *Force coefficient* — A non-dimensional coefficient such that the total wind force on a body is the product of the force coefficient, the dynamic pressure of the incident design wind speed and the reference area over which the force is required.

NOTE — When the force is in the direction of the incident wind, the non-dimensional coefficient will be called as 'drag coefficient'. When the force is perpendicular to the direction of incident wind, the non-dimensional coefficient will be called as 'lift coefficient'.

4.3.1.8 *Ground roughness* — The nature of the earth's surface as influenced by small scale obstructions such as trees and buildings (as distinct from topography) is called ground roughness.

4.3.1.9 *Gust* — A positive or negative departure of wind speed from its mean value, lasting for not more than, say, 2 min over a specified interval of time.

4.3.1.10 *Peak gust* — A peak gust or peak gust speed is the wind speed associated with the maximum amplitude.

4.3.1.11 *Fetch length* — It is the distance measured along the wind from a boundary at which a change in the type of terrain occurs. When the changes in terrain types are encountered (such as, the boundary of a town or city, forest, etc), the wind profile changes in character but such changes are gradual and start at ground level, spreading or penetrating upwards with increasing fetch length.

4.3.1.12 *Gradient height* — It is the height above the mean ground level at which the gradient wind blows as a result of balance among pressure gradient force, Coriolis force and centrifugal force. For the purpose of this Section, the gradient height is taken as the height above the mean ground level, above which the variation of wind speed with height need not be considered.

4.3.1.13 *Tall building* — A building with a height more than or equal to 50 m or having a height to smaller lateral dimension more than 6.

4.3.1.14 *Low rise building* — A building having its height less than 20 m.

4.3.1.15 *Mean ground level* — The mean ground level is the average horizontal plane of the area enclosed by the boundaries of the structure.

4.3.1.16 *Pressure coefficient* — It is the ratio of the difference between the pressure acting at a point on the surface and the static pressure of the incident wind to the design wind pressure, where the static and design wind pressures are determined at the height of the point considered after taking into account the geographical location, terrain conditions and shielding effect. The pressure coefficient is also equal to $[1 - (V_p/V_z)^2]$, where V_p is the actual wind speed at any point on the structure at a height corresponding to that of V_z.

NOTE — Positive sign of the pressure coefficient indicates pressure acting towards the surface and negative sign indicates pressure acting away from the surface.

4.3.1.17 *Return period* — It is the number of years, reciprocal of which gives the probability of extreme wind exceeding a given wind speed in anyone year.

4.3.1.18 *Shielding effect* — Shielding effect or shielding refers to the condition where wind has to pass along some structure(s) or structural element(s) located on the upstream wind side, before meeting the structure or structural element under consideration. A factor called ‘shielding factor’ is used to account for such effects in estimating the force on the shielded structures.

4.3.1.19 *Suction* — It means pressure less than the atmospheric (static) pressure and is taken to act away from the surface.

4.3.1.20 *Solidity ratio* — It is equal to the effective area (projected area of all the individual elements) of a frame normal to the wind direction divided by the area enclosed by the boundary of the frame normal to the wind direction.

NOTE — Solidity ratio is to be calculated for individual frames.

4.3.1.21 *Terrain category* — It means the characteristics of the surface irregularities of an area which arise from natural or constructed features. The categories are numbered in increasing order of roughness.

4.3.1.22 *Topography* — The nature of the earth's surface as influenced by the hill and valley configurations.

4.3.1.23 *Velocity profile* — The variation of the horizontal component of the atmospheric wind speed at different heights above the mean ground level is termed as velocity profile.

4.4 Wind Speed

4.4.1 *Nature of Wind in Atmosphere*

In general, wind speed in the atmospheric boundary layer increases with height from zero at ground level to maximum at a height called the gradient height. There is usually a slight change in direction (Ekman effect) but this is ignored in this Section. The variation with height depends primarily on the terrain conditions. However, the wind speed at any height never remains constant and it has been found convenient to resolve its instantaneous magnitude into an average or mean value and a fluctuating component around this average value. The average value depends on the average time employed in analyzing the meteorological data and this averaging time varies from few seconds to several minutes. The magnitude of fluctuating component of the wind speed, which is called gust, depends on the averaging time. In general, smaller the averaging interval more is the magnitude of the gust speed.

4.4.2 *Basic Wind Speed*

Figure 1 gives basic wind speed map of India, as applicable to 10 m height above mean ground level for different zones of the country. Basic wind speed is based on peak gust velocity averaged over a short time interval of about 3 s and corresponds to mean heights above ground level in an open terrain (Category 2). Basic wind speeds presented in Fig. 1 have been worked out for a 50 year return period. Basic wind speed for some important cities/towns is also given in Annex D.

4.4.3 *Design Wind Speed* (V_z)

The basic wind speed (V_b) for any site shall be obtained from Fig. 1 and shall be modified to include the following effects to get design wind speed, V_z at any height z, for the chosen structure:

a) Risk level;

b) Terrain roughness and height of structure;

c) Local topography; and

d) Importance factor for the cyclonic region.

It can be mathematically expressed as follows:

$$V_z = V_b\, k_1\, k_2\, k_3\, k_4$$

where

V_z = design, in m/s, wind speed at height z;

k_1 = probability factor (risk coefficient) (*see* **4.4.3.1**);

k_2 = terrain roughness and height factor (*see* **4.4.3.2**);

k_3 = topography factor (*see* **4.4.3.3**); and

k_4 = importance factor for the cyclonic region (*see* **4.4.3.4**).

NOTE — Wind speed may be taken as constant up to a height of 10 m. However, pressures for buildings less than 10 m high may be reduced by 20 percent for evaluating stability and design of the framing.

4.4.3.1 *Risk coefficient* (k_1 factor)

Figure 1 gives basic wind speeds for terrain Category 2 as applicable at 10 m above ground level based on 50 years mean return period. The suggested life period to be assumed in design and the corresponding k_1 factors for different class of structures for the purpose of design are given in Table 4. In the design of buildings and structures, a regional basic wind speed having a mean return period of 50 years shall be used except as specified in the Note of Table 4.

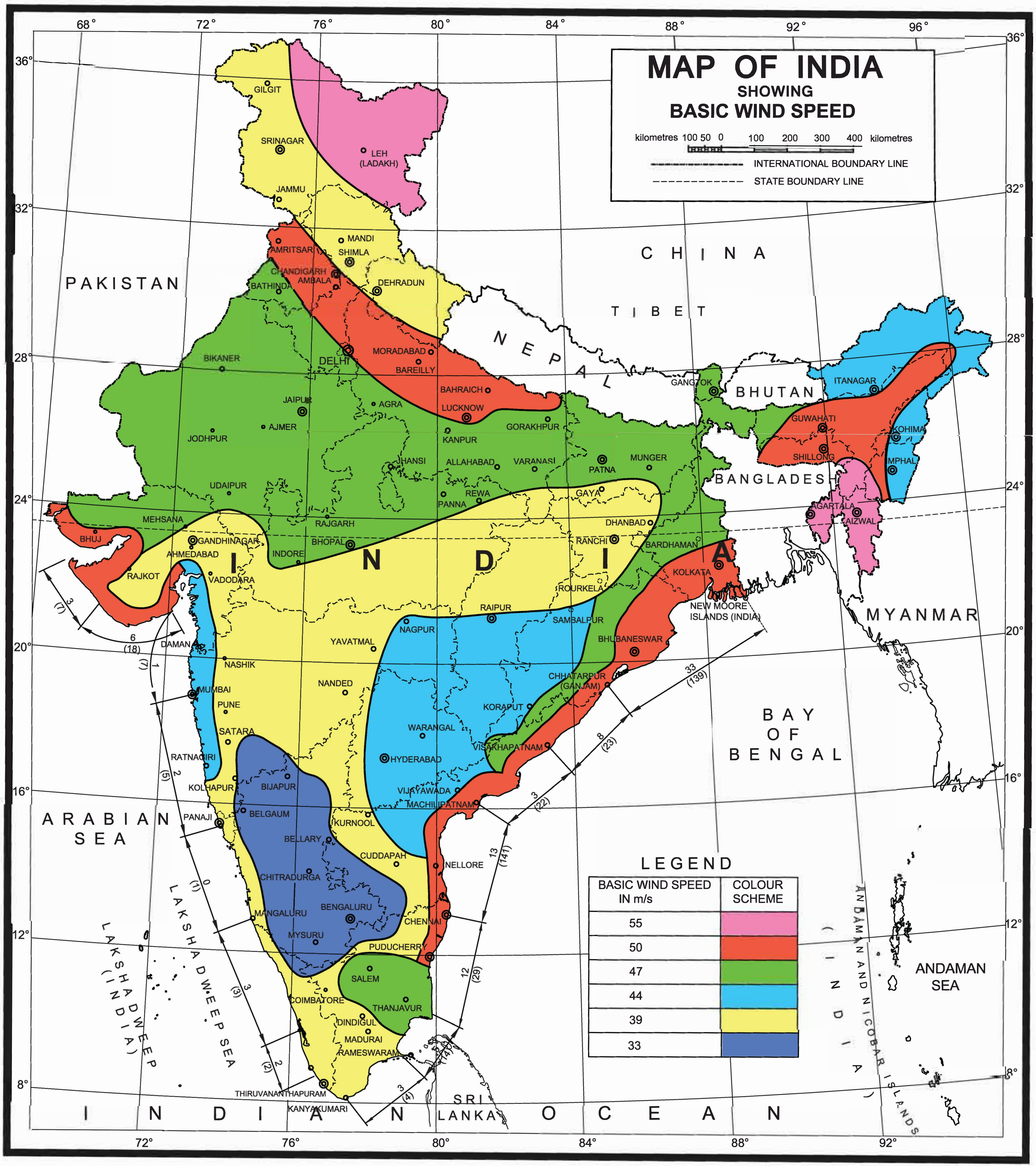
4.4.3.2 *Terrain, height factor* (k_2 factor)

4.4.3.2.1 *Terrain*

Selection of terrain categories shall be made with due regard to the effect of obstructions which constitute the ground surface roughness. The terrain category used in the design of a structure may vary depending on the direction of wind under consideration. Wherever sufficient meteorological information is available about the nature of wind direction, the orientation of any building or structure may be suitably planned.

Terrain in which a specific structure stands shall be assessed as being one of the following terrain categories:

a) *Category* 1 — Exposed open terrain with few or no obstructions and in which the average height of any


MAP OF INDIA
SHOWING
BASIC WIND SPEED
kilometres 100 50 0 100 200 300 400 kilometres
INTERNATIONAL BOUNDARY LINE
STATE BOUNDARY LINE
LEGEND
BASIC WIND SPEED IN m/s
COLOUR SCHEME
55
50
47
44
39
33
PAKISTAN
CHINA
TIBET
NEPAL
BHUTAN
BANGLADESH
MYANMAR
SRI LANKA
INDIA
ARABIAN SEA
BAY OF BENGAL
INDIAN OCEAN
ANDAMAN SEA
LAKSHADWEEP SEA
LAKSHADWEEP (INDIA)
ANDAMAN AND NICOBAR ISLANDS (INDIA)
NEW MOORE ISLANDS (INDIA)
GILGIT
SRINAGAR
LEH (LADAKH)
JAMMU
AMRITSAR
MANDI
SHIMLA
CHANDIGARH
AMBALA
BATHINDA
DEHRADUN
DELHI
MORADABAD
BAREILLY
BIKANER
JAIPUR
AGRA
AJMER
JODHPUR
BAHRAICH
LUCKNOW
KANPUR
GORAKHPUR
GANGTOK
ITANAGAR
GUWAHATI
KOHIMA
SHILLONG
IMPHAL
AGARTALA
AIZWAL
JHANSI
ALLAHABAD
VARANASI
PATNA
MUNGER
UDAIPUR
GAYA
REWA
PANNA
MEHSANA
BHUJ
GANDHINAGAR
AHMEDABAD
RAJGARH
BHOPAL
INDORE
DHANBAD
RANCHI
BARDHAMAN
KOLKATA
RAJKOT
VADODARA
ROURKELA
RAIPUR
SAMBALPUR
NAGPUR
YAVATMAL
DAMAN
NASHIK
BHUBANESWAR
CHHATARPUR (GANJAM)
NANDED
MUMBAI
PUNE
KORAPUT
WARANGAL
SATARA
VISAKHAPATNAM
HYDERABAD
RATNAGIRI
KOLHAPUR
BIJAPUR
VIJAYAWADA
MACHILIPATNAM
PANAJI
BELGAUM
KURNOOL
BELLARY
CUDDAPAH
NELLORE
CHITRADURGA
MANGALURU
BENGALURU
CHENNAI
MYSURU
PUDUCHERRY
SALEM
COIMBATORE
THANJAVUR
DINDIGUL
MADURAI
RAMESWARAM
THIRUVANANTHAPURAM
KANYAKUMARI
3 (7)
6 (18)
1 (7)
2 (5)
0 (1)
3 (3)
2 (2)
3 (4)
14 (44)
12 (29)
13 (141)
3 (22)
8 (23)
33 (139)
68°
72°
76°
80°
84°
88°
92°
96°
36°
32°
28°
24°
20°
16°
12°
8°

Based upon Survey of India Political map printed in 2002.

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The territorial waters of India extend into the sea to a distance of twelve nautical miles measured from the appropriate baseline.

The interstate boundaries between Arunachal Pradesh, Assam and Meghalaya shown on this map are as interpreted from the North-Eastern Areas (Reorganization) Act, 1971, but have yet to be verified.

The external boundaries and coastlines of India agree with the Record/Master Copy certified by Survey of India.

The responsibility for the correctness of internal details rest with the publisher.

NOTES

1 The occurrence of a tornado is possible in virtually any part of India. They are particularly more severe in the northern parts of India. The recorded number of these tornados is too small to assign any frequency. The devastation caused by a tornado is due to exceptionally high winds about its periphery, and the sudden reduction in atmospheric pressure at its centre, resulting in an explosive outward pressure on the elements of the structure. the regional basic wind speeds do not include any specific allowance for tornados. It is not the usual practice to allow for the effect of tornados unless special requirements are called for as in the case of important structures such as, nuclear power reactors and satellite communication towers.

2 The total number of cyclonic storms that have struck different sections of east and west coasts are included in Fig. 1, based on available records for the period from 1877 to 1982. The figures above the lines (between the stations) indicate the total number of severe cyclonic storms with or without a core of hurricane winds (speeds above 87 km/h) and the figures in the brackets below the lines indicate the total number of cyclonic storms. Their effect on land is already reflected in the basic wind speeds specified in Fig. 1. These have been included only as additional information.

FIG. 1 BASIC WIND SPEED IN m/s (BASED ON 50-YEARS RETURN PERIOD)

object surrounding the structure is less than 1.5 m. The equivalent aerodynamic roughness height, ($z_{0,1}$) for this terrain is 0.002 m. Typically this category represents open sea-coasts and flat plains without trees;

b) *Category* 2 — Open terrain with well scattered obstructions having heights generally between 1.5 m and 10 m. The equivalent aerodynamic roughness height, ($z_{0,2}$) for this terrain is 0.02 m. This is the criterion for measurement of regional basic wind speeds and represents airfields, open park lands and undeveloped sparsely built-up outskirts of towns and suburbs. Open land adjacent to sea coast may also be classified as Category 2 due to roughness of large sea waves at high winds;

c) *Category* 3 — Terrain with numerous closely spaced obstructions having the size of buildings/structures up to 10 m in height with or without a few isolated tall structures. The equivalent aerodynamic roughness height, ($z_{0,3}$) for this terrain is 0.2 m. This category represents well wooded areas and shrubs, towns and industrial areas full or partially developed. It is likely that the, next higher category than this will not exist in most design situations and that selection of a more severe category will be deliberate; and

d) *Category* 4 — Terrain with numerous large high closely spaced obstructions. The equivalent aerodynamic roughness height, ($z_{0,4}$) for this terrain is 2.0 m. This category represents large city centres, generally with obstructions above 25 m and well developed industrial complexes.

Table 4 Risk Coefficients for Different Classes of Structures in Different Wind Speed Zones

(*Clause* 4.4.3.1)

Sl No.	**Class of Structure**	**Mean Probable Design Life of Structure in Years**	**k_1 Factor for Basic Wind Speed** (in m/s) **of**					
			33	39	44	47	50	55
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
i)	All general buildings and structures and ground based free standing tower up to 50 m	50	1.0	1.0	1.0	1.0	1.0	1.0
ii)	Temporary sheds, structures such as those used during construction operations (for example forL-work and false work), structures during construction stages and boundary walls	5	0.82	0.76	0.73	0.71	0.70	0.67
iii)	Buildings and structures presenting a low degree of hazard to life and property in the event of failure, such as isolated towers in wooded areas, farm buildings other than residential buildings	25	0.94	0.92	0.91	0.90	0.90	0.89
iv)	Important buildings and structures, such as hospitals, communication buildings/towers and power plant structures	100	1.05	1.06	1.07	1.07	1.08	1.08

NOTE — The factor k_1 is based on statistical concepts which take into account the degree of reliability required and period of time in years during which there will be exposure to wind, that is, life of the structure. Whatever wind speed is adopted for design purposes, there is always a probability (however small) that it may be exceeded in a storm of exceptional violence; more the period of years over which there is exposure to the wind, more is the probability. Larger return periods ranging from 100 to 1 000 years (implying lower risk level) in association with larger periods of exposure may have to be selected for exceptionally important structures, such as, nuclear power reactors and satellite communication towers. Equation given below may be used in such cases to estimate k_1 factors for different periods of exposure and chosen probability of exceedance (risk level). The probability level of 0.63 is normally considered sufficient for design of buildings and structures against wind effects and the values of k_1 corresponding to this risk level are given above.

Table 4 (*Concluded*)

$$k_1 = \frac{X_{\mathrm{N,P}}}{X_{50,0.63}} = \frac{A - B\left[l_n\left\{-\frac{1}{N}l_n\left(1-P_N\right)\right\}\right]}{A+4B}$$

where

N = mean probable design life of structure in years;

P_{N} = risk level in N consecutive years (probability that the design wind speed is exceeded;

$X_{\mathrm{N,P}}$ = at least once in N successive years), nominal value = 0.63; and

$X_{50,0.63}$ = extreme wind speed for given values of N and P_{N}; .

A and *B* have the following values for different basic wind speed zones:

Zone m/s	***A**** m/s	***B**** m/s
33	23.1 (83.2)	2.6 (9.2)
39	23.3 (84.0)	3.9 (14.0)
44	24.4 (88.0)	5.0 (18.0)
47	24.4 (88.0)	5.7 (20.5)
50	24.7 (88.8)	6.3 (22.8)
55	25.2 (90.8)	7.6 (27.3)

* Values of *A* and *B* in ‘km/h’ are given within bracket

4.4.3.2.2 *Variation of wind speed with height in different terrains* (k_2)

Table 5 gives multiplying factors (k_2) by which the basic wind speed given in Fig. 1 shall be multiplied to obtain the wind speed at different heights, in each terrain category.

Table 5 Factors to Obtain Design Wind Speed Variation with Height in Different Terrains

(*Clause* 4.4.3.2.2)

Sl No.	**Height (z),** m	**Terrain and Height Multiplier (k_2)**			
		Terrain Category 1	Terrain Category 2	Terrain Category 3	Terrain Category 4
(1)	(2)	(3)	(4)	(5)	(6)
i)	10	1.05	1.00	0.91	0.80
ii)	15	1.09	1.05	0.97	0.80
iii)	20	1.12	1.07	1.01	0.80
iv)	30	1.15	1.12	1.06	0.97
v)	50	1.20	1.17	1.12	1.10
vi)	100	1.26	1.24	1.20	1.20
vii)	150	1.30	1.28	1.24	1.24
viii)	200	1.32	1.30	1.27	1.27
ix)	250	1.34	1.32	1.29	1.28
x)	300	1.35	1.34	1.31	1.30

Table 5 (*Concluded*)

Sl No.	Height (z), m	Terrain and Height Multiplier (k_2)			
		Terrain Category 1	Terrain Category 2	Terrain Category 3	Terrain Category 4
(1)	(2)	(3)	(4)	(5)	(6)
xi)	350	1.35	1.35	1.32	1.31
xii)	400	1.35	1.35	1.34	1.32
xiii)	450	1.35	1.35	1.35	1.33
xiv)	500	1.35	1.35	1.35	1.34

NOTE — For intermediate values of height *z* in a given terrain category, use linear interpolation.

4.4.3.2.3 *Terrain categories in relation to the direction of wind*

The terrain category used in the design of a structure may vary depending on the direction of wind under consideration. Where sufficient meteorological information is available, the basic wind speed may be varied for specific wind direction.

4.4.3.2.4 *Changes in terrain categories*

The velocity profile for a given terrain category does not develop to full height immediately with the commencement of that terrain category but develop gradually to height (h_x) which increases with the fetch or upwind distance (x).

a) *Fetch and developed height relationship* — The relation between the developed height (h_x) and the fetch (x) for wind-flow over each of the four terrain categories may be taken as given in Table 6; and

b) For structures of heights more than the developed height (h_x) in Table 6, the velocity profile may be determined in accordance with the following:

   1) The less or least rough terrain; or

   2) The method described in Annex E.

Table 6 Fetch and Developed Height Relationship

(*Clause* 4.4.3.2.4)

Sl No.	Fetch (x) km	Developed Height (h_x) m			
		Terrain Category 1	Terrain Category 2	Terrain Category 3	Terrain Category 4
(1)	(2)	(3)	(4)	(5)	(6)
i)	0.2	12	20	35	60
ii)	0.5	20	30	35	95
iii)	1	25	45	80	130
iv)	2	35	65	110	190
v)	5	60	100	170	300
vi)	10	80	140	250	450

Table 6 (*Concluded*)

Sl No.	**Fetch (x)** km	**Developed Height (h_x)** m			
		Terrain Category 1	Terrain Category 2	Terrain Category 3	Terrain Category 4
(1)	(2)	(3)	(4)	(5)	(6)
vii)	20	120	200	350	500
viii)	50	180	300	400	500

4.4.3.3 *Topography* (k_3 *factor*)

The basic wind speed V_b given in Fig. 1 takes into account the general level of site above sea level. This does not allow for local topographic features such as hills, valleys, cliffs, escarpments, or ridges which can significantly affect wind speed in their vicinity. The effect of topography is to accelerate wind near the summits of hills or crests of cliffs, escarpments or ridges and decelerate the wind in valleys or near the foot of cliffs, steep escarpments, or ridges.

The effect of topography shall be significant at a site when the upwind slope (θ) is more than about 3° and below that, the value of k_3 may be taken to be equal to 1.0. The value of k_3 is confined in the range of 1.0 to 1.36 for slopes more than 3°. A method of evaluating the value of k_3 for values more than 1.0 is given in Annex F. It may be noted that the value of k_3 varies with height above ground level, with a maximum near the ground and reducing to 1.0 at higher levels.

4.4.3.4 *Importance factor for cyclonic region* (k_4 *factor*)

The east coast of India is relatively more vulnerable for occurrences of severe cyclones. On the west coast, Gujarat is vulnerable for severe cyclones. Studies of wind speed and damage to buildings and structures point to the fact that the speeds given in the basic wind speed map are often exceeded during the cyclones. The effect of cyclonic storms is largely felt in a belt of approximately 60 km width at the coast. In order to ensure better safety of structures in this region (60 km wide on the east coast as well as on the Gujarat coast), the values of k_4 are stipulated as applicable according to the importance of the structure:

	k_4
Structures of post-cyclone importance for emergency services (such as cyclone shelters, hospitals, schools, communication towers, etc)	1.30
Industrial structures	1.15
All other structures	1.00

NOTE — For guidelines related to estimation of cyclonic factor (k4) as given in good practice [C-1(5)] may be referred.

4.4.4 *Hourly Mean Wind Speed*

The hourly mean wind speed at height z, for different terrains can be obtained as:

$$\overline{V}_{z,H} = \overline{k}_{2,i} V_b$$

where

$\overline{k}_{2,i}$ = hourly mean wind speed factor for terrain category 'i'.

$$= 0.1423\left[\ln\left(\frac{z}{z_{0,\mathrm{i}}}\right)\right]\left(z_{0,\mathrm{i}}\right)^{0.0706}$$

The design hourly mean wind speed at height z can be obtained as:

$$\overline{V}_{\mathrm{z,d}} = \overline{V}_{\mathrm{z,H}} k_1 k_3 k_4 \quad = V_{\mathrm{b}} k_1 \overline{k}_{2,\mathrm{i}} k_3 k_4$$

4.4.5 *Turbulence Intensity*

The turbulence intensity variations with height for different terrains can be obtained using the relations given below:

a) *Terrain category* 1

$$I_{\mathrm{z},1} = 0.3507 - 0.0535 \log_{10}\left(\frac{z}{z_{0,1}}\right)$$

b) *Terrain category* 2

$$I_{\mathrm{z},2} = I_{\mathrm{z},1} + \frac{1}{7}\left(I_{\mathrm{z},4} - I_{\mathrm{z},1}\right)$$

c) *Terrain category* 3

$$I_{\mathrm{z},3} = I_{\mathrm{z},1} + \frac{3}{7}\left(I_{\mathrm{z},4} - I_{\mathrm{z},1}\right)$$

d) *Terrain category* 4

$$I_{z,4} = 0.466 - 0.1358 \log_{10}\left(\frac{z}{z_{0,4}}\right)$$

4.4.6 *Off-shore Wind Velocity*

Cyclonic storms form far away from the sea coast and gradually reduce in speed as they approach the sea coast. Cyclonic storms generally extend up to about 60 km inland after striking the coast. Their effect on land is already reflected in basic wind speeds specified in Fig. 1. The influence of wind speed off the coast up to a distance of about 200 km may be taken as 1.15 times the value on the nearest coast in the absence of any definite wind data. The factor 1.15 shall be used in addition to k_4.

4.5 Wind Pressures and Forces on Buildings/Structures

4.5.1 *General*

The wind load on a building/structure shall be calculated for:

a) the building/structure as a whole;

b) individual structural elements as roofs and walls; and

c) individual cladding units including glazing and their fixings.

4.5.2 *Design Wind Pressure*

The wind pressure at any height above mean ground level shall be obtained by the following relationship between wind pressure and wind speed:

$$p_z = 0.6 V_{\mathrm{z}}^{2}$$

where

p_z = wind pressure at height z, in N/m^2; and

V_z = design wind speed at height z, in m/s.

The design wind pressure p_d can be obtained as:

$$p_d = K_d\,K_a\,K_c\,p_z$$

where

K_d = wind directionality factor;

K_a = area averaging factor; and

K_c = combination factor [*see* **4.5.3.3.13**].

The value of p_d, however shall not be taken as less than 0.70 p_z.

NOTES

1 The coefficient 0.6 (in SI units) in the above formula depends on a number of factors and mainly on the atmospheric pressure and air temperature. The value chosen corresponds to the average Indian atmospheric conditions.

2 K_d should be taken as 1.0 when considering local pressure coefficients.

4.5.2.1 *Wind directionality factor, K_d*

Considering the randomness in the directionality of wind and recognizing the fact that pressure or force coefficients are determined for specific wind directions, it is specified that for buildings, solid signs, open signs, lattice frameworks and trussed towers (triangular, square, rectangular) a factor of 0.90 may be used on the design wind pressure. For circular or near-circular forms this factor may be taken as 1.0.

For the cyclone affected regions also the factor K_d shall be taken as 1.0.

4.5.2.2 *Area averaging factor, K_a*

Pressure coefficients given in **4.5.3** are a result of averaging the measured pressure values over a given area. As the area becomes larger, the correlation of measured values decrease and *vice-versa*. The decrease in pressures due to larger areas may be taken into account as given in Table 7.

Table 7 Area Averaging Factor (K_a)

(*Clause* 4.5.2.2)

Sl No. (1)	**Tributary Area (A)** m^2 (2)	**Area Averaging Factor (K_a)**[1] (3)
i)	≤ 10	1.0
ii)	25	0.9
iii)	≥ 100	0.8

[1] Linear interpolation for intermediate values of tributary area, A is permitted.

4.5.2.2.1 *Tributary area*

a) *Overall structure* — For evaluating loads on frames the tributary area shall be taken as the centre to centre distances between frames multiplied by the individual panel dimension in the other direction together with overall pressure coefficients;

b) *Individual elements* — For beam type elements, purlins, etc, the tributary area shall be taken as effective span multiplied by spacing. The effective span is the actual span for mid span and cantilever load effects; and half the sum of adjacent spans for support moments and reactions;

c) For plate type elements, the area of individual plates between supports is taken as the tributary area; and

d) For glass cladding, individual pane area of glass is the tributary area.

4.5.3 *Pressure Coefficients*

The pressure coefficients are always given for a particular surface or part of the surface of a building/structure. The wind load acting normal to a surface is obtained by multiplying the area of that surface or its appropriate portion by the pressure coefficient (C_p) and the design wind pressure at the height of the surface from the ground. The average values of these pressure coefficients for some building shapes are given in **4.5.3.2** and **4.5.3.3**.

Average values of pressure coefficients are given for critical wind directions in one or more quadrants. In order to determine the maximum wind load on the building/structure, the total load should be calculated for each of the critical directions shown from all quadrants. Where considerable variation of pressure occurs over a surface, it has been sub-divided and mean pressure coefficients given for each of its several parts.

In addition, areas of high local suction (negative pressure concentration) frequently occurring near the edges of walls and roofs are separately shown. Coefficients for the local effects should only be used for calculation of forces on these local areas affecting roof sheeting, glass panels and individual cladding units including their fixtures. They should not be used for calculating force on entire structural elements such as roof, walls or structure as a whole.

NOTES

1 The pressure coefficients given in different tables have been obtained mainly from measurements on models in wind tunnels and the great majority of data available has been obtained in conditions of relatively smooth flow. Where sufficient field data exists as in the case of rectangular buildings, values have been obtained to allow for turbulent flow.

2 In recent years, wall glazing and cladding design has been a source of major concern. Although of less consequence than the collapse of main structures, damage to glass can be hazardous and cause considerable financial losses.

3 For pressure coefficients for structures not covered herein, reference may be made to specialist literature on the subject or advice may be sought from specialists in the subject.

4.5.3.1 *Wind load on individual members*

When calculating the wind load on individual structural elements such as roofs and walls and individual cladding units and their fittings, it is essential to take account of the pressure difference between opposite faces of such elements or units. For clad structures, it is, therefore, necessary to know the internal pressure as well as the external pressure. Then the wind load, F (in N), acting in a direction normal to the individual structural element or cladding unit is:

$$F = (C_{pe} - C_{pi})\,A\,p_d$$

where

C_{pe} = external pressure coefficient;

C_{pi} = internal pressure coefficient;

A = surface area of structural element or cladding unit, in m^2; and

p_d = design wind pressure, in N/m^2.

NOTES

1 If the surface design pressure varies with height, the surface areas of the structural element may be sub-divided so that the specified pressures are taken over appropriate areas.

2 Positive wind load indicates the force acting towards the structural element and negative away from it.

4.5.3.2 *Internal pressure coefficients*

Internal air pressure in a building depends upon the degree of permeability of cladding to the flow of air. The internal air pressure may be positive or negative depending on the direction of flow of air in relation to openings in the buildings.

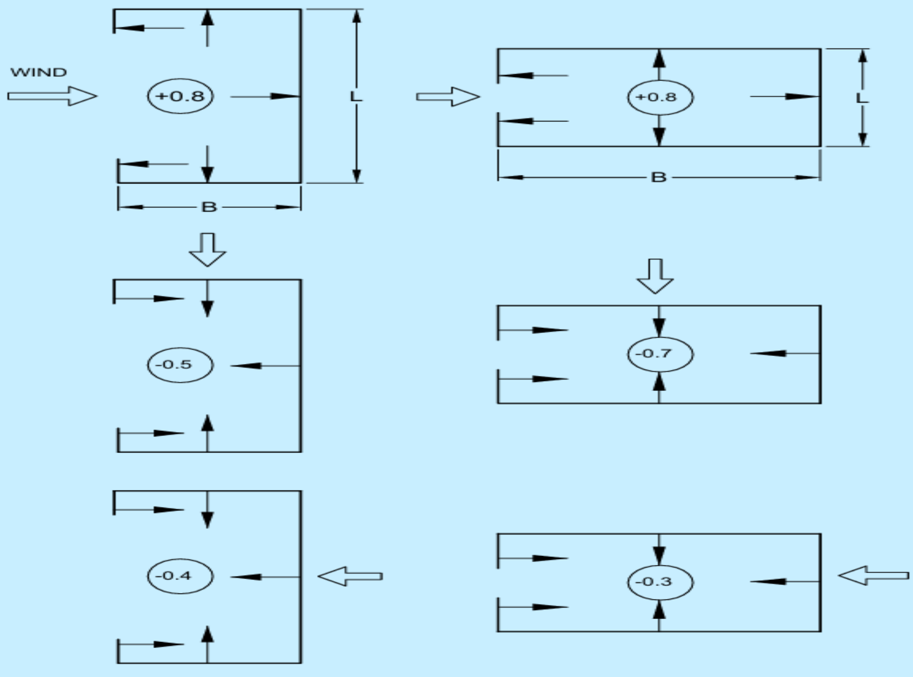
a) In the case of buildings where the claddings permit the flow of air with openings not more than about 5 percent of the wall area but where there are no large openings, it is necessary to consider the possibility of the internal pressure being positive or negative. Two design conditions shall be examined, one with an internal pressure coefficient of + 0.2 and another with an internal pressure coefficient of - 0.2.

   The internal pressure coefficient is algebraically added to the external pressure coefficient and the analysis which indicates greater distress of the member shall be adopted. In most situations a simple inspection of the sign of external pressure will at once indicate the proper sign of the internal pressure coefficient to be taken for design.

   NOTE — The term normal permeability relates to the flow of air commonly afforded by claddings not only through open windows and doors, but also through the slits round the closed windows and doors and through chimneys, ventilators and through the joints between roof coverings, the total open area being less than 5 percent of area of the walls having the openings.

b) *Buildings/structures with medium and large openings* — Buildings/structures with medium and large openings may also exhibit either positive or negative internal pressure depending upon the direction of wind. Buildings/structures with medium openings between about 5 percent to 20 percent of wall area shall be examined for an internal pressure coefficient of + 0.5 and later with an internal pressure coefficient of - 0.5 and the analysis which produces greater distress of the member shall be adopted. Buildings/structures with large openings, that is, openings larger than 20 percent of the wall area shall be examined once with an internal pressure coefficient of + 0.7 and again with an internal pressure coefficient of - 0.7 and the analysis which produces greater distress of the member shall be adopted.

Buildings/structures with one open side or opening exceeding 20 percent of wall area may be assumed to be subjected to internal positive pressure or suction similar to those of buildings with large openings. A few examples of buildings with one side openings are shown in Fig. 2 indicating values of internal pressure coefficients with respect to the direction of wind.



(a) FOR $\frac{B}{L} < 1$ (b) FOR $\frac{B}{L} > 1$

(c) FOR $\frac{B}{L} = 1$, USE AVERAGE VALUES
(ARROWS INDICATE DIRECTION OF WIND FLOW)

FIG. 2 VALUES OF INTERNAL PRESSURE COEFFICIENTS WITH RESPECT TO THE DIRECTION OF WIND FOR BUILDINGS WITH ONE SIDE OPENINGS

4.5.3.3 *External pressure coefficients*

4.5.3.3.1 *Walls*

The average external pressure coefficient for the walls of clad buildings of rectangular plan shall be as given in Table 8. In addition, local pressure concentration coefficients are also given.

4.5.3.3.2 *Pitched, hipped and monoslope roofs of clad buildings*

The average external pressure coefficients and pressure concentration coefficients for pitched roofs of rectangular clad building shall be as given in Table 9. Where no pressure concentration coefficients are given, the average coefficients shall apply. The pressure coefficients on the underside of any overhanging roof shall be taken in accordance with **4.5.3.3.5**.

NOTES

1 The pressure concentration shall be assumed to act outward (suction pressure) at the ridges, eaves, cornices and 90° corners of roofs.

2 The pressure concentration shall not be included with the net external pressure when computing overall loads.

3 For hipped roofs, pressure coefficients (including local values) may be taken on all the four slopes, as appropriate from Table 9 and be reduced by 20 percent for the hip slope.

For mono slope roofs of rectangular clad buildings, the average pressure coefficient and pressure concentration coefficient for mono slope (lean-to) roofs of rectangular clad buildings shall be as given in Table 10.

4.5.3.3.3 *Canopy roofs with* ($1/4 < h/w < 1$ *and* $1 < L/w < 3$)

The pressure coefficients are given in Table 11 and Table 12 separately for mono pitch and double pitch canopy roofs such as open-air parking garages, shelter areas, outdoor areas, railway platforms, stadiums and theatres. The coefficients take into account of the combined effect of the wind exerted on and under the roof for all wind directions; the resultant is to be taken normal to the canopy. Where the local coefficients overlap, the greater of the two given values should be taken. However, the effect of partial closures of one side and or both sides, such as those due to trains, buses and stored materials shall be foreseen and taken into account.

The solidity ratio, ϕ, is equal to the area of obstructions under the canopy divided by the gross area under the canopy, both areas normal to the wind direction. $\phi = 0$ represents a canopy with no obstructions underneath. $\phi = 1$ represents the canopy fully blocked with contents to the downwind eaves. Values of C_p for intermediate solidities may be linearly interpolated between these two extremes and apply upwind of the position of maximum blockage only. For downwind of the position of maximum blockage, the coefficients for $\phi = 0$ may be used.

In addition to the forces due to the pressures normal to the canopy, there will be horizontal loads on the canopy due to the wind pressure on any fascia and to friction over the surface of the canopy. For any wind direction, only the greater of these two forces need to be taken into account. Fascia loads should be calculated on the area of the surface facing the wind, using a force coefficient of 1.3. Frictional drag should be calculated using the coefficients given in **4.5.4.1**.

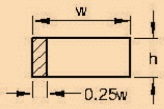
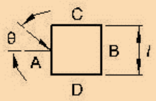
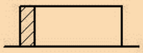
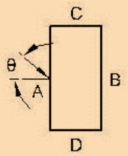
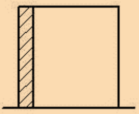
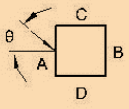
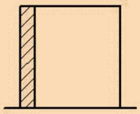
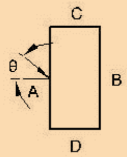
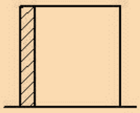
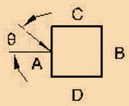
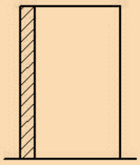
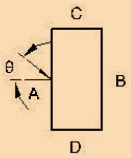
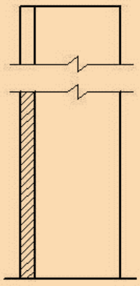
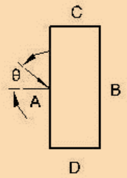
NOTE — Table 13 to Table 18 may be used to get internal and external pressure coefficients for pitches and troughed free roofs for some specific cases for which aspect ratios and roof slopes have been specified. However, while using Table 13 to Table 18 any significant departure from it should be investigated carefully. No increase shall be made for local effects except as indicated.

4.5.3.3.4 *Pitched and saw-tooth roofs of multi-span buildings*

For pitched and saw-tooth roofs of multi-span buildings, the external average pressure coefficients shall be as given in Table 19 and Table 20, respectively provided that all the spans shall be equal and the height to the eaves shall not exceed the span.

Table 8 External Pressure Coefficients (C_{pe}) for Walls of Rectangular Clad Buildings

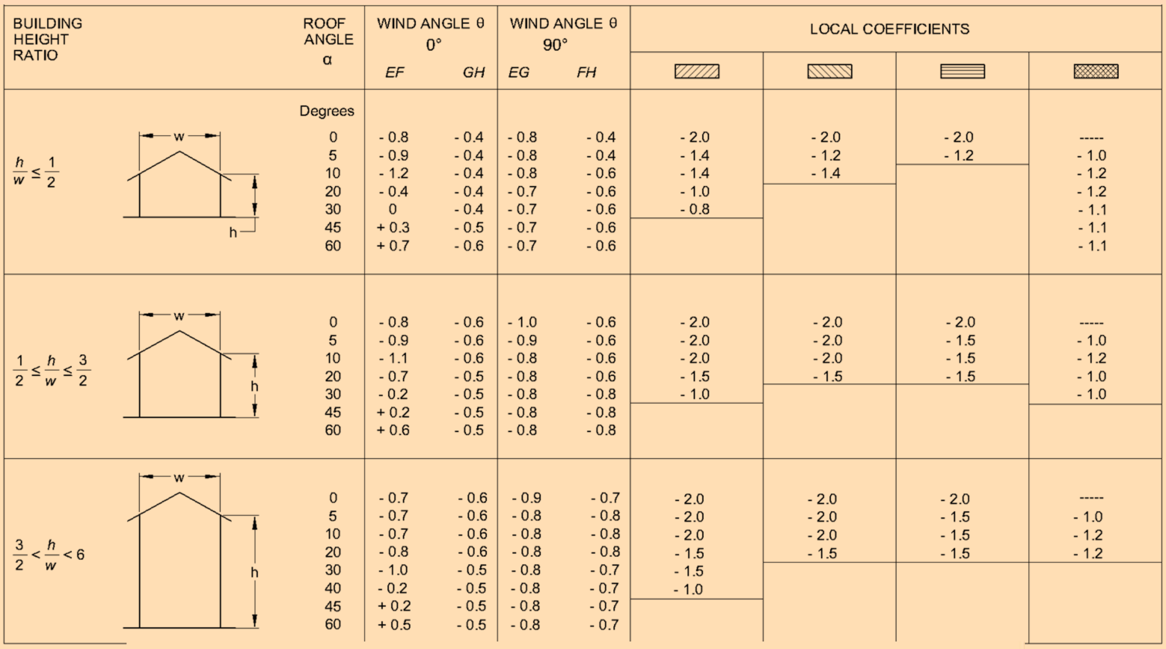
(*Clause* 4.5.3.3.1)

BUILDING HEIGHT RATIO	BUILDING PLAN RATIO	ELEVATION	PLAN	WIND ANGLE θ	C_{pe} FOR SURFACE				LOCAL C_{pe}
					A	B	C	D	▨
				Degrees					
$\frac{h}{w}\le\frac{1}{2}$	$1<\frac{l}{w}\le\frac{3}{2}$			0	+ 0.7	- 0.2	- 0.5	- 0.5	- 0.8
				90	- 0.5	- 0.5	+ 0.7	- 0.2	
	$\frac{3}{2}<\frac{l}{w}<4$			0	+ 0.7	- 0.25	- 0.6	- 0.6	- 1.0
				90	- 0.5	- 0.5	+ 0.7	- 0.1	
$\frac{1}{2}<\frac{h}{w}\le\frac{3}{2}$	$1\le\frac{l}{w}\le\frac{3}{2}$			0	+ 0.7	- 0.25	- 0.6	- 0.6	- 1.1
				90	- 0.6	- 0.6	+ 0.7	- 0.25	
	$\frac{3}{2}\le\frac{l}{w}<4$			0	+ 0.7	- 0.3	- 0.7	- 0.7	- 1.1
				90	- 0.5	- 0.5	+ 0.7	- 0.1	
$\frac{3}{2}<\frac{h}{w}<6$	$1<\frac{l}{w}\le\frac{3}{2}$			0	+ 0.8	- 0.25	- 0.8	- 0.8	- 1.2
				90	- 0.8	- 0.8	+ 0.8	- 0.25	
	$\frac{3}{2}\le\frac{l}{w}<4$			0	+ 0.7	- 0.4	- 0.7	- 0.7	- 1.2
				90	- 0.5	- 0.5	+ 0.8	- 0.1	
$\frac{h}{w}\ge 6$	$\frac{l}{w}=\frac{3}{2}$			0	+ 0.95	- 1.85	- 0.9	- 0.9	1.25
				90	- 0.8	- 0.8	+ 0.9	- 0.85	
	$\frac{l}{w}=1.0$			0	+ 0.95	- 1.25	- 0.7	- 0.7	1.25
				90	- 0.7	- 0.7	+ 0.95	- 1.25	
	$\frac{l}{w}=2$			0	+ 0.85	- 0.75	- 0.75	- 0.75	1.25
				90	- 0.75	- 0.75	+ 0.85	- 0.75	

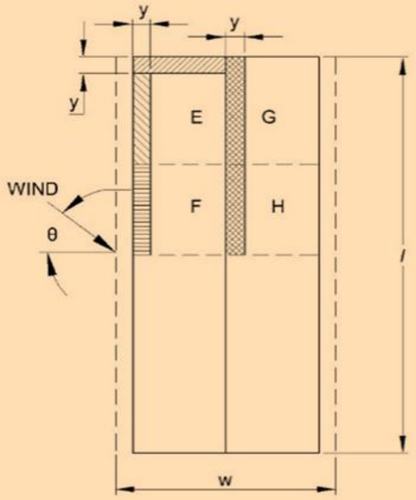
NOTE : *h* is the height to eaves or parapet, *l* is the greater horizontal dimension of a building and *w* is the lesser horizontal dimension of a building.

Table 9 External Pressure Coefficients (C_{pe}) for Pitched Roofs of Rectangular Clad Buildings

(*Clause* 4.5.3.3.2)



BUILDING HEIGHT RATIO	ROOF ANGLE α	WIND ANGLE θ 0°		WIND ANGLE θ 90°		LOCAL COEFFICIENTS			
		EF	*GH*	*EG*	*FH*	▨	▧	▤	▩
	Degrees								
$\frac{h}{w} \leq \frac{1}{2}$	0	- 0.8	- 0.4	- 0.8	- 0.4	- 2.0	- 2.0	- 2.0	-----
	5	- 0.9	- 0.4	- 0.8	- 0.4	- 1.4	- 1.2	- 1.2	- 1.0
	10	- 1.2	- 0.4	- 0.8	- 0.6	- 1.4	- 1.4		- 1.2
	20	- 0.4	- 0.4	- 0.7	- 0.6	- 1.0			- 1.2
	30	0	- 0.4	- 0.7	- 0.6	- 0.8			- 1.1
	45	+ 0.3	- 0.5	- 0.7	- 0.6				- 1.1
	60	+ 0.7	- 0.6	- 0.7	- 0.6				- 1.1
$\frac{1}{2} \leq \frac{h}{w} \leq \frac{3}{2}$	0	- 0.8	- 0.6	- 1.0	- 0.6	- 2.0	- 2.0	- 2.0	-----
	5	- 0.9	- 0.6	- 0.9	- 0.6	- 2.0	- 2.0	- 1.5	- 1.0
	10	- 1.1	- 0.6	- 0.8	- 0.6	- 2.0	- 2.0	- 1.5	- 1.2
	20	- 0.7	- 0.5	- 0.8	- 0.6	- 1.5	- 1.5	- 1.5	- 1.0
	30	- 0.2	- 0.5	- 0.8	- 0.8	- 1.0			- 1.0
	45	+ 0.2	- 0.5	- 0.8	- 0.8				
	60	+ 0.6	- 0.5	- 0.8	- 0.8				
$\frac{3}{2} < \frac{h}{w} < 6$	0	- 0.7	- 0.6	- 0.9	- 0.7	- 2.0	- 2.0	- 2.0	-----
	5	- 0.7	- 0.6	- 0.8	- 0.8	- 2.0	- 2.0	- 1.5	- 1.0
	10	- 0.7	- 0.6	- 0.8	- 0.8	- 2.0	- 2.0	- 1.5	- 1.2
	20	- 0.8	- 0.6	- 0.8	- 0.8	- 1.5	- 1.5	- 1.5	- 1.2
	30	- 1.0	- 0.5	- 0.8	- 0.7	- 1.5			
	40	- 0.2	- 0.5	- 0.8	- 0.7	- 1.0			
	45	+ 0.2	- 0.5	- 0.8	- 0.7				
	60	+ 0.5	- 0.5	- 0.8	- 0.7				



KEY PLAN

y = *h* or 0.15 *w*

Whichever is the lesser.

NOTE - 1 *h* is the height to eaves or parapet and *w* is the lesser horizontal dimension of a building.

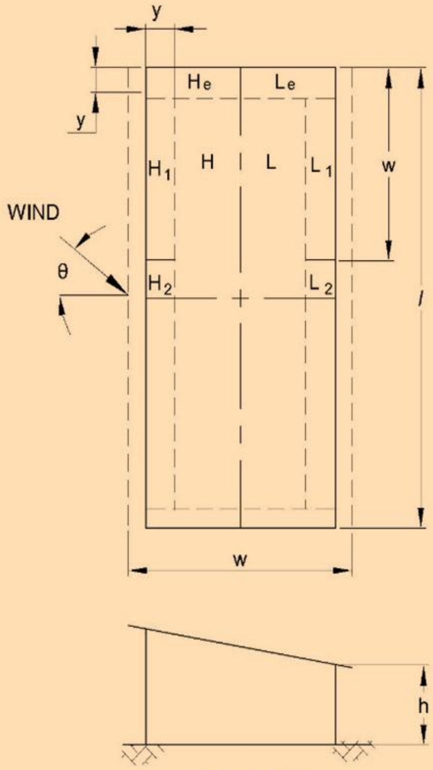
NOTE - 2 Where no local coefficients are given, the overall coefficient apply.

NOTE - 3 For hipped roofs the local coefficient for the hip ridge may be conservatively taken as the the appropriate ridge value.

NOTE - 4 *w* and *l* are dimensions between the walls excluding overhangs.

Table 10 External Pressure Coefficients (C_{pe}) for Monoslope Roofs for Rectangular Clad Buildings $\frac{h}{w}<2$

(*Clause* 4.5.3.3.2)



y = *h* or 0.15 *w*

Whichever is the lesser.

NOTE :- Area *H* and area *L* refer to the whole quadrant.

ROOF ANGLE α	WIND ANGLE θ										LOCAL COEFFICIENTS (C_{pe})					
	0°		45°		90°		135°		180°							
	H	*L*	*H*	*L*	*H* & *L* *	*H* & *L* **	*H*	*L*	*H*	*L*	H_1	H_2	L_1	L_2	H_e	L_e
Degrees																
5	- 1.0	- 0.5	- 1.0	- 0.9	- 1.0	- 0.5	- 0.9	- 1.0	- 0.5	- 1.0	- 2.0	- 1.5	- 2.0	- 1.5	- 2.0	- 2.0
10	- 1.0	- 0.5	- 1.0	- 0.8	- 1.0	- 0.5	- 0.8	- 1.0	- 0.4	- 1.0	- 2.0	- 1.5	- 2.0	- 1.5	- 2.0	- 2.0
15	- 0.9	- 0.5	- 1.0	- 0.7	- 1.0	- 0.5	- 0.6	- 1.0	- 0.3	- 1.0	- 1.8	- 0.9	- 1.8	- 1.4	- 2.0	- 2.0
20	- 0.8	- 0.5	- 1.0	- 0.6	- 0.9	- 0.5	- 0.5	- 1.0	- 0.2	- 1.0	- 1.8	- 0.8	- 1.8	- 1.4	- 2.0	- 2.0
25	- 0.7	- 0.5	- 1.0	- 0.6	- 0.8	- 0.5	- 0.3	- 0.9	- 0.1	- 0.9	- 1.8	- 0.7	- 0.9	- 0.9	- 2.0	- 2.0
30	- 0.5	- 0.5	- 1.0	- 0.6	- 0.8	- 0.5	- 0.1	- 0.6	0	- 0.6	- 1.8	- 0.5	- 0.5	- 0.5	- 2.0	- 2.0

* Applied to length *w* / 2 from wind-ward end.

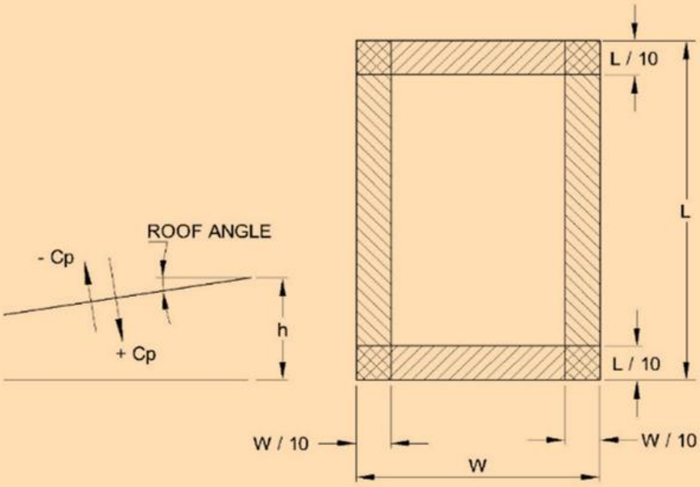
** Applies to remainder

NOTE :- 1 *h* is the height of eaves at lower side, *l* is the greater horizontal dimensions of a building and *w* is the lesser horizontal dimension of a building.

NOTE :- 2 l and w are overall length and width including overhangs,

Table 11 Pressure Coefficients for Monoslope Free Roofs

(*Clause* 4.5.3.3.3)



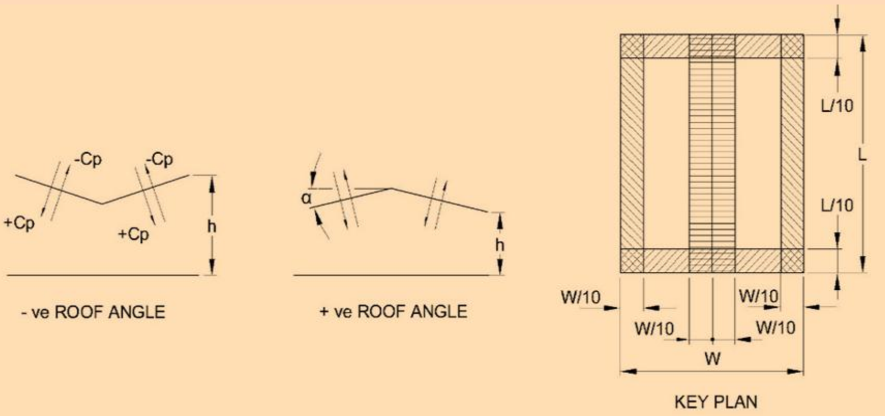
ROOF ANGLE (Degrees) α	SOLIDITY RATIO Φ	MAXIMUM (LARGEST + ve) AND MINIMUM (LARGEST - ve) PRESSURE COEFFICIENTS			
		OVERALL COEFFICIENTS	LOCAL COEFFICIENTS		
			▭	▨	▧
0	All values of Φ	+ 0.2	+ 0.5	+ 1.8	+ 1.1
5		+ 0.4	+ 0.8	+ 2.1	+ 1.3
10		+ 0.5	+ 1.2	+ 2.4	+ 1.6
15		+ 0.7	+ 1.4	+ 2.7	+ 1.8
20		+ 0.8	+ 1.7	+ 2.9	+ 2.1
25		+ 1.0	+ 2.0	+ 3.1	+ 2.3
30		+ 1.2	+ 2.2	+ 3.2	+ 2.4
0	Φ = 0	- 0.5	- 0.6	- 1.3	- 1.4
	Φ = 1	- 1.0	- 1.2	- 1.8	- 1.9
5	Φ = 0	- 0.7	- 1.1	- 1.7	- 1.8
	Φ = 1	- 1.1	- 1.6	- 2.2	- 2.3
10	Φ = 0	- 0.9	- 1.5	- 2.0	- 2.1
	Φ = 1	- 1.3	- 2.1	- 2.6	- 2.7
15	Φ = 0	- 1.1	- 1.8	- 2.4	- 2.5
	Φ = 1	- 1.4	- 2.3	- 2.9	- 3.0
20	Φ = 0	- 1.3	- 2.2	- 2.8	- 2.9
	Φ = 1	- 1.5	- 2.6	- 3.1	- 3.2
25	Φ = 0	- 1.6	- 2.6	- 3.2	- 3.2
	Φ = 1	- 1.7	- 2.8	- 3.5	- 3.5
30	Φ = 0	- 1.8	- 3.0	- 3.8	- 3.6
	Φ = 1	- 1.8	- 3.0	- 3.8	- 3.6

NOTE 1: For monopitch canopies the centre of pressure should be taken to act at 0.3 w from the windward edge.

NOTE 2: W and L are overall width and length including overhangs,

Table 12 Pressure Coefficients for Free Standing Double Sloped Roofs

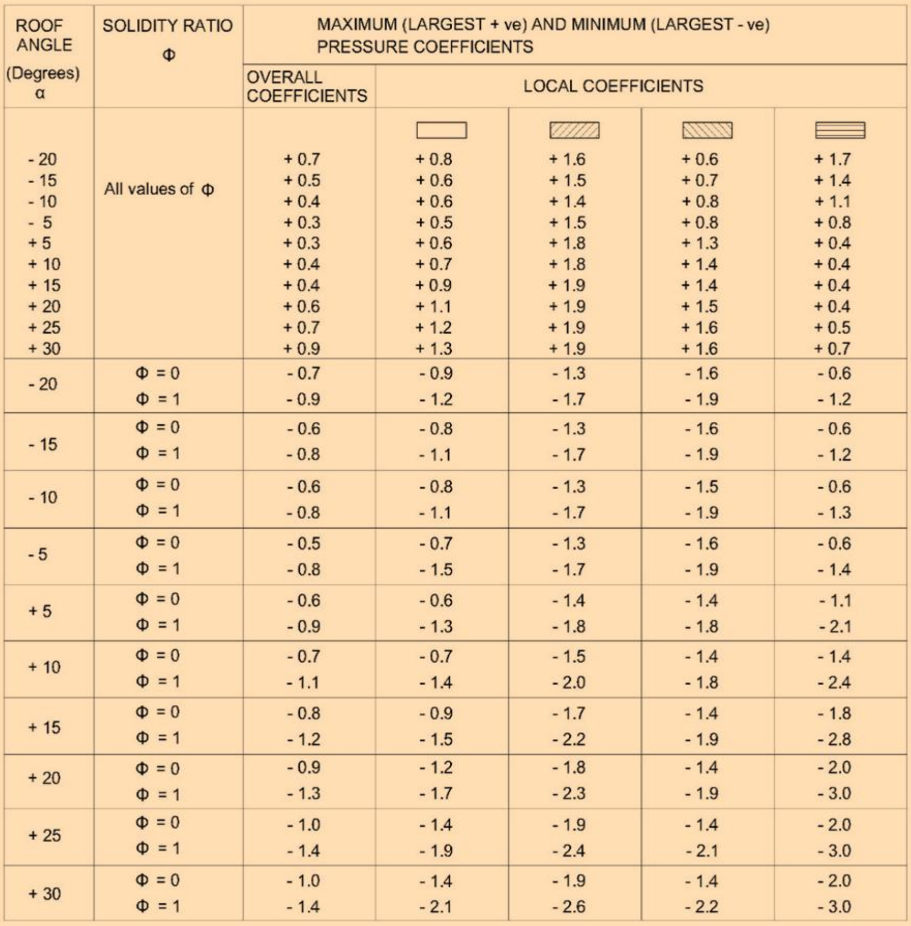
(*Clause* 4.5.3.3.3)



- ve ROOF ANGLE

+ ve ROOF ANGLE

KEY PLAN



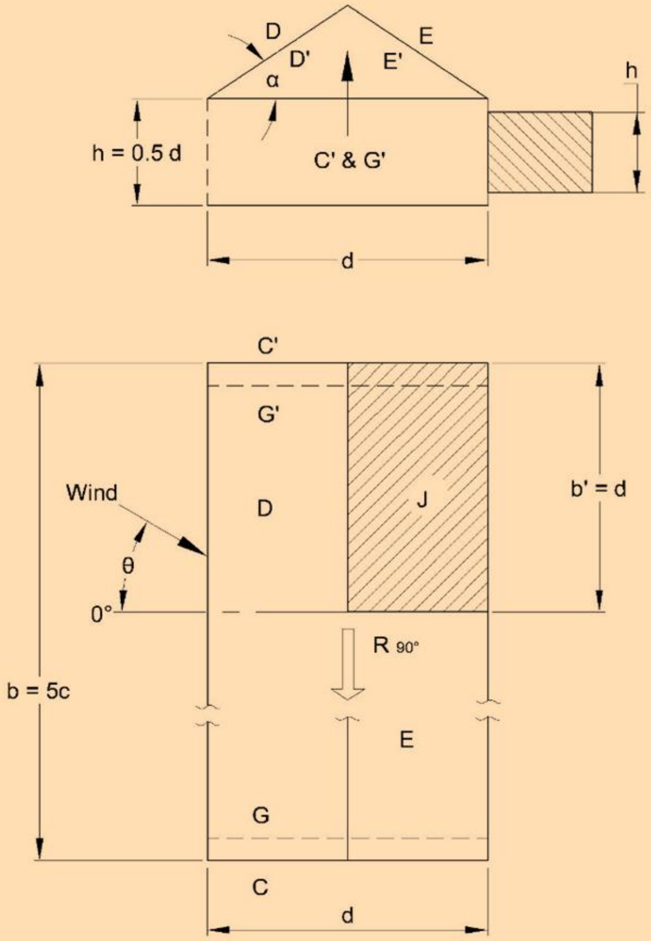
ROOF ANGLE (Degrees) α	SOLIDITY RATIO Φ	MAXIMUM (LARGEST + ve) AND MINIMUM (LARGEST - ve) PRESSURE COEFFICIENTS				
		OVERALL COEFFICIENTS	LOCAL COEFFICIENTS			
			▭	▨	▧	▤
- 20	All values of Φ	+ 0.7	+ 0.8	+ 1.6	+ 0.6	+ 1.7
- 15		+ 0.5	+ 0.6	+ 1.5	+ 0.7	+ 1.4
- 10		+ 0.4	+ 0.6	+ 1.4	+ 0.8	+ 1.1
- 5		+ 0.3	+ 0.5	+ 1.5	+ 0.8	+ 0.8
+ 5		+ 0.3	+ 0.6	+ 1.8	+ 1.3	+ 0.4
+ 10		+ 0.4	+ 0.7	+ 1.8	+ 1.4	+ 0.4
+ 15		+ 0.4	+ 0.9	+ 1.9	+ 1.4	+ 0.4
+ 20		+ 0.6	+ 1.1	+ 1.9	+ 1.5	+ 0.4
+ 25		+ 0.7	+ 1.2	+ 1.9	+ 1.6	+ 0.5
+ 30		+ 0.9	+ 1.3	+ 1.9	+ 1.6	+ 0.7
- 20	Φ = 0	- 0.7	- 0.9	- 1.3	- 1.6	- 0.6
	Φ = 1	- 0.9	- 1.2	- 1.7	- 1.9	- 1.2
- 15	Φ = 0	- 0.6	- 0.8	- 1.3	- 1.6	- 0.6
	Φ = 1	- 0.8	- 1.1	- 1.7	- 1.9	- 1.2
- 10	Φ = 0	- 0.6	- 0.8	- 1.3	- 1.5	- 0.6
	Φ = 1	- 0.8	- 1.1	- 1.7	- 1.9	- 1.3
- 5	Φ = 0	- 0.5	- 0.7	- 1.3	- 1.6	- 0.6
	Φ = 1	- 0.8	- 1.5	- 1.7	- 1.9	- 1.4
+ 5	Φ = 0	- 0.6	- 0.6	- 1.4	- 1.4	- 1.1
	Φ = 1	- 0.9	- 1.3	- 1.8	- 1.8	- 2.1
+ 10	Φ = 0	- 0.7	- 0.7	- 1.5	- 1.4	- 1.4
	Φ = 1	- 1.1	- 1.4	- 2.0	- 1.8	- 2.4
+ 15	Φ = 0	- 0.8	- 0.9	- 1.7	- 1.4	- 1.8
	Φ = 1	- 1.2	- 1.5	- 2.2	- 1.9	- 2.8
+ 20	Φ = 0	- 0.9	- 1.2	- 1.8	- 1.4	- 2.0
	Φ = 1	- 1.3	- 1.7	- 2.3	- 1.9	- 3.0
+ 25	Φ = 0	- 1.0	- 1.4	- 1.9	- 1.4	- 2.0
	Φ = 1	- 1.4	- 1.9	- 2.4	- 2.1	- 3.0
+ 30	Φ = 0	- 1.0	- 1.4	- 1.9	- 1.4	- 2.0
	Φ = 1	- 1.4	- 2.1	- 2.6	- 2.2	- 3.0

Each slope of a duopitch canopy should be able to withstand forces using both the maximum and the minimum coefficients, and the whole canopy should be able to support forces using one slope at the maximum coefficient with the other slope at the minimum coefficient. For duoptich canopies the centre of pressure should be taken to act at the centre of each slope.

Note :- W and L are overall width and length including overhangs

Table 13 Pressure Coefficients (Top and Bottom) for Pitched Roofs, Roof Slope,

(*Clause* 4.5.3.3.3)



Roof slope α = 30°

θ = 0°- 45°, *D, D', E, E'* full length.

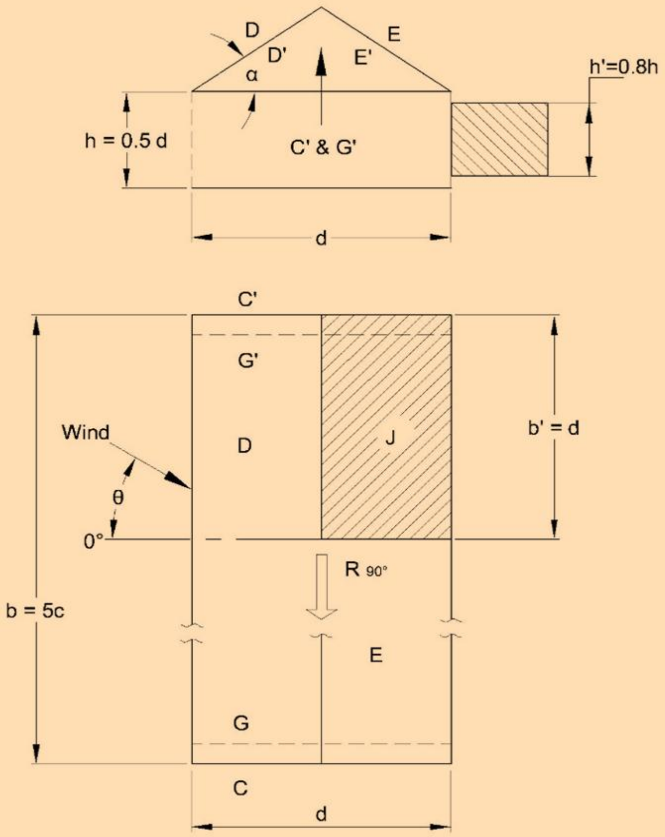
θ = 90°, *D, D', E, E'* part length.

b', thereafter $C_p = 0$

θ	PRESSURE COEFFICIENTS, C_p							
					END SURFACES			
	D	*D'*	*E*	*E'*	*C*	*C'*	*G*	*G'*
0°	+ 0.6	- 1.0	- 0.5	- 0.9				
45°	+ 0.1	- 0.3	- 0.6	- 0.3				
90°	- 0.3	- 0.4	- 0.3	- 0.4	- 0.3	- 0.8	- 0.3	- 0.4
For all value of θ	For J : C_p Top = 1.0, C_p bottom = - 0.2 Tangentially acting friction : $R_{90°} = 0.05\, p_d\, bd$							

Table 14 Pressure Coefficients (Top and Bottom) for Pitched Free Roofs, $\alpha = 30^\circ$ With Effects of Train or Stored Materials

(*Clause* 4.5.3.3.3)

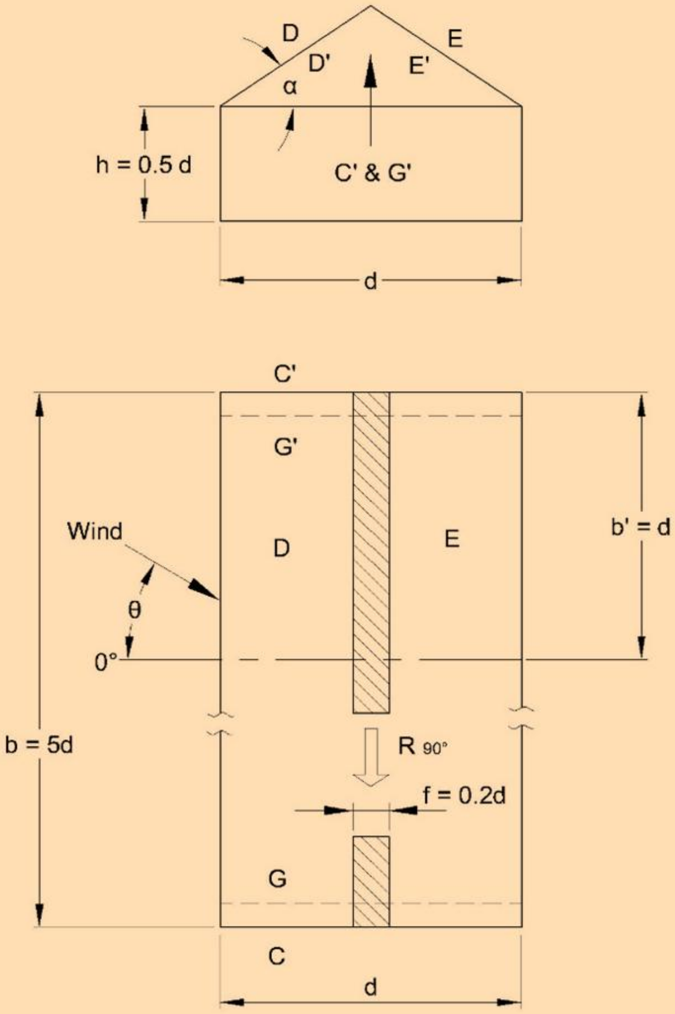


Roof slope α = 30°
Effects of trains or stored materials.
θ = 0°- 45°, or 135° - 180°, *D, D', E, E'* full length.
θ = 90°, *D, D', E, E'* part length.
b', thereafter $C_p = 0$

θ	PRESSURE COEFFICIENTS, C_p							
					END SURFACES			
	D	*D'*	*E*	*E'*	*C*	*C'*	*G*	*G'*
0°	+ 0.1	+ 0.8	- 0.7	+ 0.9	- 0.3	+ 0.8	+ 0.3	- 0.4
45°	- 0.1	+ 0.5	- 0.8	+ 0.5				
90°	- 0.4	- 0.5	- 0.4	- 0.5				
180°	- 0.3	- 0.6	+ 0.4	- 0.6				
For all value of θ	For J : C_p Top = -1.5, C_p bottom = 0.5 Tangentially acting friction : $R_{90^\circ} = 0.05\, p_d\, bd$							

Table 15 Pressure Coefficients (Top and Bottom) for Pitched Free Roofs, $\alpha = 10^\circ$

(*Clause* 4.5.3.3.3)



Roof slope α = 10°

θ = 0°- 45°, *D, D', E, E'* full length.

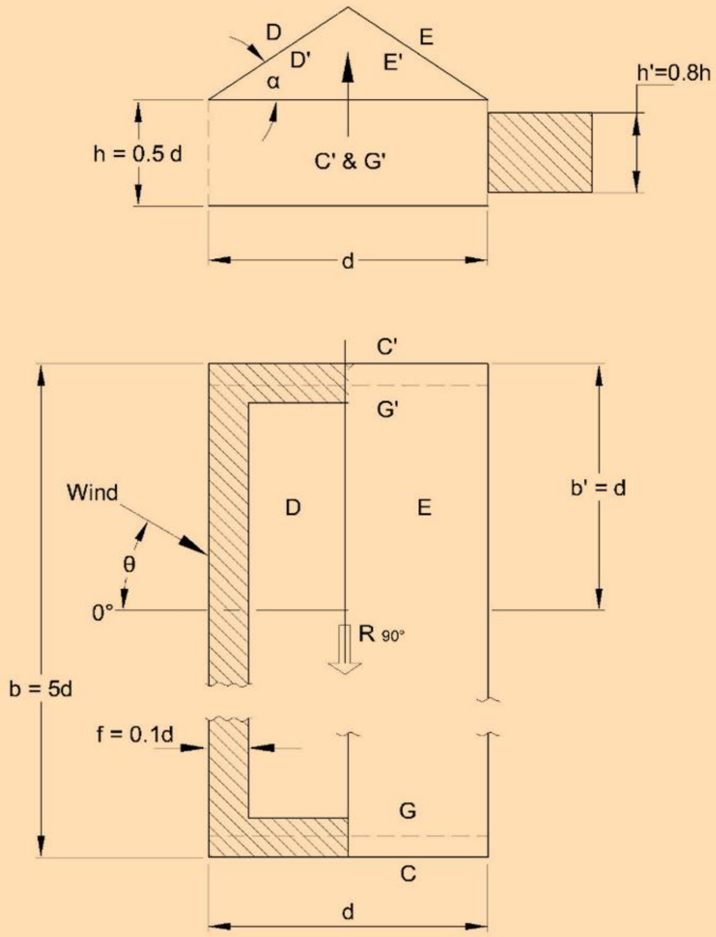
θ = 90°, *D, D', E, E'* part length.

b', thereafter $C_p = 0$

θ	PRESSURE COEFFICIENTS, C_p							
	D	*D'*	*E*	*E'*	END SURFACES			
					C	*C'*	*G*	*G'*
0°	- 1.0	+ 0.3	- 0.5	+ 0.2				
45°	- 0.3	+ 0.1	- 0.3	+ 0.1				
90°	- 0.3	0	- 0.3	0	- 0.4	+ 0.8	+ 0.3	- 0.6
For all value of θ	For *f* : C_p Top = - 1.0, C_p bottom = 0.4 Tangentially acting friction : $R_{90^\circ} = 0.1\, p_d\, bd$							

Table 16 Pressure Coefficients (Top and Bottom) for Pitched Free Roofs, $\alpha = 10^\circ$ With Effects of Train or Stored Materials

(*Clause* 4.5.3.3.3)

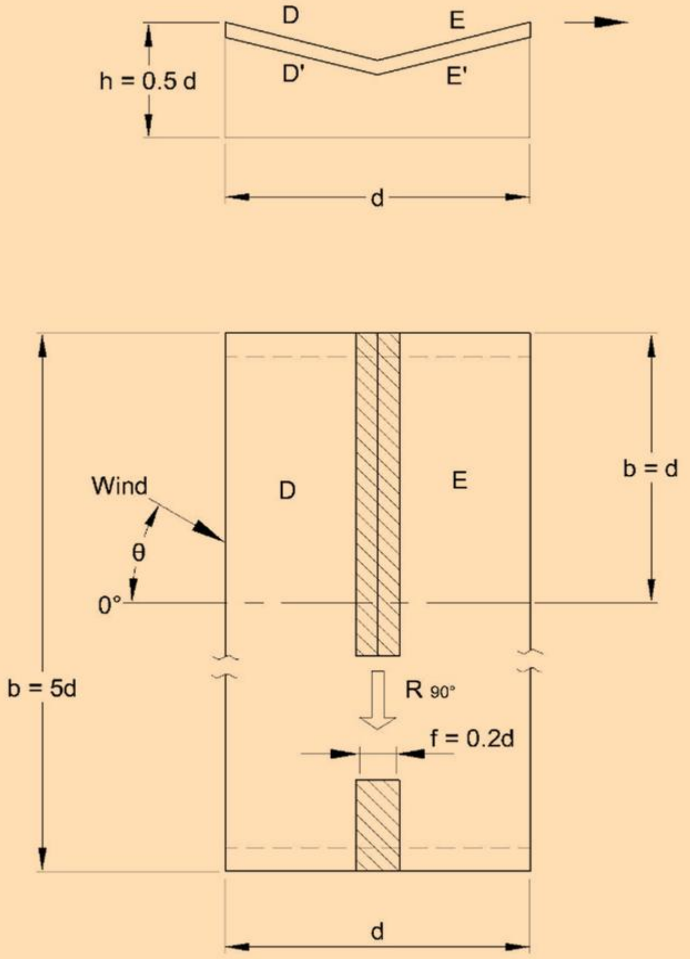


Roof slope α = 10°
Effects of trains or stored materials.
θ = 0°- 45°, or 135° - 180°, *D, D', E, E'* full length.
θ = 90°, *D, D', E, E'* part length.
b', thereafter $C_p = 0$

θ	PRESSURE COEFFICIENTS, C_p							
	D	*D'*	*E*	*E'*	END SURFACES			
					C	*C'*	*G*	*G'*
0°	- 1.3	+ 0.8	- 0.6	0.7	- 0.4	+ 0.8	+ 0.3	- 0.6
45°	- 0.5	+ 0.4	- 0.3	+ 0.3				
90°	- 0.3	0	- 0.3	0				
180°	- 0.4	- 0.3	- 0.6	- 0.3				
For all value of θ	For *f* : C_p Top = -1.6, C_p bottom = - 0.9 Tangentially acting friction : $R_{90^\circ} = 0.1\, p_d\, bd$							

Table 17 Pressure Coefficients for Troughed Free Roofs, $\alpha = 10^\circ$

(*Clause* 4.5.3.3.3)



Roof slope $\alpha = 10^\circ$

$\theta = 0^\circ - 45^\circ$, *D, D′, E, E′* full length.

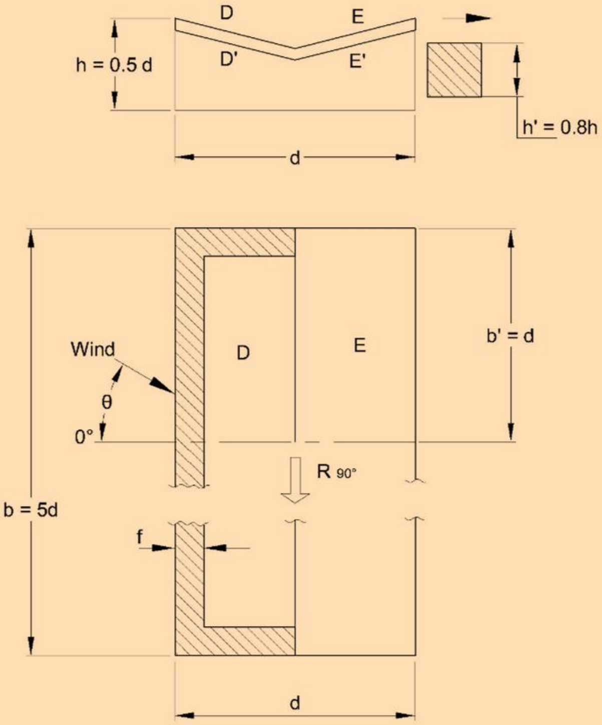
$\theta = 90^\circ$, *D, D′, E, E′* part length.

b′, thereafter $C_p = 0$

θ	PRESSURE COEFFICIENTS, C_p			
	D	*D′*	*E*	*E′*
0°	+ 0.3	- 0.7	+ 0.2	- 0.9
45°	0	- 0.2	+ 0.1	- 0.3
90°	- 0.1	0.1	- 0.1	+ 0.1
For all value of θ	For *f* : C_p Top = 0.4, C_p bottom = - 1.5 Tangentially acting friction : $R_{90^\circ} = 0.1\, p_d\, bd$			

Table 18 Pressure Coefficients (Top and Bottom) for Troughed Free Roofs, $\alpha = 10^\circ$ With Effects of Train or Stored Material

(*Clause* 4.5.3.3.3)

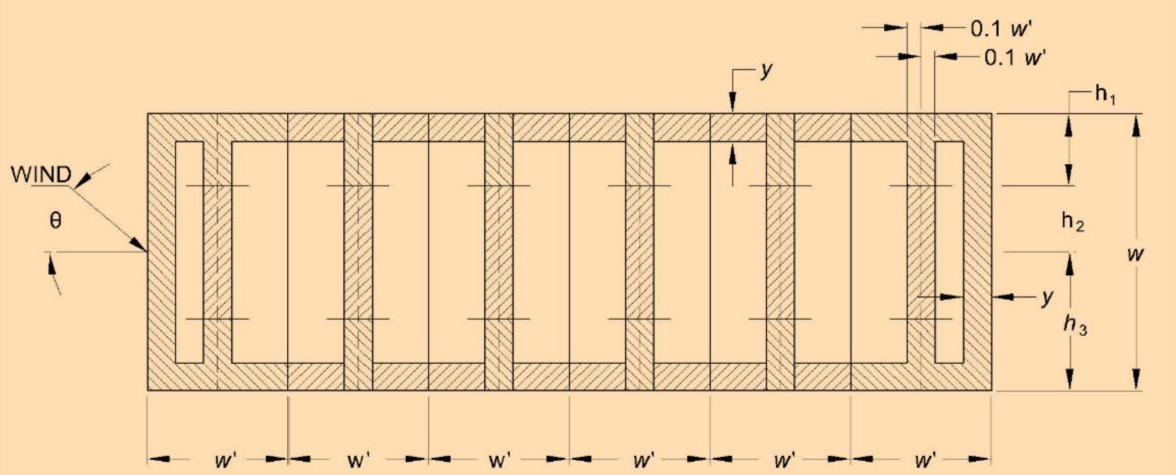


Roof slope $\alpha = 10^\circ$
Effects of trains or stored materials.
$\theta = 0^\circ - 45^\circ$, or $135^\circ - 180^\circ$, *D, D', E, E'* full length.
$\theta = 90^\circ$, *D, D', E, E'* part length.
b', thereafter $C_p = 0$

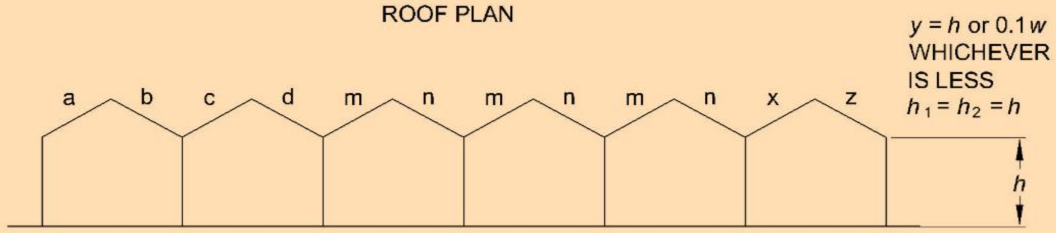
θ	PRESSURE COEFFICIENTS, C_p			
	D	*D'*	*E*	*E'*
0°	- 0.7	+ 0.8	- 0.6	+ 0.6
45°	- 0.4	+ 0.3	- 0.2	+ 0.2
90°	- 0.1	+ 0.1	- 0.1	+ 0.1
180°	- 0.4	- 0.2	- 0.6	- 0.3
For all value of θ	For *f* : C_p Top = -1.1, C_p bottom = 0.9 Tangentially acting friction : $R_{90^\circ} = 0.1\, p_d\, bd$			

Table 19 External Pressure Coefficients (C_{pe}) for Pitched Roofs of Multi-span Buildings (All Spans Equal) with $h < w'$

(*Clause* 4.5.3.3.4)



ROOF PLAN



SECTION

ROOF ANGLE	WIND ANGLE	FIRST SPAN		FIRST INTERMEDIATE SPAN		OTHER INTERMEDIATE SPANS		END SPAN		LOCAL COEFFICIENT	
α Degrees	θ Degrees	a	b	c	d	m	n	x	z	▧	▨
5	0	- 0.9	- 0.6	- 0.4	- 0.3	- 0.3	- 0.3	- 0.3	- 0.3	- 2.0	- 1.5
10		- 1.1	- 0.6	- 0.4	- 0.3	- 0.3	- 0.3	- 0.3	- 0.4		
20		- 0.7	- 0.6	- 0.4	- 0.3	- 0.3	- 0.3	- 0.3	- 0.5		
30		- 0.2	- 0.6	- 0.4	- 0.3	- 0.2	- 0.3	- 0.2	- 0.5		
45		+ 0.3	- 0.6	- 0.6	- 0.4	- 0.2	- 0.4	- 0.2	- 0.5		
DISTANCE											
ROOF ANGLE α DEGREES		WIND ANGLE θ DEGREES		h_1		h_2		h_3			
UP TO 45		90		- 0.8		- 0.6		- 0.2			

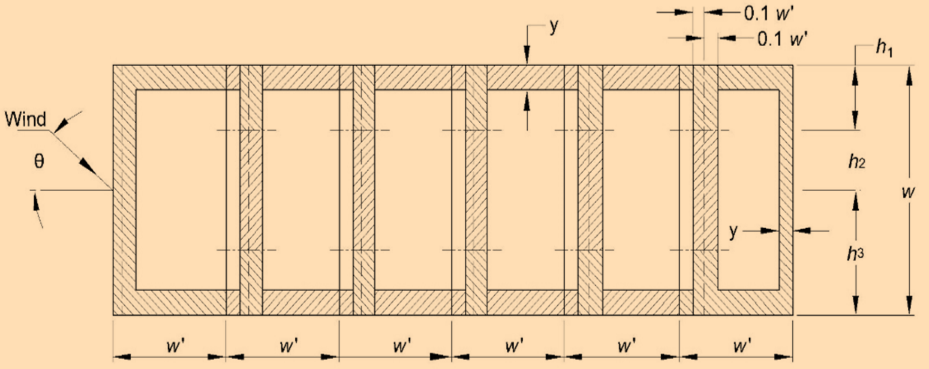
Frictional drag : When wind angle θ = 0°, horizontal forces due to frictional drag are allowed for in the above values, and

When wind angle θ = 90°, allow for frictional drag in accordance with **4.5.4.1**

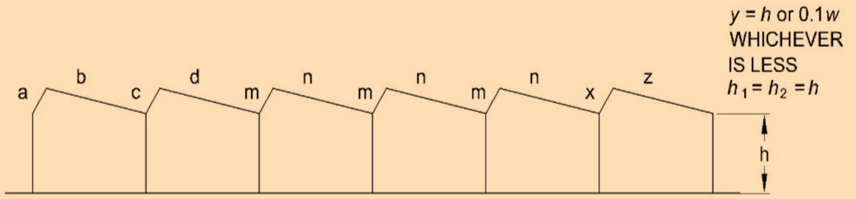
NOTE — Evidence on these buildings is fragmentary and any departure from the cases given should be investigated separately.

Table 20 External Pressure Coefficients (Cpe) for Saw Tooth Roofs of Multi-Span Buildings (All Spans Equal) with h < w'

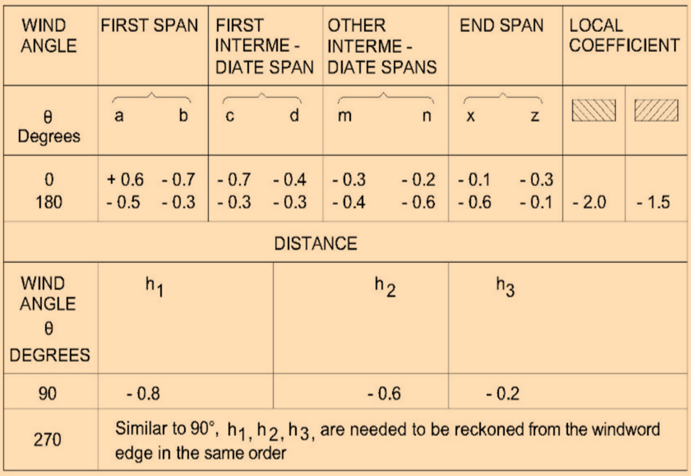
(*Clause* 4.5.3.3.4)



ROOF PLAN



SECTION



WIND ANGLE	FIRST SPAN		FIRST INTERME - DIATE SPAN		OTHER INTERME - DIATE SPANS		END SPAN		LOCAL COEFFICIENT	
θ Degrees	a	b	c	d	m	n	x	z	▧	▨
0	+ 0.6	- 0.7	- 0.7	- 0.4	- 0.3	- 0.2	- 0.1	- 0.3		
180	- 0.5	- 0.3	- 0.3	- 0.3	- 0.4	- 0.6	- 0.6	- 0.1	- 2.0	- 1.5

DISTANCE

WIND ANGLE θ DEGREES	h_1	h_2	h_3
90	- 0.8	- 0.6	- 0.2
270	Similar to 90°, h_1, h_2, h_3, are needed to be reckoned from the windword edge in the same order		

Frictional drag : When wing angle θ = 0°, horizontal forces due to frictional drag are allowed for in the above values, and

When wind angle θ = 90˚, allow for frictional drag in accordance with **4.5.4.1**

NOTE — Evidence on these buildings is fragmentary and any departure from the cases given should be investigated separately.

4.5.3.3.5 *Pressure coefficients on overhangs from roofs*

The pressure coefficients on the top overhanging portion of the roofs shall be taken to be the same as that of the nearest top portion of the non-overhanging portion of the roofs. The pressure coefficients for the underside surface of the overhanging portions shall be taken as follows and shall be taken as positive, if the overhanging portion is on the windward side:

a) 1.25, if the overhanging slopes downwards;

b) 1.00, if the overhanging is horizontal; and

c) 0.75, if the overhanging slopes upwards.

For overhanging portions on sides other than windward side, the average pressure coefficients on adjoining walls may be used.

4.5.3.3.6 *Curved roofs*

For curved roofs the external pressure coefficients shall be as given in Table 21. Allowance for local effects shall be made in accordance with Table 9. Two values of C_2 have been given for elevated curved roofs. Both the load cases have to be analysed and critical load effects are to be considered in design.

4.5.3.3.7 *Cylindrical structures*

For the purpose of calculating the wind pressure distribution around a cylindrical structure of circular cross section, the value of external pressure coefficients given in Table 22 may be used, provided that the Reynolds number is more than 10 000. They may be used for wind blowing normal to the axis of cylinders having axis normal to the ground plane and cylinders having their axis parallel to the ground plane. 'h' is height of a vertical cylinder or length of a horizontal cylinder. Where there is a free flow of air around both ends, h is to be taken as half the length when calculating h/D ratio.

In the calculation of resultant load on the periphery of the cylinder, the value of C_{pi} shall be taken into account. For open ended cylinders, C_{pi} shall be taken as follows:

a) - 0.8, where h/D is more than or equal to 0.3; and

b) - 0.5, where h/D is less than 0.3.

4.5.3.3.8 *Roofs and bottoms of cylindrical elevated structures*

The external pressure coefficients for roofs and bottoms of cylindrical elevated structures shall be as given in Table 23. Alternately, the pressure distribution given in Fig. 3 can be used together with the force coefficients given in Table 28 for the cylindrical portion.

4.5.3.3.9 *Combined roofs*

The average external pressure coefficients for combined roofs are shown in Table 24.

4.5.3.3.10 *Roofs with skylight*

The average external pressure coefficients for roofs with skylight are shown in Table 25.

4.5.3.3.11 *Grandstands*

The pressure coefficients on the roof (top and bottom) and rear wall of a typical grandstand roof which is open on three sides are given in Table 26. The pressure coefficients are valid for a particular ratio of dimensions as specified in Table 24 but may be used for deviations up to 20 percent. In general, the maximum wind load occurs when the wind is blowing into the open front of the stand, causing positive pressure under the roof and negative pressure on the roof.

4.5.3.3.12 *Spheres*

The external pressure coefficients for spheres shall be as given in Table 27.

4.5.3.3.13 *Frames*

When taking wind loads on frames of clad buildings it is reasonable to assume that the pressures or suctions inside and outside the structure shall not be fully correlated. Therefore, when taking the combined effect of wind loads on the frame, a reduction factor of $K_c = 0.90$ may be used over the building envelope when roof is subjected to pressure and internal pressure is suction, or *vice-versa*.

4.5.4 *Force Coefficients*

The value of force coefficients (C_f) apply to a building or structure as a whole and when multiplied by the effective frontal area (A_e) of the building or structure and design wind pressure, p_d gives the total wind load (F) on that particular building or structure, expressed as:

$$F = C_f A_e p_d$$

where

F = force acting in a direction specified in the respective tables; and

C_f = force coefficient for the building.

NOTES

1 The value of the force coefficient differs for the wind acting on different faces of a building or structure. In order to determine the critical load, the total wind load should be calculated for each wind direction.

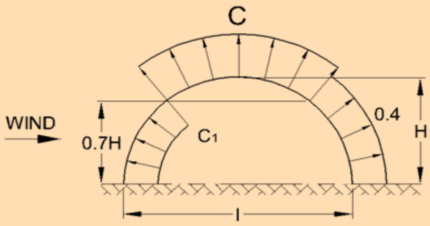
2 If surface design pressure varies with height, the surface area of the building/structure may be sub-divided so that specified pressures are taken over appropriate areas.

3 In tapered buildings/structures, the force coefficients shall be applied after sub-dividing the building/structure into suitable number of strips and the load on each strip calculated individually, taking the area of each strip as A_e.

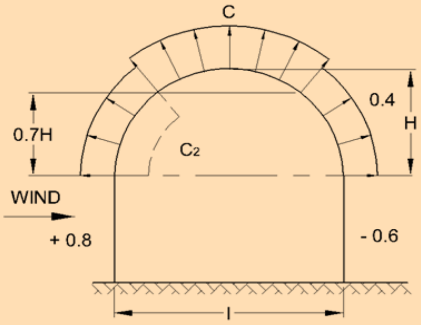
4 For force coefficients for structures not covered herein, reference may be made to specialist literature on the subject or advice may be sought from specialist in the subject.

Table 21 External Pressure Coefficients (Cpe) for Curved Roofs

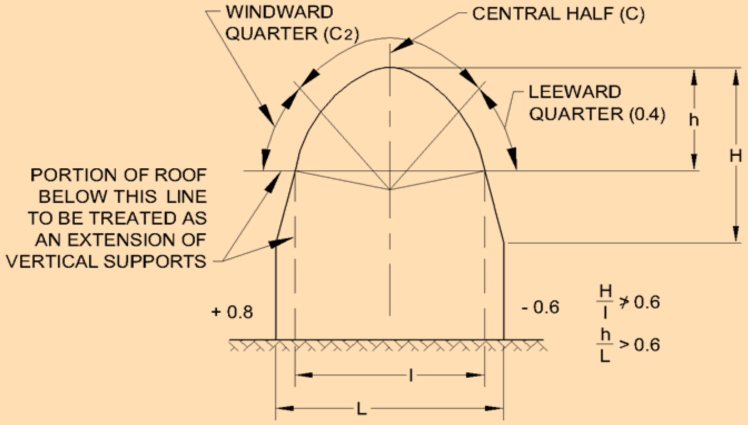
(*Clause* 4.5.3.3.6)


C
WIND
0.7H
C_1
0.4
H
l

a) ROOF SPRINGING FROM GROUND LEVEL


C
0.7H
C_2
0.4
H
WIND
+ 0.8
- 0.6
l

b) ROOF ON ELEVATED STRUCTURE


WINDWARD QUARTER (C_2)
CENTRAL HALF (C)
LEEWARD QUARTER (0.4)
h
H
PORTION OF ROOF BELOW THIS LINE TO BE TREATED AS AN EXTENSION OF VERTICAL SUPPORTS
+ 0.8
- 0.6
$\frac{H}{l} \ngtr 0.6$
$\frac{h}{L} > 0.6$
l
L

c) DOUBLE CURVED ROOFS

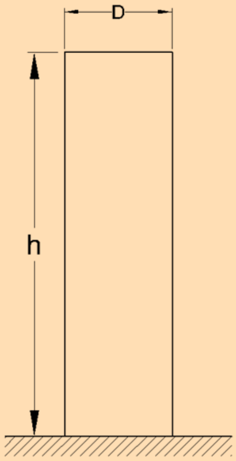
VALUES OF C, C_1 and C_2

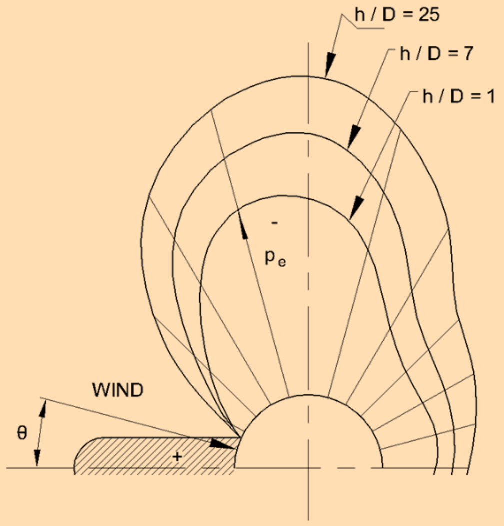
H/l	C	C_1	C_2	C_2
0.1	- 0.8	+ 0.1	- 0.8	+ 0.05
0.2	- 0.9	+ 0.3	- 0.7	+ 0.1
0.3	- 1.0	+ 0.4	- 0.3	+ 0.15
0.4	- 1.1	+ 0.6	+ 0.4	-
0.5	- 1.2	+ 0.7	+ 0.7	-

Note :- When the wind is blowing normal to gable ends, C_{pe} may be taken as equal to - 0.7 for the full width of the roof over a length of $l/2$ from the gable ends and - 0.5 for the remaining portion.

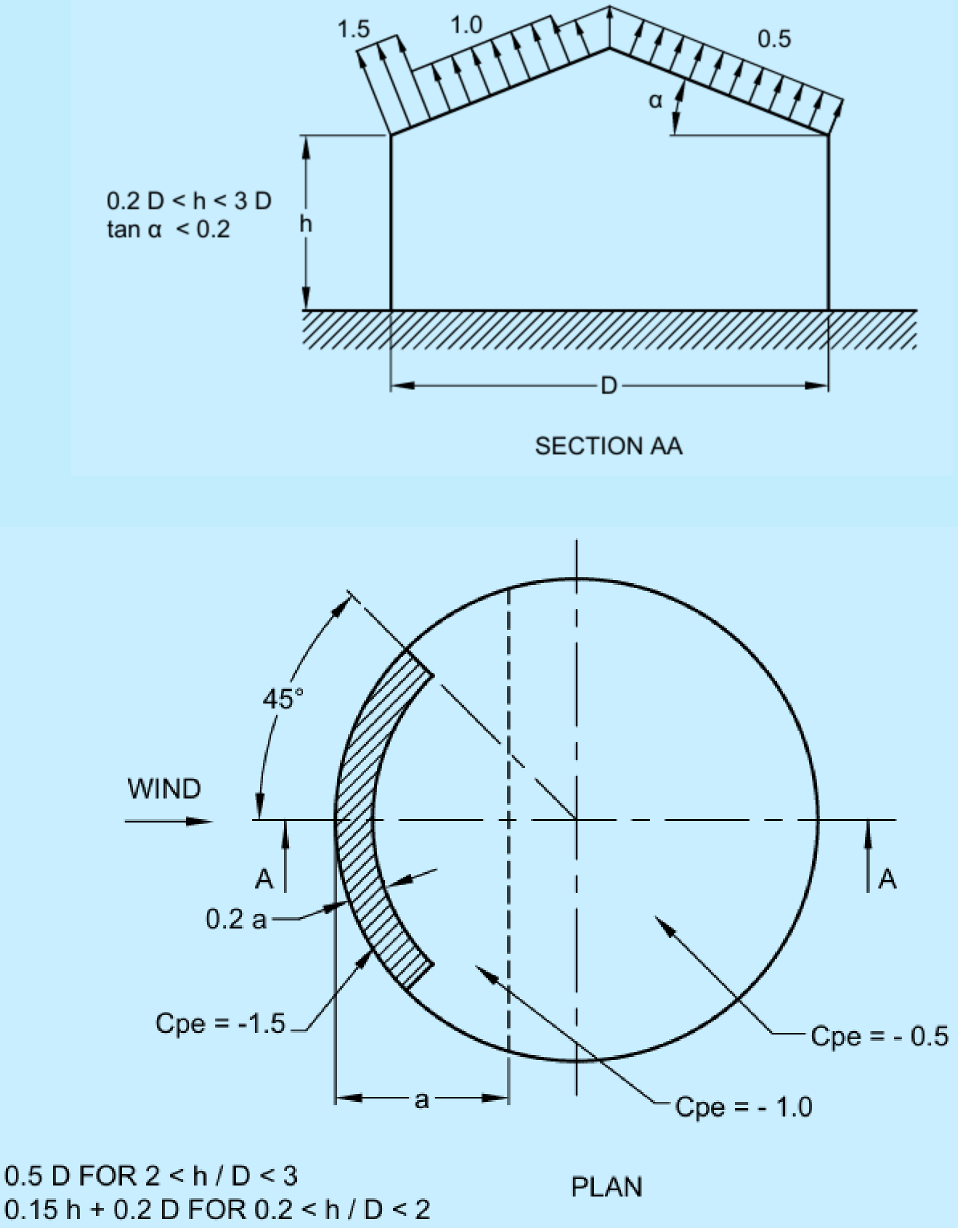
Table 22 External Pressure Coefficients (C_{pe}) Around Cylindrical Structures

(*Clause* 4.5.3.3.7)





POSITION OF PERIPHERY, θ IN DEGREES	PRESSURE COEFFICIENTS C_{pe}		
	h / *D* = 25	*h* / *D* = 7	*h* / *D* = 1
0	1.0	1.0	1.0
15	0.8	0.8	0.8
30	0.1	0.1	0.1
45	- 0.9	- 0.8	- 0.7
60	- 1.9	- 1.7	- 1.2
75	- 2.5	- 2.2	- 1.6
90	- 2.6	- 2.2	- 1.7
105	- 1.9	- 1.7	- 1.2
120	- 0.9	- 0.8	- 0.7
135	- 0.7	- 0.6	- 0.5
150	- 0.6	- 0.5	- 0.4
165	- 0.6	- 0.5	- 0.4
180	- 0.6	- 0.5	- 0.4

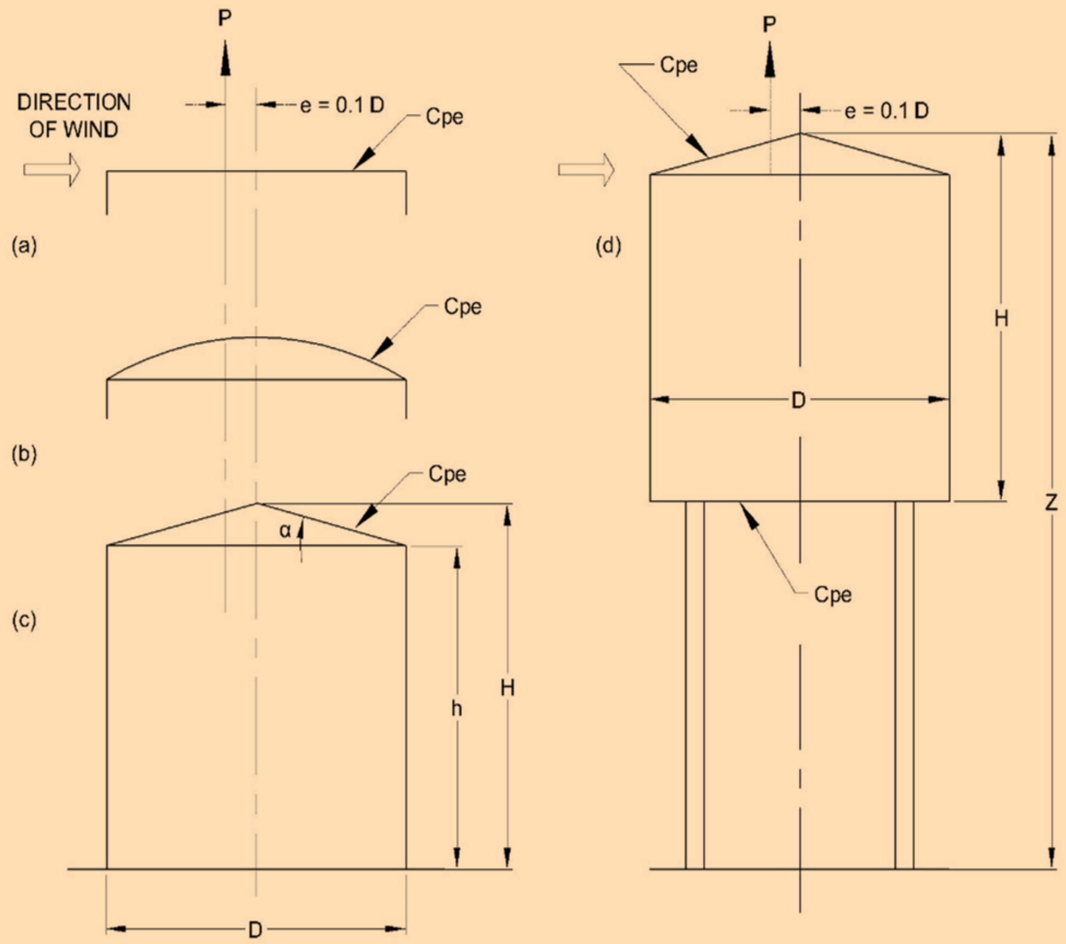

1.5
1.0
0.5
α
0.2 D < h < 3 D
tan α < 0.2
h
D
SECTION AA
45°
WIND
A
A
0.2 a
Cpe = -1.5
Cpe = - 0.5
Cpe = - 1.0
a
0.5 D FOR 2 < h / D < 3
0.15 h + 0.2 D FOR 0.2 < h / D < 2
PLAN

(For force coefficient corresponding to shell portion)
(*See* Table 28)

FIG. 3 EXTERNAL PRESSURE COEFFICIENTS ON THE UPPER ROOF SURFACE OF CYLINDRICAL STRUCTURES STANDING ON THE GROUND

Table 23 External Pressure Coefficients (C_{pe}) for Roofs and Bottoms of Cylindrical Structures

(*Clause* 4.5.3.3.8)


P
DIRECTION OF WIND
e = 0.1 D
Cpe
(a)
Cpe
(b)
Cpe
α
(c)
h
H
D
P
Cpe
e = 0.1 D
(d)
H
D
Z
Cpe

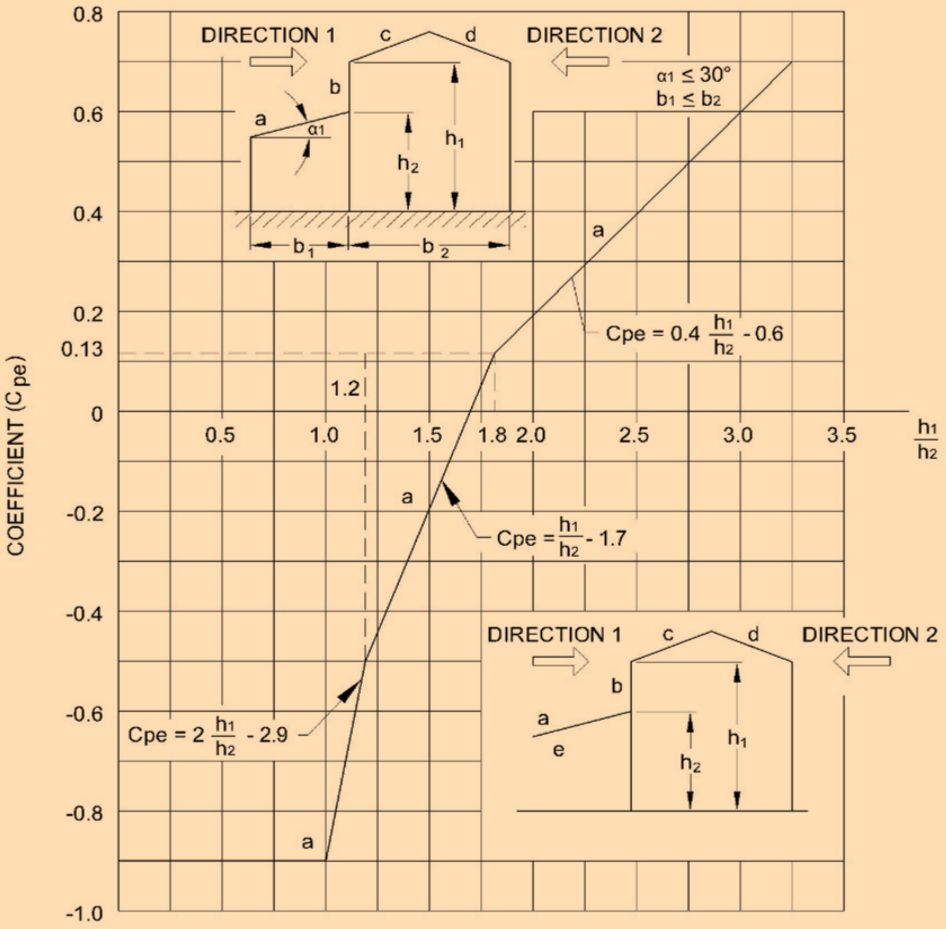
COEFFICIENTS OF EXTERNAL PRESSURE C_{pe}				
STRUCTURE ACCORDING TO SHAPE				
a, b and c		d		
H / D	ROOF	(z / H) - 1	ROOF	BOTTOM
0.5	- 0.65	1.00	- 0.75	- 0.8
1.00	- 1.00	1.25	- 0.75	- 0.7
2.00	- 1.00	1.50	- 0.75	- 0.6

Total force acting on the roof of the structure, $P = 0.785\, D^2 (C_{pi} - C_{pe})\, p_d$

The resultant of P lies eccentrically, e = 0.1D

Table 24 External Pressure Coefficients (C_{pe}) for Combined Roofs

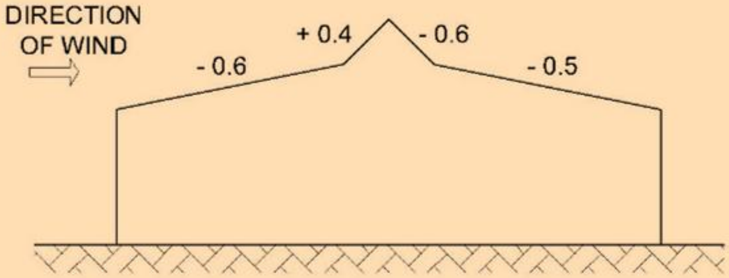
(*Clause* 4.5.3.3.9)

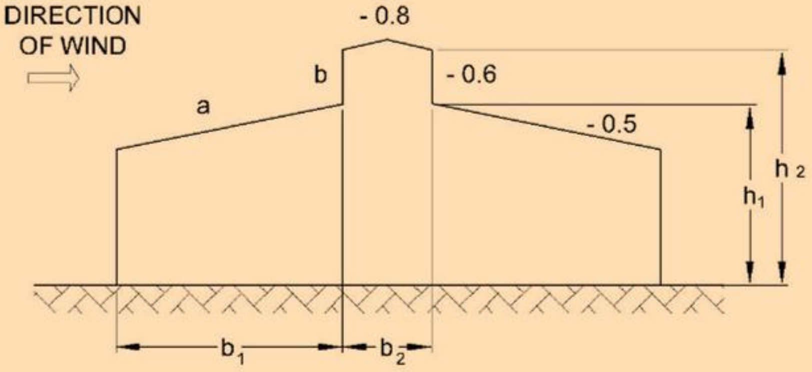


VALUES OF COEFFICIENTS (C_{pe})		
PORTION	DIRECTION 1	DIRECTION 2
a	FROM THE DIAGRAM	- 0.4
b	$C_{pe} = -0.5,\ \frac{h_1}{h_2} \leq 1.5$ $C_{pe} = +0.7;\ \frac{h_1}{h_2} > 1.5$	
c and d	See Table 6	
e	See Clause 6.3.3.5	

Table 25 External Pressure Coefficients (C_{pe}) for Roofs with a Sky Light

(*Clause* 4.5.3.3.10)


DIRECTION OF WIND
- 0.6
+ 0.4
- 0.6
- 0.5

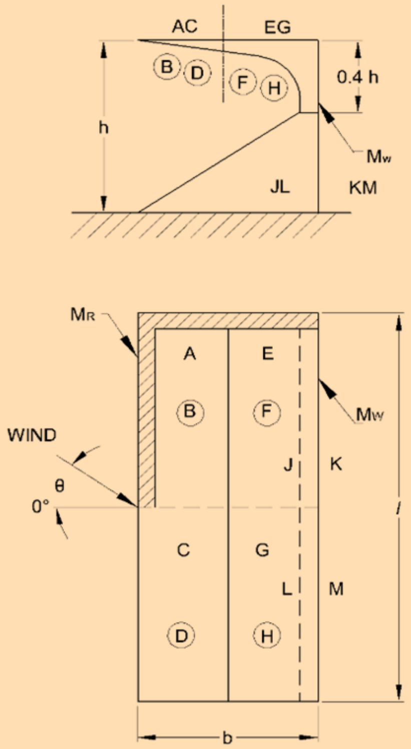

DIRECTION OF WIND
- 0.8
b
- 0.6
a
- 0.5
h 2
h1
b1
b2

b) ROOFS WITH A SKY LIGHT

VALUES OF COEFFICIENTS (C_{pe})			
PORTION	$b_1 > b_2$		$b_1 \leq b_2$
	a	*b*	*a* and *b*
C_{pe}	- 0.6	+ 0.7	See Table for combined roofs

Table 26 Pressure Coefficients at Top and Bottom Roof of Grand Stands Open Three Sides (Roof Angle Up to 3°)

(*Clause* 4.5.3.3.11)


AC
EG
B
D
F
H
0.4 h
h
Mw
JL
KM
MR
A
E
B
F
Mw
WIND
θ
0°
J
K
C
G
L
M
D
H
l
b

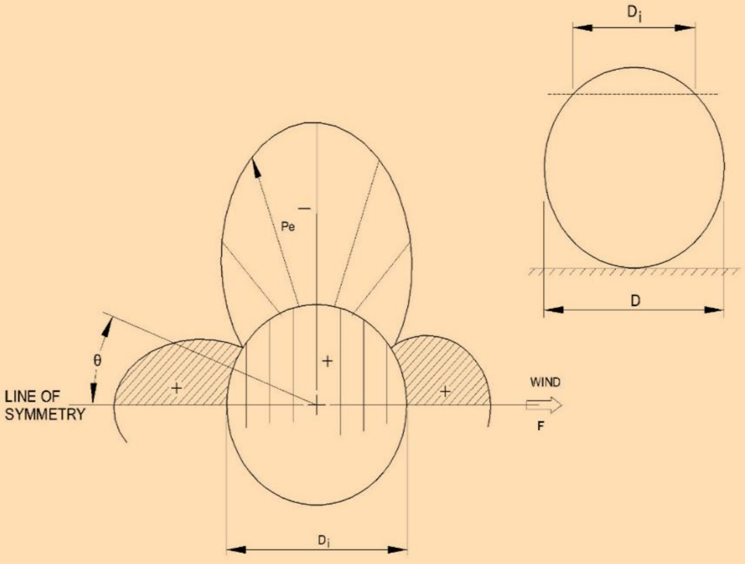
(Shaded area to scale)

FRONT AND BACK OF WALL				
θ	*J*	*K*	*L*	*M*
0°	+ 0.9	- 0.5	+ 0.9	- 0.5
45°	+ 0.8	- 0.6	+ 0.4	- 0.4
135°	- 1.1	+ 0.6	- 1.0	+ 0.4
180°	- 0.3	+ 0.9	- 0.3	+ 0.9
60°		*Mw* - C_p of K = - 1.0		
60°		*Mw* - C_p of J = + 1.0		

TOP AND BOTTOM ROOF								
θ	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*
0°	- 1.0	+ 0.9	- 1.0	+ 0.9	- 0.7	+ 0.9	+ 0.7	+ 0.9
45°	- 1.0	+ 0.7	- 0.7	+ 0.4	- 0.5	+ 0.8	- 0.5	+ 0.3
135°	- 0.4	- 1.1	- 0.7	- 1.0	- 0.9	- 1.1	- 0.9	- 1.0
180°	- 0.6	- 0.3	- 0.6	- 0.3	- 0.6	- 0.3	- 0.6	- 0.3
45°	'M_R' - C_p (top) = - 2.0							
45°	'M_R' - C_p (bottom) = + 1.0							

Table 27 External Pressure Coefficients (C_{pe}) Around Spherical Structures

(*Clause* 4.5.3.3.12)



POSITION OF PERIPHERY, θ IN DEGREES	Cpe
0	+ 1.0
15	+ 0.9
30	+ 0.5
45	- 0.1
60	- 0.7
75	- 1.1
90	- 1.2
105	- 1.0
120	- 0.6
135	- 0.2
150	+ 0.1
165	+ 0.3
180	+ 0.4

4.5.4.1 *Frictional drag*

In certain buildings of special shape, a force due to frictional drag shall be taken into account in addition to those loads specified in **4.5.3**. For rectangular clad buildings, this addition is necessary only where the ratio d/h or d/b is more than 4. The frictional drag force, F', in the direction of the wind is given by the following formulae:

a) If $h \leq b$, $F' = C_f'(d - 4h)\, b\, p_d + C'_f(d - 4h)\, 2h\, p_d$; and

b) If $h > b$, $F' = C_f'(d - 4b)\, b\, p_d + C'_f(d - 4b)\, 2h\, p_d$.

The first term in each case gives the drag on the roof and the second on the walls. The C_f' has the following values:

a) 0.01 for smooth surfaces without corrugations or ribs across the wind direction;

b) 0.02 for surfaces with corrugations across the wind direction; and

c) 0.04 for surfaces with ribs across the wind direction.

For other buildings, the frictional drag has been indicated, where necessary, in the tables of pressure coefficients and force coefficients.

4.5.4.2 *Force coefficients for clad buildings*

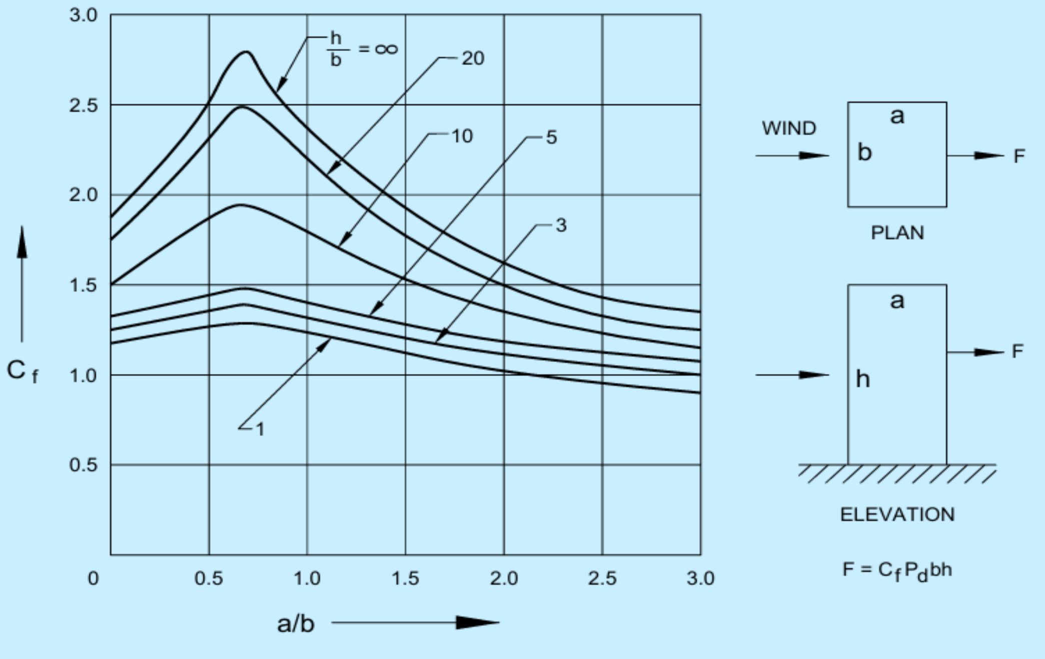
4.5.4.2.1 *Clad buildings of uniform section*

The overall force coefficients for rectangular clad buildings of uniform section with flat roofs in uniform flow shall be as given in Fig. 4 and for other clad buildings of uniform section (without projections, except where otherwise shown) shall be as given in Table 28.

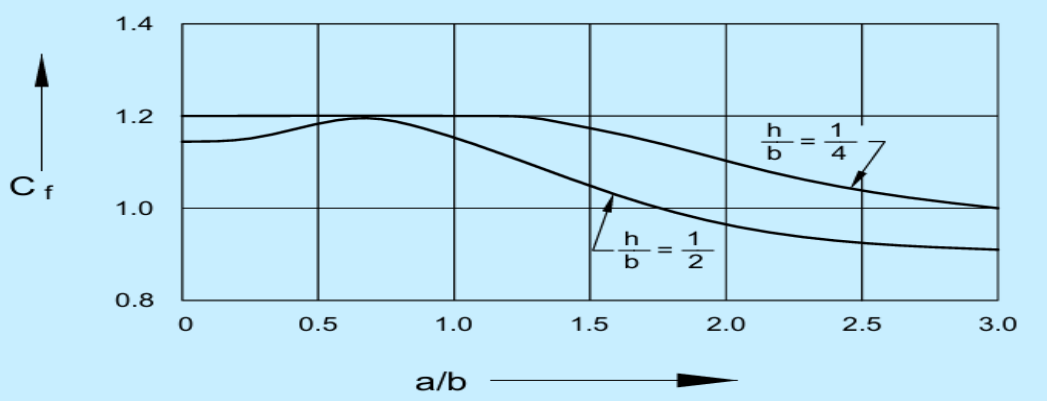
NOTE — Structures that are in the supercritical flow regime, because of their size and design wind velocity, may need further calculation to ensure that the greatest loads do not occur at some wind speed below the maximum, when the flow will be sub-critical.

The coefficients are for buildings without projections, except where otherwise shown.

In Table 28, $\overline{V}_d b$ is used as an indication of the airflow regime.



4A VALUES OF C_f VERSUS a / b for h / b ≥ 1

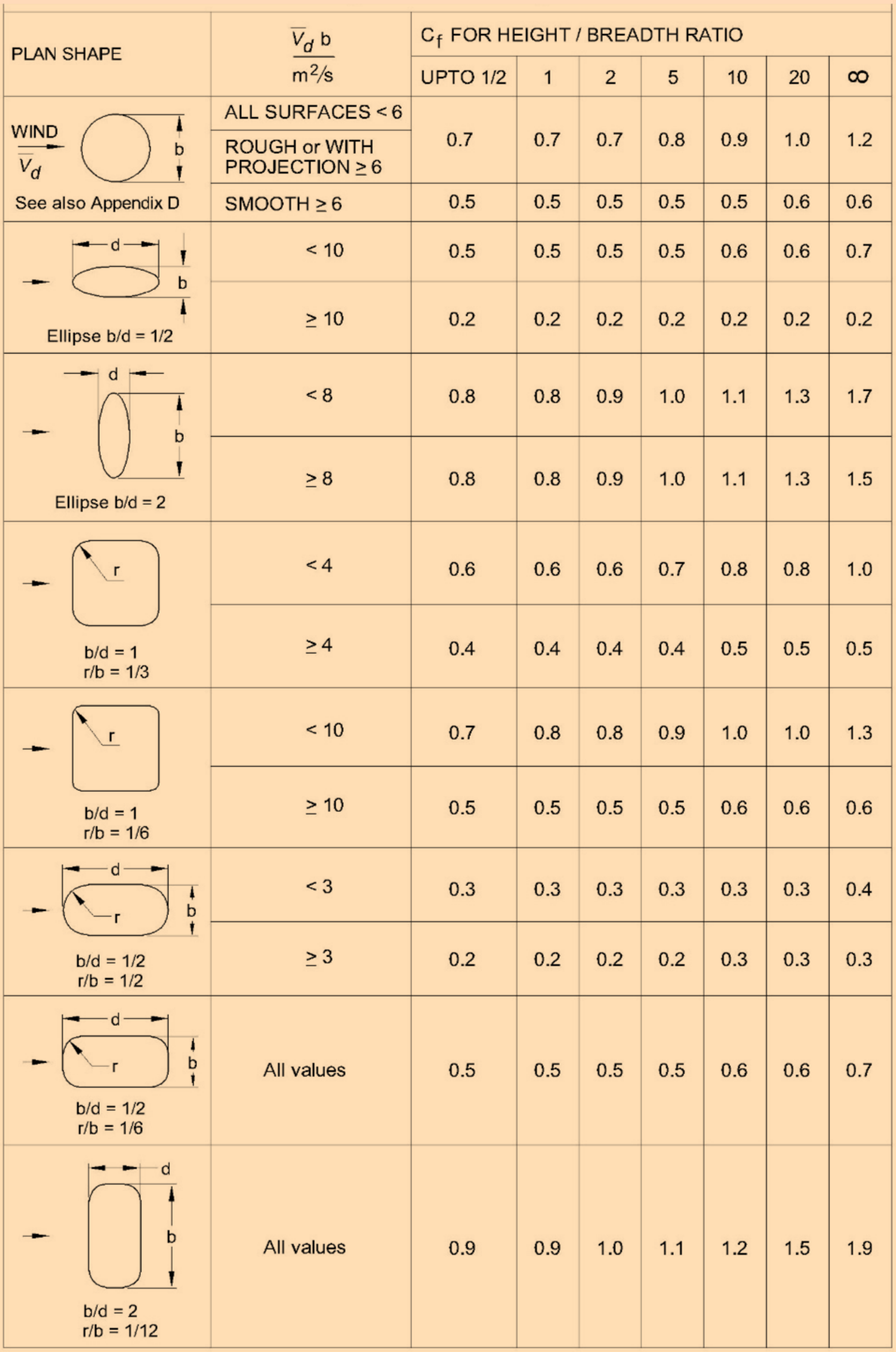


4B VALUES OF C_f VERSUS a/b FOR h/b< 1

FIG. 4 FORCE COEFFICIENT FOR RECTANGULAR CLAD BUILDING IN UNIFORM FLOW

Table 28 Force Coefficients, C_f for Clad Buildings of Uniform Section (Acting in the Direction of Wind)

(*Clause* 4.5.4.2.1)


WIND
$\bar{V}_d$
b
d
r

PLAN SHAPE	$\frac{\bar{V}_d b}{m^2/s}$	C_f FOR HEIGHT / BREADTH RATIO						
		UPTO 1/2	1	2	5	10	20	∞
See also Appendix D	ALL SURFACES < 6 ROUGH or WITH PROJECTION ≥ 6	0.7	0.7	0.7	0.8	0.9	1.0	1.2
	SMOOTH ≥ 6	0.5	0.5	0.5	0.5	0.5	0.6	0.6
Ellipse b/d = 1/2	< 10	0.5	0.5	0.5	0.5	0.6	0.6	0.7
	≥ 10	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Ellipse b/d = 2	< 8	0.8	0.8	0.9	1.0	1.1	1.3	1.7
	≥ 8	0.8	0.8	0.9	1.0	1.1	1.3	1.5
b/d = 1 r/b = 1/3	< 4	0.6	0.6	0.6	0.7	0.8	0.8	1.0
	≥ 4	0.4	0.4	0.4	0.4	0.5	0.5	0.5
b/d = 1 r/b = 1/6	< 10	0.7	0.8	0.8	0.9	1.0	1.0	1.3
	≥ 10	0.5	0.5	0.5	0.5	0.6	0.6	0.6
b/d = 1/2 r/b = 1/2	< 3	0.3	0.3	0.3	0.3	0.3	0.3	0.4
	≥ 3	0.2	0.2	0.2	0.2	0.3	0.3	0.3
b/d = 1/2 r/b = 1/6	All values	0.5	0.5	0.5	0.5	0.6	0.6	0.7
b/d = 2 r/b = 1/12	All values	0.9	0.9	1.0	1.1	1.2	1.5	1.9

Table 28 (*Continued*)

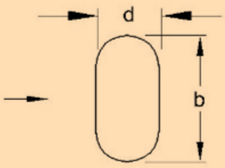
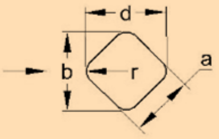
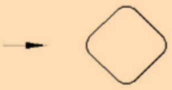
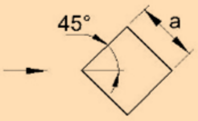
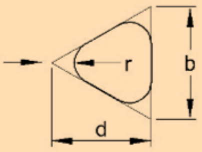
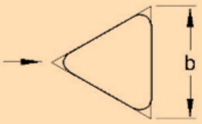
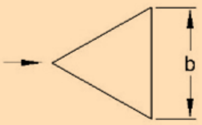
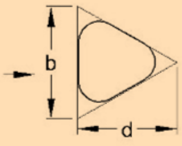
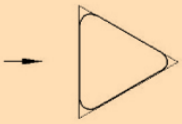
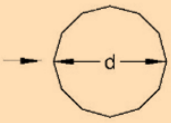
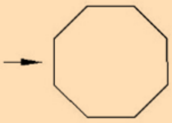
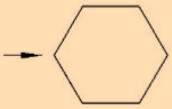
PLAN SHAPE	$\frac{\bar{V}_d b}{m^2/s}$	C_f FOR HEIGHT / BREADTH RATIO						
		UPTO 1/2	1	2	5	10	20	∞
 b/d = 2 r/b = 1/4	< 6	0.7	0.8	0.8	0.9	1.0	1.2	1.6
	≥ 6	0.5	0.5	0.5	0.5	0.5	0.6	0.6
 r/a = 1/3	< 10	0.8	0.8	0.9	1.0	1.1	1.3	1.5
	≥ 10	0.5	0.5	0.5	0.5	0.5	0.6	0.6
 r/a = 1/12	All values	0.9	0.9	0.9	1.1	1.2	1.3	1.6
 r/a = 1/48	All values	0.9	0.9	0.9	1.1	1.2	1.3	1.6
 r/b = 1/4	< 11	0.7	0.7	0.7	0.8	0.9	1.0	1.2
	≥ 11	0.4	0.4	0.4	0.4	0.5	0.5	0.5
 r/b = 1/12	All values	0.8	0.8	0.8	1.0	1.1	1.2	1.4
 r/b = 1/48	All values	0.7	0.7	0.8	0.9	1.0	1.1	1.3
 r/b = 1/4	< 8	0.7	0.7	0.8	0.9	1.0	1.1	1.3
	≤ 8	0.4	0.4	0.4	0.4	0.5	0.5	0.5

Table 28 (*Concluded*)

PLAN SHAPE	$\frac{\bar{V}_d\, b}{m^2/s}$	C_f FOR HEIGHT / BREADTH RATIO						
		UPTO 1/2	1	2	5	10	20	∞
 1/48 < r/b < 1/12	All values	1.2	1.2	1.2	1.4	1.6	1.7	2.1
 12 SIDED POLYGON	< 12	0.7	0.7	0.8	0.9	1.0	1.1	1.3
	≥ 12	0.7	0.7	0.7	0.7	0.8	0.9	1.1
 OCTAGON	All values	1.0	1.0	1.1	1.2	1.2	1.3	1.4
 HEXAGON	All values	1.0	1.1	1.2	1.3	1.4	1.4	1.5

4.5.4.2.2 *Buildings of circular shapes*

Force coefficients for buildings of circular cross section shapes shall be as given in Table 28. However, more precise estimation of force coefficients for circular shapes of infinite length can be obtained from Fig. 5 taking into account the average height of surface roughness ε. When the length is finite the values obtained from Fig. 5 shall be reduced by the multiplication factor K (*See also* Table 31 and Annex G).

4.5.4.2.3 *Free standing walls and hoardings*

Force coefficients for free standing walls and hoardings shall be as given in Table 29.

To allow for oblique winds, the design shall also be checked for net pressure normal to the surface varying linearly from a maximum of 1.7 C_f at the windward edge to 0.44 C_f at the leeward edge.

The wind load on appurtenances and supports for hoardings shall be accounted for separately by using the appropriate net pressure coefficients. Allowance shall be made for shielding effects of one element on another.

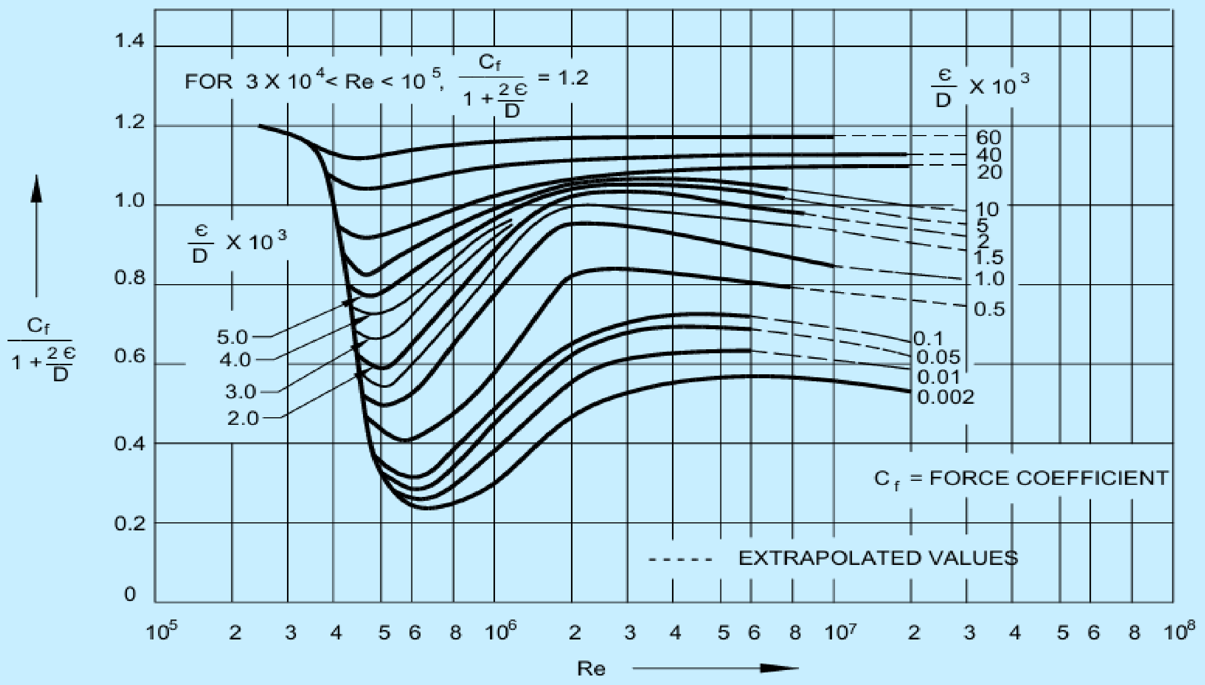
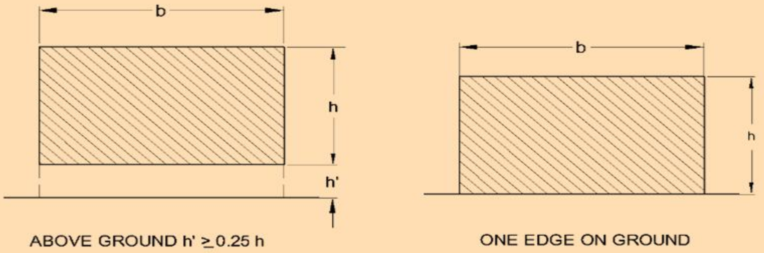


Fig. 5 VARIATION OF $\frac{C_f}{1+\frac{2\epsilon}{D}}$ WITH Re < 3×10^4 FOR CIRCULAR SECTIONS

Table 29 Force Coefficients, C_f for Low Walls or Hoardings (< 15m High)

(*Clause* 4.5.4.2.3)



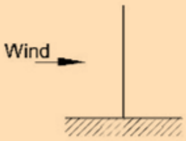
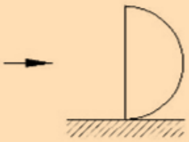
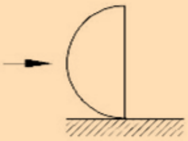
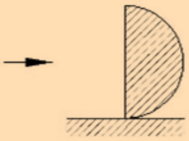
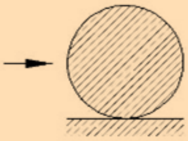
(WIND NORMAL TO FACE)

FORCE COEFFICIENT

WIDTH TO HEIGHT RATIO, *b/h*		DRAG COEFFICIENT C_f
WALL ABOVE GROUND	WALL ON GROUND	
FROM 0.5 TO 6	FROM 1 TO 12	1.2
10	20	1.3
16	32	1.4
20	40	1.5
40	80	1.75
60	120	1.8
80 OR MORE	160 OR MORE	2.0

Table 30 Force Coefficients, C_f for Solid Shapes Mounted on a Surface

(*Clause* 4.5.4.2.4)

SIDE ELEVATION	DESCRIPTION OF SHAPE	C_f
	CIRCULAR DISC	1.2
	HEMISPHERICAL BOWL	1.4
	HEMISPHERICAL BOWL	0.4
	HEMISPHERICAL SOLID	1.2
	SPHERICAL SOLID	0.5 FOR $V_z D < 7$ 0.2 FOR $V_z D \geq 7$

4.5.4.2.4 *Solid circular shapes mounted on a surface*

The force coefficients for solid circular shapes mounted on a surface shall be as given in Table 30.

4.5.4.3 *Force coefficients for unclad buildings*

4.5.4.3.1 This section applies to permanently unclad buildings and to frameworks of buildings while temporarily unclad. In the case of buildings whose surfaces are well-rounded, such as those with elliptic, circular or oval cross sections, the total force can be more at a wind speed much less than maximum due to transition in the nature of boundary layer on them. Although this phenomenon is well known in the case of circular cylinders, the same phenomenon exists in the case of many other well-rounded structures and this possibility must be checked.

4.5.4.3.2 *Individual members*

a) The force coefficient given in Table 32 refers to members of infinite length. For members of finite length, the coefficients should be multiplied by a factor *K* that depends on the ratio *l*/*b* where *l* is the length of the member and *b* is the width across the direction of wind. Table 31 gives the required values of *K*. The following special cases must be noted while estimating *K*:

    1) when any member abuts on to a plate or wall in such a way that free flow of air around that end of the member is prevented, then the ratio of *l*/*b* shall be doubled for the purpose of determining *K*; and

    2) when both ends of a member are so obstructed, the ratio shall be taken as infinity for the purpose of determining *K*.

b) *Flat-sided members* — Force coefficients for wind normal to the longitudinal axis of flat-sided structural members shall be as given in Table 32.

The force coefficients are given for two mutually perpendicular directions relative to a reference axis on the structural member. They are denoted by C_{fn} and C_{ft} and give the forces normal and transverse, respectively to the reference plane as shown in Table 32.

Normal force $F_n = (C_{fn}\, p_d\, K)/b$

Transverse force $F_t = (C_{ft}\, p_d\, K)/b$

c) *Circular sections* — Force coefficients for members of circular section shall be as given in Table 28 (*See also* Annex G).

d) Force coefficients for wires and cables shall be as given in Table 33 according to the diameter (D), the design wind speed (V_d) and the surface roughness.

Table 31 Reduction Factor *K* for Individual Members

[*Clauses* 4.5.4.2.2, 4.5.4.3.2(a) *and* 4.5.4.3.3(b)(2)]

Sl No. (1)	***l*/*b* or *l*/*D*** (2)	**2** (3)	**5** (4)	**10** (5)	**20** (6)	**40** (7)	**50** (8)	**100** (9)	**∞** (10)
i)	Circular cylinder, sub-critical flow	0.58	0.62	0.68	0.74	0.82	0.87	0.98	1.00
ii)	Circular cylinder, supercritical flow ($DV_d \geq 6$ m²/s)	0.80	0.80	0.82	0.90	0.98	0.99	1.00	1.00
iii)	For plate perpendicular to wind ($bV_d \geq 6$ m²/s)	0.62	0.66	0.69	0.81	0.87	0.90	0.95	1.00

Table 32 Force Coefficients, C_f for Individual Structural Members of Infinite Length

[*Clause* 4.5.4.3.2(b)]

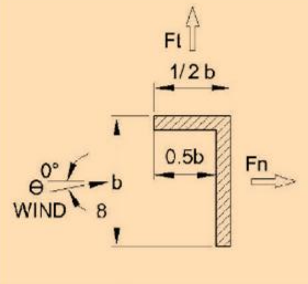
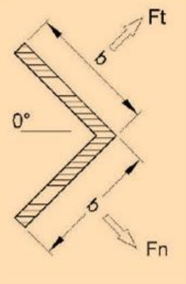
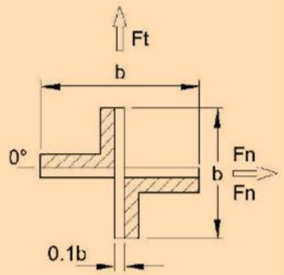
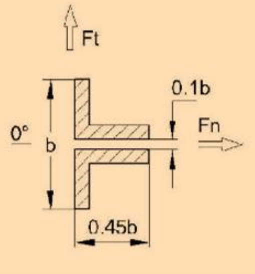
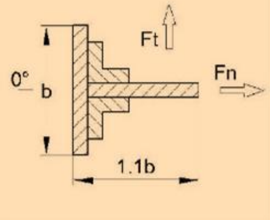
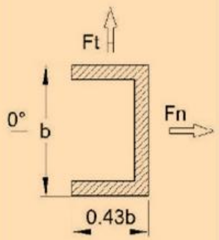
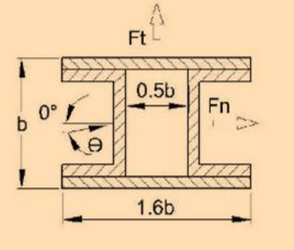
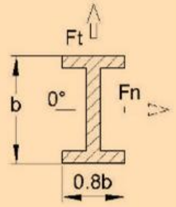
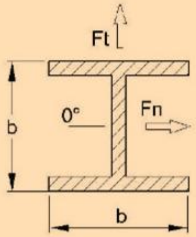
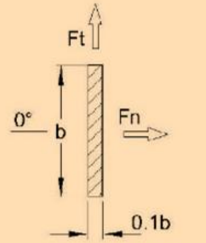
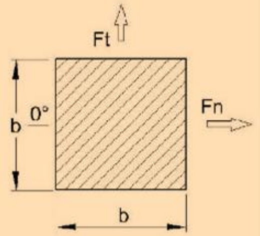
 Ft 1/2 b 0.5b Fn 0° θ WIND b 8					 Ft b 0° Fn b Fn 0.1b		 Ft 0.1b 0° b Fn 0.45b				 Ft 0° b Fn 0.43b	
θ DEGREE	C_{fn}	C_{ft}	C_{fn}	C_{ft}	C_{fn}	C_{ft}	C_{fn}	C_{ft}	C_{fn}	C_{ft}	C_{fn}	C_{ft}
0	+ 1.9	+ 0.95	+ 1.8	+ 1.8	+ 1.75	+ 0.1	+ 1.6	0	+ 2.0	0	+ 2.05	0
45	+ 1.8	+ 0.8	+ 2.1	+ 1.8	+ 0.85	+ 0.85	+ 1.5	- 0.1	+ 1.2	+ 0.9	+ 1.85	+ 0.6
90	+ 2.0	+ 1.7	- 1.9	- 1.0	+ 0.1	+ 1.75	- 0.95	+ 0.7	- 1.6	+ 2.15	0	+ 0.6
135	- 1.8	- 0.1	- 2.0	+ 0.3	- 0.75	+ 0.75	- 0.5	+ 1.05	- 1.1	+ 2.4	- 1.6	+ 0.4
180	- 2.0	+ 0.1	- 1.4	- 1.4	- 1.75	- 0.1	- 1.5	0	- 1.7	+ 2.1	- 1.8	0
 Ft 0.5b b 0° Fn θ 1.6b												
θ DEGREE	C_{fn}	C_{ft}	C_{fn}	C_{ft}	C_{fn}	C_{ft}	C_{fn}	C_{ft}	C_{fn}	C_{ft}		
0	+ 1.4	0	+ 2.05	0	+ 1.6	0	+ 2.0	0	+ 2.0	0		
45	+ 1.2	+ 1.6	+ 1.95	+ 0.6	+ 1.5	+ 1.5	+ 1.8	+ 0.1	+ 1.55	+ 1.55		
90	0	+ 2.2	+ 0.5	+ 0.9	0	+ 1.9	0	+ 0.1	0	+ 2.0		

Table 33 Force Coefficients, C_f for Wires and Cables ($l/D = 100$)

[*Clause* 4.5.4.3.2(d)]

Sl No.	**Flow Regime**	**Force Coefficient, C_f for**			
		Smooth Surface	Moderately Smooth Wire (Galvanized or Painted)	Fine Stranded Cables	Thick Stranded Cables
(1)	(2)	(3)	(4)	(5)	(6)
i)	$D\bar{V}_d < 6$ m^2/s	1.2	1.2	1.2	1.3
ii)	$D\bar{V}_d \geq 6$ m^2/s	0.5	0.7	0.9	1.1

4.5.4.3.3 *Single frames*

Force coefficients for a single frame having either:

a) all flat sided members; or

b) all circular members in which all the members of the frame have either:

   1) $D\bar{V}_d$ less than 6 m^2/s; or

   2) $D\bar{V}_d$ more than or equal to 6 m^2/s. shall be as given in Table 31 according to the type of the member, the diameter (D), the design hourly mean wind speed ($\bar{V}_d$) and the solidity ratio (Φ). Force coefficients for a single frame not complying with the above requirements shall be calculated as follows:

$$C_f = \gamma\, C_{f\,\mathrm{super}} + (1-\gamma)\frac{A_{\mathrm{circ\,sub}}}{A_{\mathrm{sub}}} C_{f\,\mathrm{sub}} + (1-\gamma)\frac{A_{\mathrm{flat}}}{A_{\mathrm{sub}}} C_{f\,\mathrm{flat}}$$

where

$C_{f\,\mathrm{super}}$ = force coefficient for the supercritical circular members as given in Table 34 or Annex G;

γ = $\frac{\text{Area of the frame in a supercritical flow}}{A_e}$;

A_e = effective frontal area;

$A_{\mathrm{circ\,sub}}$ = effective area of subcritical circular members;

$C_{f\,\mathrm{sub}}$ = force coefficient for subcritical circular members as given in Table 34 or Annex G;

$C_{f\,\mathrm{flat}}$ = force coefficient for the flat sided members as given in Table 34;

A_{flat} = effective area of flat-sided members; and

A_{sub} = $A\mathrm{circ\ sub} + A\mathrm{flat}$.

Table 34 Force Coefficients for Single Frames

(*Clause* 4.5.4.3.3)

Sl No.	Solidity Ratio, Φ	Force Coefficient, C_f For		
		Flat Sided Members	Circular Sections	
			Subcritical Flow ($D\overline{V}_d < 6$ m^2/s)	Super Critical Flow ($D\overline{V}_d \geq 6$ m^2/s)
(1)	(2)	(3)	(4)	(5)
i)	0.1	1.9	1.2	0.7
ii)	0.2	1.8	1.2	0.8
iii)	0.3	1.7	1.2	0.8
iv)	0.4	1.7	1.1	0.8
v)	0.5	1.6	1.1	0.8
vi)	0.75	1.6	1.5	1.4
vii)	1.00	2.0	2.0	2.0

NOTE — Linear interpolation between the values is permitted.

4.5.4.3.4 *Multiple frame buildings*

This Section applies to structures having two or more parallel frames where the windward frames may have a shielding effect upon the frames to leeward side. The windward frame and any unshielded parts of other frames shall be calculated in accordance with **4.5.4.3.3**, but the wind load on the parts of frames that are sheltered should be multiplied by a shielding factor which is dependent upon the solidity ratio of the windward frame, the types of members comprising the frame and the spacing ratio of the frames. The values of the shielding factors are given in Table 35.

Where there are more than two frames of similar geometry and spacing, the wind load on the third and subsequent frames should be taken as equal to that on the second frame. The loads on the various frames shall be added to obtain total load on the structure.

a) The frame spacing ratio is equal to the centre to centre distance between the frames, beams or girders divided by the least overall dimension of the frames, beam or girder measured in a direction normal to the direction of wind. For triangular framed structures or rectangular framed structures diagonal to the wind, the spacing ratio should be calculated from the mean distance between the frames in the direction of the wind.

b) Effective solidity ratio, Φ_e:

$\Phi_e = \Phi$ for flat-sided members.

Φ_e is to be obtained from Fig. 6 for members of circular cross sections.

Table 35 Shielding Factor, η for Multiple Frames

(*Clause* 4.5.4.3.4)

Sl No.	Effective Solidity Ratio, Φ_e	Frame Spacing Ratio				
		< 0.5	1.0	2.0	4.0	> 8.0
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	0	1.0	1.0	1.0	1.0	1.0
ii)	0.1	0.9	1.0	1.0	1.0	1.0
iii)	0.2	0.8	0.9	1.0	1.0	1.0
iv)	0.3	0.7	0.8	1.0	1.0	1.0
v)	0.4	0.6	0.7	1.0	1.0	1.0
vi)	0.5	0.5	0.6	0.9	1.0	1.0
vii)	0.7	0.3	0.6	0.8	0.9	1.0
viii)	1.0	0.3	0.6	0.6	0.8	1.0

NOTE — Linear interpolation between the values is permitted.

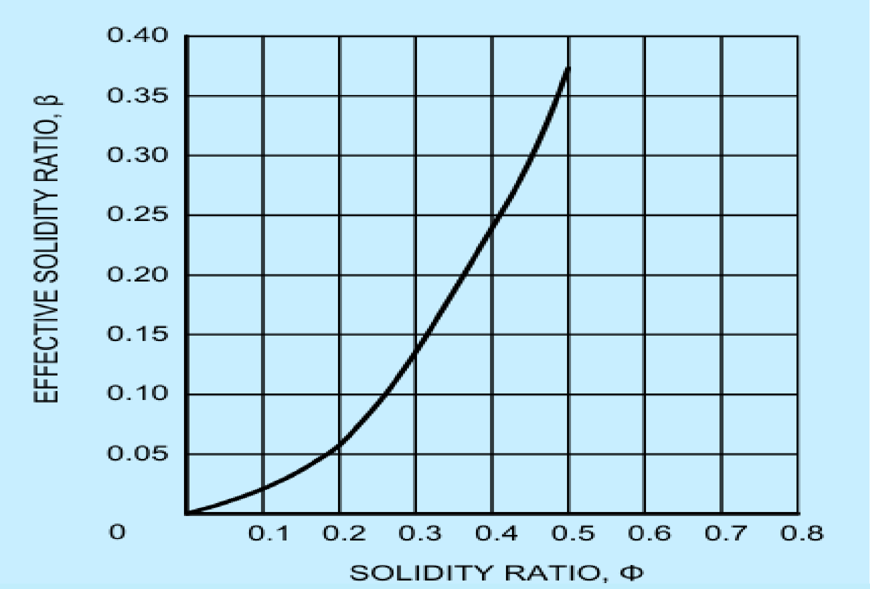


FIG. 6 EFFECTIVE SOLIDITY RATIO FOR CIRCULAR SECTION MEMBERS

4.5.4.3.5 *Lattice towers*

a) Force coefficient for lattice towers of square or equilateral triangle section with flat sided members for wind blowing against any face shall be as given in Table 36;

b) For square lattice towers with flat-sided members the maximum load, which occurs when the wind blows into a corner, shall be taken as 1.2 times the load for the wind blowing against a face;

c) For equilateral triangle lattice towers with flat-sided members, the load may be assumed to be constant for any inclination of wind to a face;

d) Force coefficients for lattice towers of square section with circular members, all in the same flow regime, may be as given in Table 37; and

e) Force coefficients for lattice towers of equilateral-triangle section with circular members all in the same flow regime may be as given in Table 38.

4.5.4.3.6 *Tower appurtenances*

The wind loading on tower appurtenances, such as ladders, conduits, lights, elevators, etc shall be calculated using appropriate net pressure coefficients for these elements. Allowance may be made for shielding effect from other elements.

Table 36 Overall Force Coefficients for Towers Composed of Flat Sided Members

[*Clause* 4.5.4.3.5(a)]

Sl No.	**Solidity Ratio, Φ**	**Force Coefficient**	
		Square Towers	Equilateral Triangular Towers
(1)	(2)	(3)	(4)
i)	< 0.1	3.8	3.1
ii)	0.2	3.3	2.7
iii)	0.3	2.8	2.3
iv)	0.4	2.3	1.9
v)	0.5	2.1	1.5

Table 37 Overall Force Coefficients for Square Towers Composed of Circular Members

[*Clause* 4.5.4.3.5(d)]

Sl No.	**Solidity Ratio of Front Face Φ**	**Force Coefficient**			
		Subcritical Flow ($D\overline{V}_{\text{d}} < 6\ \text{m}^2/\text{s}$)		Super Critical Flow ($D\overline{V}_{\text{d}} \geq 6\ \text{m}^2/\text{s}$)	
		Onto Face	Onto Corner	Onto Face	Onto Corner
(1)	(2)	(3)	(4)	(5)	(6)
i)	< 0.05	2.4	2.5	1.1	1.2
ii)	0.1	2.2	2.3	1.2	1.3
iii)	0.2	1.9	2.1	1.3	1.6
iv)	0.3	1.7	1.9	1.4	1.6
v)	0.4	1.6	1.9	1.4	1.6
vi)	0.5	1.4	1.9	1.4	1.6

Table 38 Overall Force Coefficients for Equilateral Triangular Towers Composed of Circular Members

[*Clause* 4.5.4.3.5(e)]

Sl No.	Solidity Ratio of Front Face Φ	Force Coefficient	
		Subcritical flow ($D\overline{V}_d < 6\ m^2/s$)	Super critical flow ($D\overline{V}_d \geq 6\ m^2/s$)
		All wind directions	All wind directions
(1)	(2)	(3)	(4)
i)	< 0.05	1.8	0.8
ii)	0.1	1.7	0.8
iii)	0.2	1.6	1.1
iv)	0.3	1.5	1.1
v)	0.4	1.5	1.1
vi)	0.5	1.4	1.2

4.6 Interference Effects

4.6.1 *General*

Wind interference is caused by modification in the wind characteristics produced by the obstruction caused by an object or a building/structure in the path of the wind. If such wind strikes another structure, the wind pressures usually get enhanced, though there can also be some shielding effect between two very closely spaced buildings/structures. The actual phenomenon is too complex to justify generalization of the wind forces/pressures produced due to interference which can only be ascertained by detailed wind tunnel/CFD studies. However, some guidance can be provided for the purpose of preliminary design. To account for the effect of interference, a wind interference factor (IF) has been introduced as a multiplying factor to be applied to the design wind pressure/force. Interference effects can be more significant for tall buildings. The interference factor is defined as the ratio between the enhanced pressure/force in the grouped configuration to the corresponding pressure/force in isolated configuration. Since the values of IF can vary considerably based on building geometry and location, the given values of IF are a kind of median values and are meant only for preliminary design estimates. The designer is advised that for assigning values of IF for final design particularly for tall buildings, specialist literature be consulted or a wind tunnel study carried out.

4.6.2 *Roof of Low Rise Buildings*

Maximum increase in wind force on the roof due to interference from similar buildings in case of closely spaced low rise buildings with flat roofs may be up to 25 percent for c/c distance (x) between the buildings of 5 times the dimension (b) of the interfering building normal to the direction of wind (*see* Fig. 7). Interference effect beyond 20b may be considered to be negligible. For intermediate spacing linear interpolation may be used.

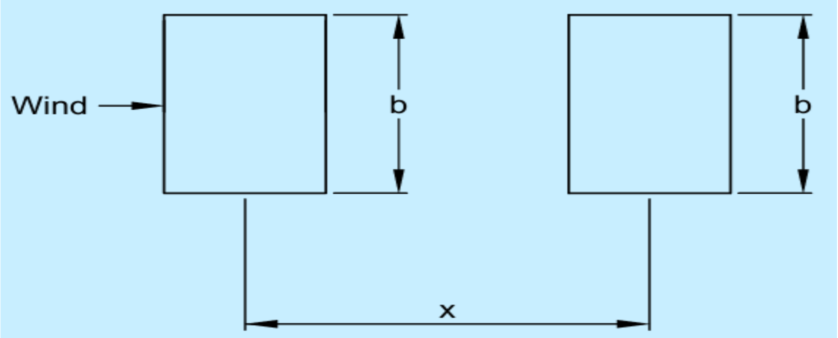


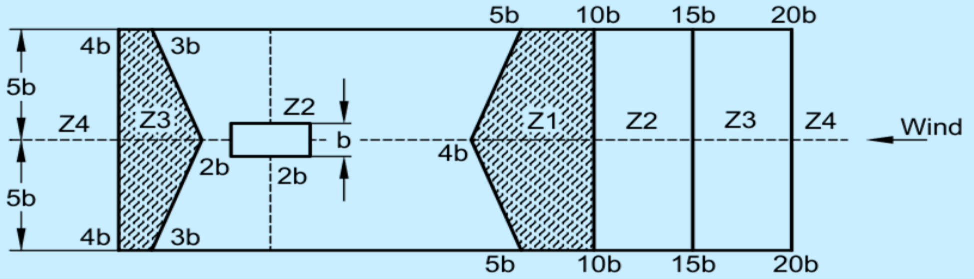
FIG. 7 LOW-RISE BUILDING IN TANDEM CAUSING INTERFERENCE EFFECT

4.6.3 *Tall Buildings*

Based on studies on tall rectangular buildings, Fig. 8 gives various zones of interference. The interference factor (IF), which needs to be considered as a multiplication factor for wind loads corresponding to isolated building, may be assumed as follows for preliminary estimate of the wind loads under interference caused by another interfering tall building of same or more height located at different zone Z1 to zone Z4 as shown in Fig. 8:

Zone	Z1	Z2	Z3	Z4
IF	1.35	1.25	1.15	1.07

The interference effect due to buildings of height less than one-third of the height of the building under consideration may be considered to be negligible while for interference from a building of intermediate height, linear interpolation may be used between one-third and full height.



Z1 Zone of high interference
Z2 Zone of moderate interference
Z3 Zone of low interference
Z4 Zone of insignificant interference

FIG. 8 INTERFERENCE ZONES FOR TALL RECTANGULAR BUILDINGS OF SAME OR GREATER HEIGHT

4.7 Dynamic Effects

4.7.1 *General*

Flexible slender structures and structural elements shall be investigated to ascertain the importance of wind induced oscillations or excitations in along wind and across wind directions.

In general, the following guidelines may be used for examining the problems of wind-induced oscillations:

a) Buildings and closed structures with a height to minimum lateral dimension ratio of more than about 5.0, or

b) Buildings and structures whose natural frequency in the first mode is less than 1.0 Hz.

Any building or structure which satisfies either of the above two criteria shall be examined for dynamic effects of wind.

NOTES

1 The fundamental time period (T), in second, may either be established by experimental observations on similar buildings or calculated by any rational method of analysis. In the absence of such data, T may be determined as follows for multi-storied buildings:

a) For moment resistant frames without bracings or shear walls resisting the lateral loads:

$$T = 0.1\,n$$

where

n = number of storeys, including basement storeys.

b) For all others:

$$T = \frac{0.09H}{\sqrt{d}}$$

where

H = total height of the main structures of the building, in m; and

d = maximum base dimension of building in metres in a direction parallel to the applied wind force.

2 If preliminary studies indicate that wind-induced oscillations are likely to be significant, investigations should be pursued with the aid of analytical methods or if necessary, by means of wind tunnel tests on models.

3 Across-wind motions may be due to lateral gustiness of the wind, unsteady wake flow (for example, vortex shedding), negative aerodynamic damping or due to a combination of these effects. These cross-wind motions may become critical in the design of tall buildings/structures.

4 Motions in the direction of wind (also known as buffeting) are caused by fluctuating wind force associated with gust. The excitation depends on gust energy available at the resonant frequency.

5 The eddies shed from an upstream body may intensify motion in the direction of the wind and may also affect cross-wind motion.

6 The designer should also be aware of the following three forms of wind-induced motion which are characterized by increasing amplitude of oscillation with the increase of wind speed.

a) *Galloping* — Galloping is transverse oscillations of some structures due to the development of aerodynamic forces which are in phase with the motion. It is characterized by the progressively increasing amplitude of transverse vibration with increase of wind speed. The cross sections which are particularly prone to this type of excitation include the following:

1) All structures with non-circular cross sections, such as triangular, square, polygons, as well as angles, crosses and T sections.
2) Twisted cables and cables with ice encrustations.

b) *Flutter* — Flutter is unstable oscillatory motion of a structure due to coupling between aerodynamic force and elastic deformation of the structure. Perhaps the most common form is oscillatory motion due to combined bending and torsion. Although oscillatory motion in each degree of freedom may be damped, instability can set in due to energy transfer from one mode of oscillation to another and the structure is seen to execute sustained or divergent oscillations with a type of motion which is a combination of the individual modes of vibration. Such energy transfer takes place when the natural frequencies of modes taken individually are close to each other (ratio being typically less than 2.0). Flutter can set in at wind speeds much less than those required for exciting the individual modes of motion. Long span suspension bridge decks or any member of a structure with large values of d/t (where d is the length of the member and t is its dimension parallel to wind stream) are prone to low speed flutter. Wind tunnel testing is required to determine critical flutter speeds and the likely structural response. Other types of flutter are single degree of freedom stall flutter, torsional flutter, etc.

c) *Ovalling* — Thin walled structures with open ends at one or both ends such as oil storage tanks and natural draught cooling towers in which the ratio of the diameter or minimum lateral dimension to the wall thickness is of the order of 100 or more are prone to ovalling oscillations. These oscillations are characterized by periodic radial deformation of the hollow structure.

7 Buildings and structures that may be subjected to significant wind excited oscillations require careful investigations. It is to be noted that wind induced oscillations may occur at wind speeds lower than the design wind speed.

8 Analytical methods for the evaluation of response of dynamic structures to wind loading can be found in the special publications.

9 In assessing wind loads due to such dynamic phenomenon as galloping, flutter and ovalling, in the absence of the required information either in the special publications or other literature, expert advice should be sought including experiments on models in boundary layer wind tunnels.

4.7.2 *Motion due to Vortex Shedding*

4.7.2.1 *Slender structures*

For a structure, the vortex shedding frequency, fs, shall be determined by the following formula:

$$fs = \frac{S_t \overline{V}_{z,H}}{b}$$

where

S_t = strouhal number

$\overline{V}_{z,H}$ = hourly mean wind speed at height z; and

b = breadth of a structure or structural member normal to the wind direction in the horizontal plane.

a) *Circular structures* — For structures of circular cross section:

S_t = 0.20 for $D\overline{V}_{z,H}$ less than 6 m^2/s; and

= 0.25 for $D\overline{V}_{z,H}$ more than or equal to 6 m^2/s.

b) *Rectangular structures* — For structures of rectangular cross section:

$$S_t = 0.10$$

NOTES

1 Significant cross wind motions may be produced by vortex shedding, if the natural frequency of the structure or structural element is equal to the frequency of the vortex shedding within the range of expected wind speeds. In such cases, further analysis should be carried out on the basis of special publications.

2 Unlined welded steel cylindrical structures are prone to excitations by vortex shedding.

3 Intensification of the effects of periodic vortex shedding has been reported in cases where two or more similar structures are located in close proximity, for example at less than $20b$ apart, where b is the dimension of the structure normal to the wind.

4 The formulae given in 4.7.2.1(a) is valid for infinitely long cylindrical structures. The value of S_t decreases slowly as the ratio of length to maximum transverse width decreases, the reduction being up to about half the value, if the structure is only three times higher than its width. Vortex shedding need not be considered, if the ratio of length to maximum transverse dimension is less than 2.0.

4.8 Dynamic Wind Response

4.8.1 *General*

Tall buildings/structures which are 'wind sensitive' shall be designed for dynamic wind loads. Hourly mean wind speed is used as a reference wind speed to be used in dynamic wind analysis. For calculation of along wind loads and response (bending moments, shear forces, or tip deflections) the Gust factor (GF) method is used as specified in 4.8.2. The across wind design peak base overturning moment and tip deflection shall be calculated using 4.8.3.

4.8.2 *Along Wind Response*

For calculation of along-wind load effects at a level s on a building/structure, the design hourly mean wind pressure at height z shall be multiplied by the Gust factor (G). This factor is dependent on both the overall height h and the level s under consideration (*see* Fig. 9). For calculation of base bending moment and deflection at the top of the building/structure, 's' should be taken as zero.

Note that $0 < s <$ h and $s < z < h$.

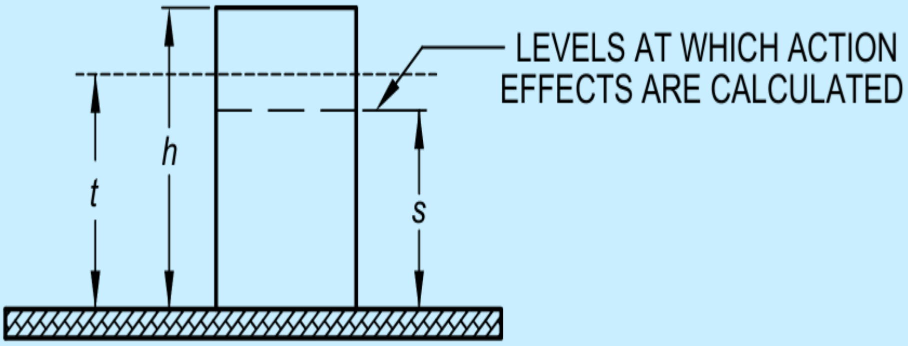


FIG. 9 NOTATIONS FOR HEIGHTS

The design peak along wind base bending moment (M_a) shall be obtained by summing the moments resulting from design peak along wind loads acting at different heights, z, along the height of the building/structure and can be obtained from:

$$M_a = \sum F_z \, z$$

$$F_z = C_{f,z} A_z \bar{p}_d G$$

where

F_z = design peak along wind load on the building/structure at any height z;

A_z = the effective frontal area of the building/structure at any height z, in m^2;

$\bar{p}_d$ = design hourly mean wind pressure corresponding to $\bar{V}_{z,d}$ and obtained as $0.6\bar{V}_{z,d}^2$ (N/m^2);

$\bar{V}_{z,d}$ = design hourly mean wind speed at height z, in m/s (*see* **4.4.4**);

$C_{f,z}$ = the drag force coefficient of the building/structure corresponding to the area A_z;

G = Gust Factor and is given by:

$$1 + r\sqrt{\left[g_v^2 B_s (1+\phi)^2 + \frac{H_s g_R^2 SE}{\beta}\right]}$$

r = roughness factor which is twice the longitudinal turbulence intensity, $I_{h,i}$ (*see* **4.4.5**);

g_v = peak factor for upwind velocity fluctuation

= 3.0 for category 1 and 2 terrains; and

= 4.0 for category 3 and 4 terrains;

B_s = background factor indicating the measure of slowly varying component of fluctuating wind load cused by the lower frequency wind speed variations

$$= \frac{1}{\left[1 + \frac{\sqrt{0.26(h-s)^2 + 0.46 b_{sh}^2}}{L_h}\right]}$$

where

b_{sh} = average breadth of the building/structure between heights s and h;

L_h = measure of effective turbulence length scale at the height, h, in m;

$= 85\left(\frac{h}{10}\right)^{0.25}$ for terrain category 1 to 3; and

$= 70\left(\frac{h}{10}\right)^{0.25}$ for terrain category 4

ϕ = factor to account for the second order turbulence intensity;

$$= \frac{g_v I_{h,i}\sqrt{B_s}}{2}$$

$I_{h,i}$ = turbulence intensity at height h in terrain category i;

H_s = height factor for resonance response;

$$= 1 + \left(\frac{s}{h}\right)^2$$

S = size reduction factor given by

$$= \frac{1}{\left[1 + \frac{3.5 f_a h}{\overline{V}_{h,d}}\right]\left[1 + \frac{4 f_a b_{0h}}{\overline{V}_{h,d}}\right]}$$

where

b_{0h} = average breadth of the building/structure between 0 and h;

E = spectrum of turbulence in the approaching wind stream:

$$\frac{\pi N}{\left(1 + 70.8 N^2\right)^{5/6}}$$

where

N = an effective reduced frequency

$$= \frac{f_a L_h}{\overline{V}_{h,d}}$$

f_a = first mode natural frequency of the building/structure in along wind direction, in Hz

$\overline{V}_{h,d}$ = design hourly mean wind speed at height, h in m/s (*see* **4.4.4**);

β = damping coefficient of the building/structure (*see* Table 39); and

g_R = peak factor for resonant response.

$$= \sqrt{\left[2\ln(3600 f_a)\right]}$$

Table 39 Suggested Values of Structural Damping Coefficients

(*Clauses* 4.8.2 *and* 4.8.3.1)

Sl No. (1)	Kind of Structure (2)	Damping Coefficient, β (3)
i)	Welded steel structures	0.010
ii)	Bolted steel structures/RCC structures	0.020
iii)	Prestressed concrete structures	0.016

4.8.2.1 *Peak acceleration in along wind direction*

The peak acceleration at the top of the building/structure in along wind direction ($\hat{\ddot{x}}$ in m/s^2) is given by the following equation:

$$\hat{\ddot{x}} = (2\pi f_a)^2 \bar{x}\, g_R\, r \sqrt{\frac{SE}{\beta}}$$

where

$\bar{x}$ = mean deflection at the position where the acceleration is required. Other notations are same as given in 9.2. For computing the peak acceleration in the along wind direction, a mean wind speed at the height of the building/structure, $\bar{V}_h$ corresponding to a 5 year mean return period shall be used. A reduced value of 0.011 is also suggested for the structural damping, β for reinforced concrete structures.

4.8.3 *Across Wind Response*

This section gives method for determining equivalent static wind load and base overturning moment in the across wind direction for tall enclosed buildings and towers of rectangular cross section. Calculation of across wind response is not required for lattice towers.

The across wind design peak base bending moment M_c for enclosed buildings and towers shall be determined as follows:

$$M_c = 0.5 g_h \bar{p}_h b h^2 (1.06 - 0.06k)\sqrt{\frac{\pi C_{fs}}{\beta}}$$

where

g_h = a peak factor;

= $\sqrt{[2\ln(3600 f_c)]}$ in cross wind direction;

$\bar{p}_h$ = hourly mean wind pressure at height h, in Pa;

b = breadth of the structure normal to the wind, in m;

h = height of the structure, in m;

k = a mode shape power exponent for representation of the fundamental mode shape as represented by:

$$\psi(z) = \left(\frac{z}{h}\right)^k \text{; and}$$

f_c = first mode natural frequency of the building/structure in across wind direction, in Hz.

The across wind load distribution on the building/structure can be obtained from M_c using linear distribution of loads as given below:

$$F_{z,c} = \left(\frac{3M_c}{h^2}\right)\left(\frac{z}{h}\right)$$

where

$F_{z,c}$ = across wind load per unit height at height z.

4.8.3.1 *Peak acceleration in across wind direction*

The peak acceleration at the top of the building/structure in across-wind direction ($\hat{\ddot{y}}$ in m/s^2) with approximately constant mass per unit height shall be determined as follows:

$$\hat{\ddot{y}} = 1.5 \frac{g_h \, \bar{p}_h \, b}{m_0}\left(0.76 + 0.24k\right)\sqrt{\left(\frac{\pi C_{fs}}{\beta}\right)}$$

where

C_{fs} = across wind force spectrum coefficient generalized for a linear mode, (*see* Fig. 10);

β = damping coefficient of the building/structure (*see* Table 39); and

m_0 = the average mass per unit height of the structure, in kg/m.

Typical values of the mode shape power exponent, k are as follows:

a) uniform cantilever, $k = 1.5$

b) slender framed structure (moment resisting), $k = 0.5$

c) building with a central core and moment resisting façade, $k = 1.0$

d) lattice tower decreasing in stiffness with height, or a tower with a large mass at the top, $k = 2.3$

4.8.4 *Combination of Along Wind and Across Wind Load Effects*

The along wind and across wind loads have to be applied simultaneously on the building/structure during design.

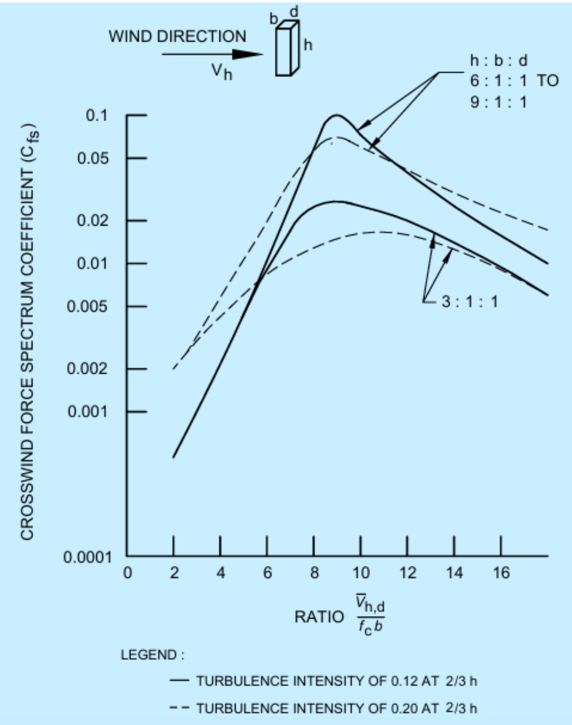


FIG. 10(A) VALUES OF THE CROSS WIND FORCE SPECTRUM COEFFICIENT FOR SQUARE SECTION BUILDINGS

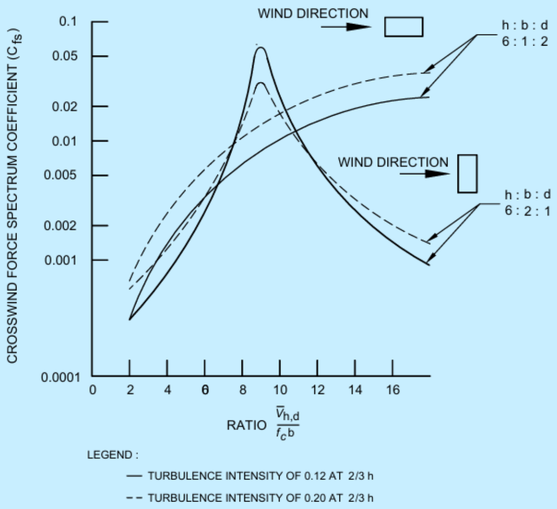


FIG. 10(B) VALUES OF THE CROSS WIND FORCE SPECTRUM COEFFICIENT FOR 2 : 1 AND 1 : 2 RECTANGULAR SECTION BUILDINGS

FIG. 10 WIND FORCE SPECTRUM COEFFICIENTS

5 EARTHQUAKE EFFECTS — GENERAL

For assessment of earthquake loads, determination of seismic zones and earthquake resistant design of buildings, good practice [C-1(6)] shall be referred to. Additionally, it outlines the principles of earthquake-resistant design, desirable and unacceptable features of earthquake-resistant structural system configurations and methods of analysis and treatment of geotechnical aspects for all types of structures.

6 EARTHQUAKE EFFECTS — BUILDINGS

6.1 *Masonry Buildings*

6.1.1 Provisions given in Part C ‘Structural Design/Section 4 Masonry’ of this NBCS deals with the selection of materials, special aspects related to design and construction of new earthquake-resistant masonry buildings, including masonry buildings using rectangular masonry units with cast in-situ or prefabricated flooring and roofing elements.

6.1.2 Guidelines for earthquake-resistant design of buildings constructed using masonry of low strength and earthen buildings are covered in as per good practice [C-1(7)].

6.2 *Concrete Buildings*

Provisions given in Part C ‘Structural Design/ Section 5 Structural Concrete’ of this NBCS and good practice [C-1(8)] deal with the selection of materials and special aspects related to design and construction for cast in-situ earthquake-resistant reinforced concrete (RC) buildings.

6.3 *Steel Buildings*

Provisions given in Part C ‘Structural Design/Sec 6A Steel’ of this NBCS and good practice [C-1(9)] deal with the selection of materials, special aspects related to design and construction for earthquake-resistant steel buildings.

7 SNOW LOAD

7.1 This clause deals with snow loads on roofs of buildings. Roofs should be designed for the actual load due to snow or for the imposed loads specified in 3, whichever is more severe.

NOTE — Mountainous regions in northern and eastern parts of India are subjected to snow-fall. In northern India, parts of union territory of Jammu and Kashmir (J and K), union territory of Ladakh, Himachal Pradesh, Uttarakhand and in eastern India, parts of Arunachal and Sikkim experience snow-fall of varying depths two to three times in a year.

7.2 Notations

a) μ (Dimensionless) — Nominal values of the shape coefficients, taking into account snow drifts, sliding snow, etc, with subscripts, if necessary;

b) l_i (m) — Horizontal dimension with numerical subscripts, if necessary;

c) h_i (m) — Vertical dimensions with numerical subscripts, if necessary;

d) β_i (degree) — Roof and other surface slope;

e) s_0 (kPa) — Characteristic value of snow load on the ground with a specified annual exceedance probability;

f) s (kPa) — Snow load on roofs other surfaces; and

g) A (m) — Site altitude above sea level.

7.3 Snow Load in Roof(s)

7.3.1 The minimum design snow load on a roof area or any other area above ground which is subjected to snow accumulation is obtained by multiplying the snow load on ground, s_o by the shape coefficient μ, as applicable to the particular roof area considered, expressed as:

$$s = \mu\, s_o$$

where

s = design snow load on plan area of roof, in Pa;

μ = shape coefficient (*see* 7.4); and

s_o = ground snow load in Pa (1 Pa=1 N/m^2).

NOTE — Ground snow load at any place depends on the critical combination of the maximum depth of undisturbed aggregate cumulative snow fall and its average density. In due course the characteristic snow load on ground for different regions will be included based on studies. Till such time the users of this NBCS are advised to contact either Defence Geoinformatics Research Establishment (DGRE), Chandigarh of Defence Research and Development Organization (DRDO), or India Meteorological Department (IMD), Pune in the absence of any specific information for any location.

7.3.2 *Characteristic Ground Snow Load* (s_0)

The characteristic ground snow load (s_0) at any site is defined based on an annual probability of exceedance of 0.034 and corresponds to a mean return period of 30 years. The value of s_0 (kPa) for any site in snow-bound regions of Indian Himalayas should be obtained using the procedure described in Annex H.

NOTE — Annex H gives the characteristic ground snow load map for union territory of Jammu and Kashmir, union territory of Ladakh, Himachal Pradesh, Uttarakhand and Sikkim resulting from studies conducted by DGRE, Chandigarh.

7.3.3 *Partial Loading Due to Melting, Sliding, Snow Redistribution and Snow Removal*

A loading corresponding to severe imbalances resulting from snow removal, redistribution, sliding, melting, etc (for example, zero snow load on specific parts of the roof) should always be considered. Such considerations are particularly important for structures which are sensitive to unbalance loading (for example, curved roofs, arches, domes, collar beam roofs, continuous beam systems). Water load due to ponding in flat roof as well as valley of pitched roof shall be taken as not less than 0.24 kPa.

7.3.4 *Ponding Instability*

7.3.4.1 Roofs shall be designed to preclude ponding.

7.3.4.2 For flat roofs (or with a small slope), roof deflections caused by snow loads shall be investigated when determining the likelihood of ponding from rain-on-snow or from snow meltwater. The angle for snow melting is 15º.

7.4 Shape Coefficients

7.4.1 *General Principles*

In perfectly calm weather, falling snow would cover roofs and the ground with a uniform blanket of snow and the design snow load could be considered as a uniformly distributed load. Truly uniform loading conditions, however, are rare and have usually only been observed in areas that are sheltered on all sides by high trees, buildings, etc. In such a case, the shape coefficient would be equal to unity.

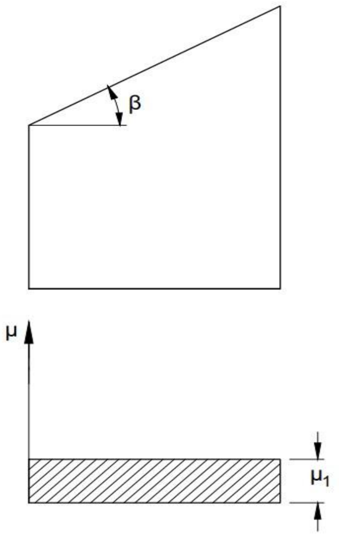
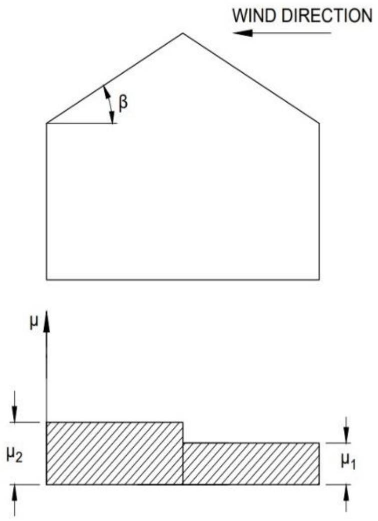
In most regions, snow-falls are accompanied or followed by winds. The winds will redistribute the snow and on some roofs especially multilevel roofs, the accumulated drift load may reach a multiple of the ground load. Roofs which are sheltered by other buildings, vegetation, etc, may collect more snow load than the ground level. The phenomenon is of the same nature as that illustrated for multilevel roofs in 7.4.2.4.

So far, sufficient data are not available to determine the shape coefficient on a statistical basis. Therefore, a nominal value is given. A representative sample of roofs is shown in 7.4.2. However, in special cases such as strip loading, cleaning of the roof periodically by deliberate heating of the roof, etc, have to be treated separately. However, no reduction in load of snow on roof having underside insulation and/or internal heating system shall be done.

The distribution of snow in the direction parallel to the caves is assumed to be uniform.

7.4.2 *Shape Coefficients for Selected Types of Roofs*

7.4.2.1 *Monopitched and simple pitched roofs*

	 Simple Flat and Monopitch Roofs	 Simple Pitched Roofs (Positive Roof Slope)*
$0° < \beta \leq 15°$		$\mu_2 = \mu_1 = 0.80$

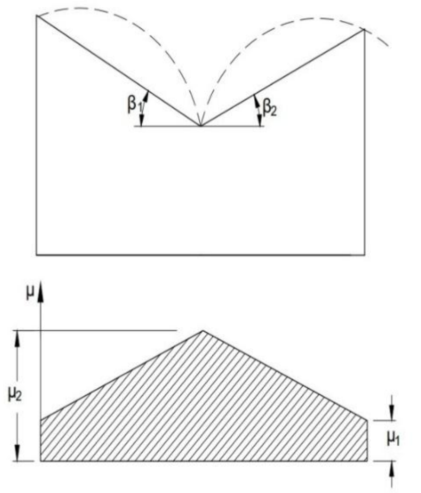
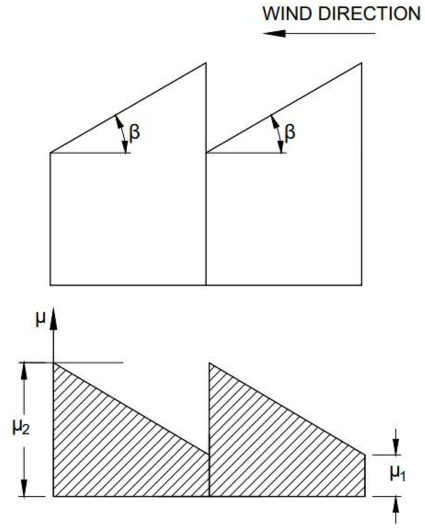
$15° < \beta \leq 30°$	$\mu_1 = 0.80$	$\mu_2 = 0.80 + 0.40\left(\frac{\beta - 15}{15}\right)$ $\mu_1 = 0.80$
$30° < \beta \leq 60°$	$\mu_1 = 0.80\left(\frac{60 - \beta}{30}\right)$	$\mu_2 = 1.20\left(\frac{60 - \beta}{30}\right)$ $\mu_1 = 0.80\left(\frac{60 - \beta}{30}\right)$
$\beta > 60°$	$\mu_1 = 0$	$\mu_2 = \mu_1 = 0$
*For asymmetrical simple pitched roofs, each side of the roof shall be treated as one half of corresponding symmetrical roofs.		

NOTES

1 For monopitch roof, wind direction will not affect the value of μ.

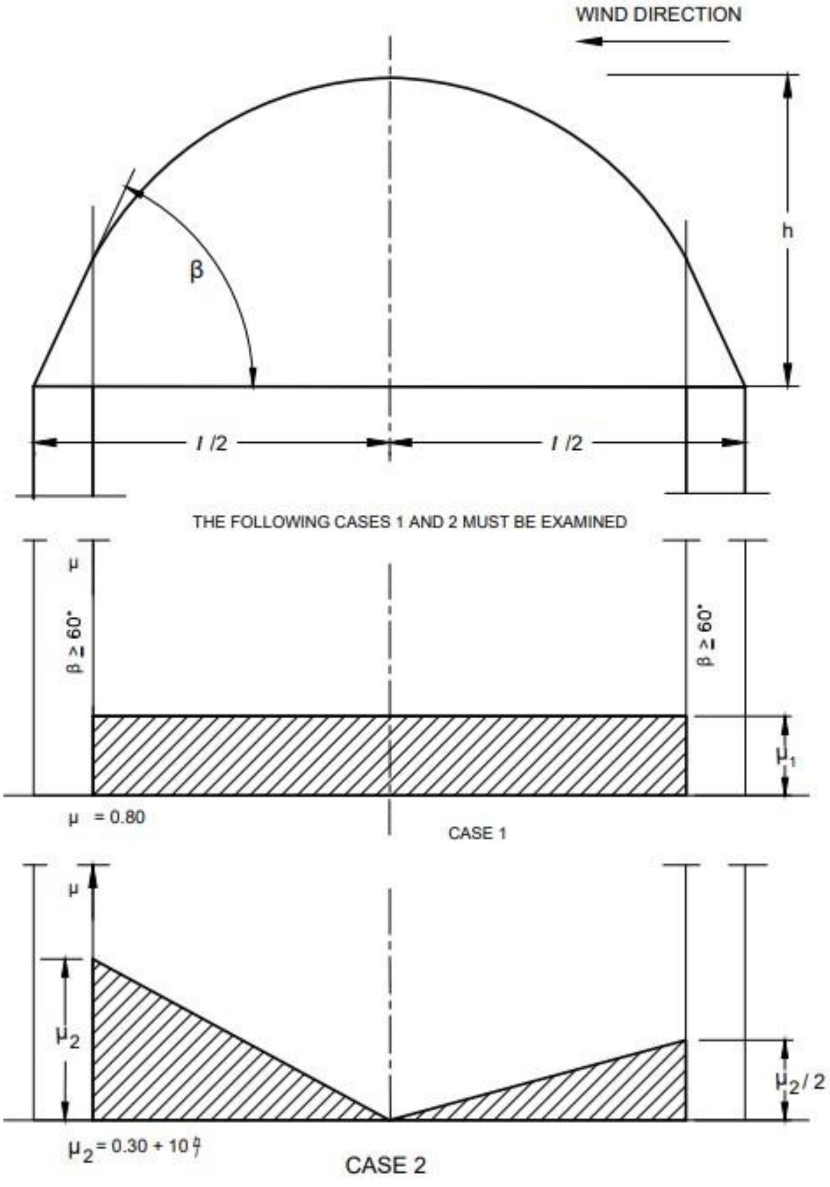
2 The values of $\mu 1$ and $\mu 2$ shall be reversed in case the wind direction changes from left to right for simple pitched roof.

7.4.2.2 *Multiple pitched roofs*

	 Simple on Multiple Pitched Roofs (Negative Roof Slope)	 Two – Span or Multispan Roofs
$0° < \beta \leq 30°$	$\mu_2 = 0.80\left(\frac{30 + \beta}{30}\right)$ $\mu_1 = 0.80$	$\mu_2 = 0.80\left(\frac{30 + \beta}{30}\right)$ $\mu_1 = 0.80$
$30° < \beta \leq 60°$	$\mu_1 = 1.60$ $\mu_1 = 0.80\left(\frac{60 - \beta}{30}\right)$	$\mu_2 = 1.60$ $\mu_1 = 0.80\left(\frac{60 - \beta}{30}\right)$

$\beta > 60°$	$\mu_1 = 1.60$ $\mu_1 = 0$	$\mu_2 = 1.60$ $\mu_1 = 0$

7.4.2.3 *Simple curved roofs*

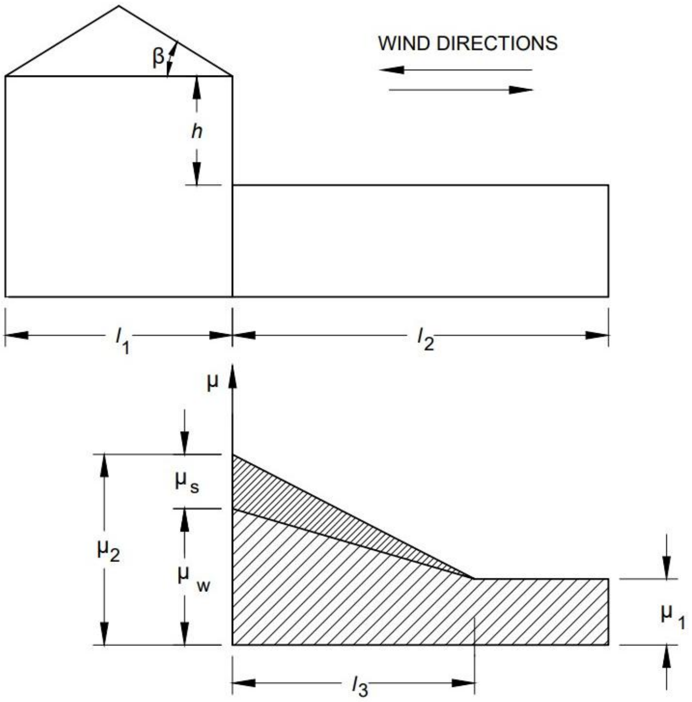

WIND DIRECTION
h
β
l /2
l /2
THE FOLLOWING CASES 1 AND 2 MUST BE EXAMINED
μ
β ≥ 60°
β ≥ 60°
μ1
μ = 0.80
CASE 1
μ
μ2
μ2 / 2
μ2 = 0.30 + 10 h/l
CASE 2

Restrictions:

$\mu_2 \leq 2.3$

$\mu = 0 \; if \; \beta \geq 60^o$

7.4.2.4 *Multilevel roofs*[1)]



$$\mu_1 = 0.80$$

$$\mu_2 = \mu_s + \mu_w$$

where

μ_s = due to sliding; and

μ_w = due to wind.

$l_3 = 2h$ [2)] but is restricted as follows:

$$5\ m \leq l_3 \leq 15\ m$$

$$\mu_w = \frac{l_1 + l_2}{2h} \leq \frac{kh}{s_0} \text{ with the restriction } 0.80 \leq \mu_w \leq 4.0$$

where

h is in metres

s_0 is in kPa (kN/m^2)

$k = 2\ \text{kN/m}^2$

NOTES

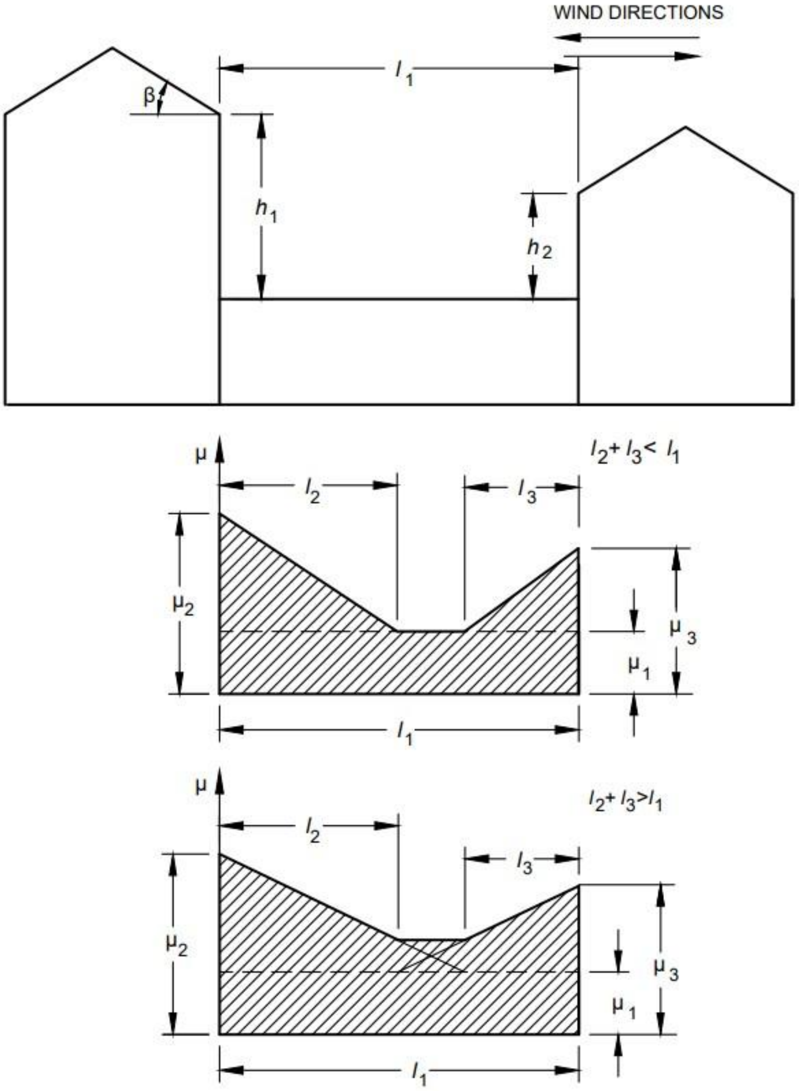
1 A more extensive formula for μ_w is described in Annex J.

2 If $l_2 < l_3$, the coefficient μ is determined by interpolation between μ_1 and μ_2.

If $\beta > 15^\circ$: μ_s is determined from an additional load amounting to 50 percent of the maximum total load on the adjacent slope of the upper roof and is distributed linearly as shown in the figure. The load on the upper roof is calculated according to **7.4.2.1** or **7.4.2.2**.

If $\beta \leq 15^\circ$: $\mu_s = 0$

7.4.2.5 *Complex multilevel roofs*


WIND DIRECTIONS
l_1
β
h_1
h_2
μ
$l_2 + l_3 < l_1$
l_2
l_3
μ_2
μ_3
μ_1
l_1
μ
$l_2 + l_3 > l_1$
l_2
l_3
μ_2
μ_3
μ_1
l_1

$l_2 = 2h_1$; $l_3 = 2h_2$; $\mu_1 = 0.80$;

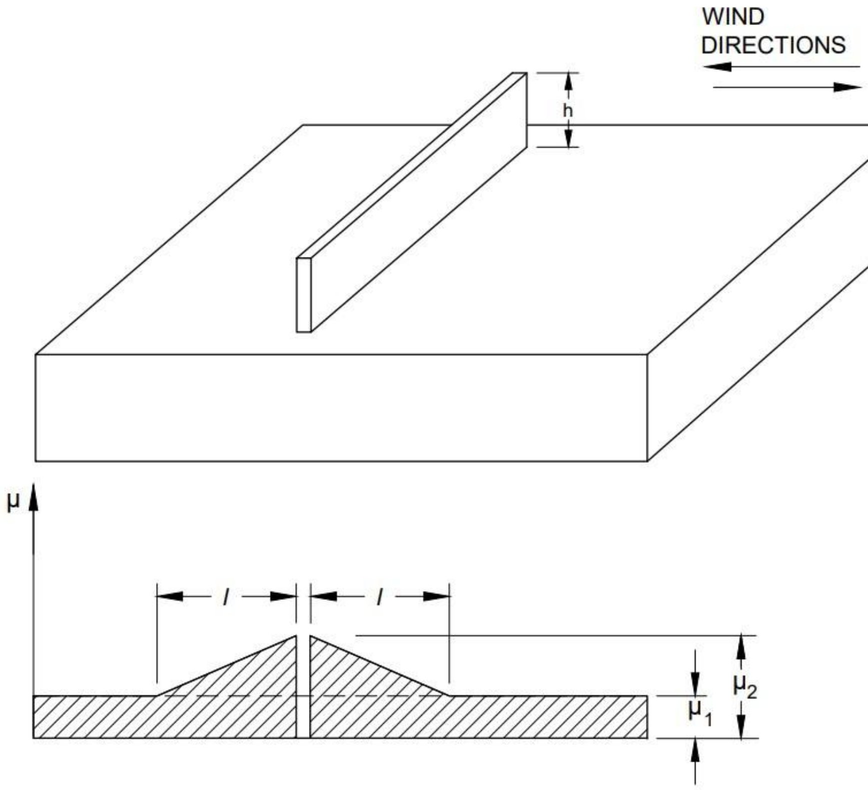
Restrictions:

$5\,m \leq l_2 \leq 15\,m$

$5\,m \leq l_3 \leq 15\,m$

μ_2 and $\mu_3 = \mu_s + \mu_w$, are calculated according to **7.4.2.1**, **7.4.2.2** and **7.4.2.4**

7.4.2.6 *Roofs with local projections and obstructions*



$$\mu_2 = \frac{kh}{s_0}$$

$$\mu_1 = 0.80$$

where

h is in metres

s_0 is in kPa $(\mathrm{kN/m^2})$

$k = 2\,\mathrm{kN/m^2}$

$l = 2\,h$

Restriction:

$0.80 \le \mu_2 \le 2.0$

$5\,m \le l \le 15\,m$

7.4.3 *Shape Coefficients in Areas Exposed to Wind*

The shape coefficients given in 7.4.2 and Annex J may be reduced by 15 percent, provided the designer has demonstrated that the following conditions are fulfilled:

a) The building is located in an exposed location such as open level terrain with only scattered buildings, trees or other obstructions so that the roof is exposed to the winds on all sides and is not likely to become shielded in the future by obstructions higher than the roof within a distance from the building equal to ten times the height of the obstruction above the roof level; and

b) The roof does not have any significant projections such as parapet walls which may prevent snow from being blown off the roof.

NOTE — In some areas, winter climate may not be of such a nature as to produce a significant reduction of roof loads from the snow load on the ground. This typically occurs in winter calm valleys in mountainous regions, where layers of snow may accumulate on roofs without any appreciable removal by wind, as well as in relatively higher temperature areas where the maximum snow load may result from a single snowstorm, occasionally without significant wind removal. In such conditions, the determination of shape coefficients should be based on local experience, with due consideration given to the likelihood of wind drifting and sliding.

8 SPECIAL LOADS

8.1 This clause gives guidance on loads and load effects due to temperature changes, soil and hydrostatic pressures, internally generating stresses (due to creep, shrinkage, differential settlement, etc), accidental loads, etc, to be considered in the design of buildings as appropriate. This clause also includes guidance on load combinations. The nature of loads to be considered for a particular situation is to be based on engineering judgment (*See also* **3.6**)

8.2 Temperature Effects

8.2.1 Expansion and contraction due to changes in temperature of the materials of a structure shall be considered in design. Provision shall be made either to relieve the stress by the provision of expansion/contraction joints in accordance with good practice [C-1(10)] or design the structure to carry additional stresses due to temperature effects as appropriate to the problem.

8.2.1.1 The temperature range varies for different regions and under different diurnal and seasonal conditions. The absolute maximum and minimum temperature which may be expected in different localities in the country are indicated in good practice [C-1(11)]. These figures may be used for guidance in assessing the maximum variations of temperature.

8.2.1.2 The temperatures indicated are the air temperatures in the shade. The range of variation in temperature of the building materials may be appreciably greater or less than the variation of air temperature and is influenced by the condition of exposure and the rate at which the materials composing the structure absorb or radiate heat. This difference in temperature variations of the material and air should be given due consideration.

8.2.1.3 The structural analysis must take account of changes of the mean (through the section) temperature in relation to the initial (st) and the temperature gradient through the section:

a) it should be borne in mind that the changes of mean temperature in relation to the initial are liable to differ as between one structural element and another in buildings or structures, as for example, between the external walls and the internal elements of a building. The distribution of temperature through section of single-leaf structural elements may be assumed linear for the purpose of analysis; and

b) the effect of mean temperature changes t_1 and t_2 and the temperature gradients v_1 and v_2 in the hot and cold seasons for single-leaf structural elements shall be evaluated on the basis of analytical principles.

NOTES

1 For portions of the structure below ground level, the variation of temperature is generally insignificant. However, during the period of construction, when the portions of the structure are exposed to weather elements, adequate provision should be made to encounter adverse effects, if any.

2 If it can be shown by engineering principles, or if it is known from experience, that neglect of some or all the effects of temperature do not affect the structural safety and serviceability, they need not be considered in design.

8.3 Hydrostatic and Soil Pressure

8.3.1 In the design of structures or parts of structures below ground level such as retaining walls and other walls in basement floors, the pressure exerted by the soil or water or both shall be duly accounted for on the basis of established theories. Due allowance shall be made for possible surcharge from stationary or moving loads. When a portion or whole of the soil is below the free water surface, the lateral earth pressure shall be evaluated for weight of soil diminished by buoyancy and the full hydrostatic pressure.

8.3.1.1 All foundation slabs and other footings subjected to water pressure shall be designed to resist a uniformly distributed uplift equal to the full hydrostatic pressure. Checking of overturning of foundation under submerged condition shall be done considering buoyant weight of foundation.

8.3.2 While determining the lateral soil pressure on column like structural members such as pillars which rest in sloping soils, the width of the member shall be taken as follows (*see* Fig. 11).

Sl No. (1)	*Actual Width of Member* (2)	*Ratio of Effective Width to Actual Width* (3)
i)	Less than 0.5 m	3.0
ii)	Beyond 0.5 m and up to 1 m	3.0 to 2.0
iii)	Beyond 1 m	2.0

The relieving pressure of soil in front of the structural member concerned may generally not be taken into account.

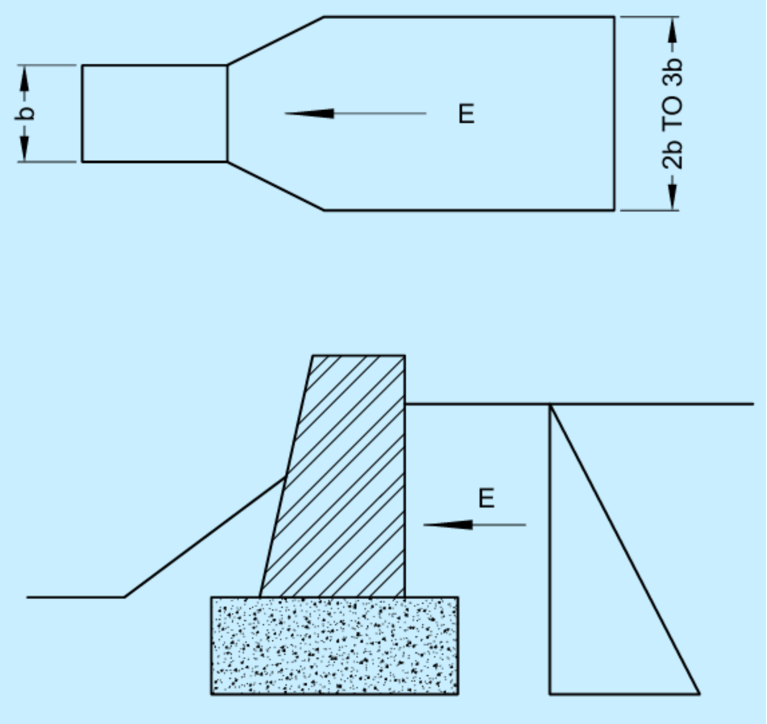


FIG. 11 SKETCH SHOWING EFFECTIVE WIDTH OF PILLAR FOR CALCULATING SOIL PRESSURE

8.3.3 Safe-guarding of structures and structural members against overturning and horizontal sliding shall be verified. Imposed loads having favourable effect shall be disregarded for the purpose. Due consideration shall be given to the possibility of soil being permanently or temporarily removed.

8.4 Fatigue

8.4.1 *General*

Fatigue cracks are usually initiated at points of high stress concentration. These stress concentrations may be caused by or associated with holes (such as bolt or rivet holes in steel structures), welds including stray or fusions in steel structures, defects in materials and local and general changes in geometry of members. The cracks usually propagate if the loading is cyclic and repetitive.

Where there is such cyclic and repetitive loading, sudden changes of shape of a member or part of a member, especially in regions of tensile stress and/or local secondary bending, shall be avoided. Suitable steps shall be taken to avoid critical vibrations due to wind and other causes.

8.4.2 Where necessary, permissible stresses shall be reduced to allow for the effects of fatigue. Allowance for fatigue shall be made for combinations of stresses due to dead load and imposed load. Stresses due to wind and earthquakes may be ignored, when fatigue is being considered, unless otherwise specified in relevant Codes of practice.

Each element of the structure shall be designed for the number of stress cycles of each magnitude to which it is estimated that the element is liable to be subjected during the expected life of the structure. The number of cycles of each magnitude shall be estimated in the light of available date regarding the probable frequency of occurrence of each type of loading.

NOTE — Apart from the general observations made herein, the section is unable to provide any precise guidance in estimating the probabilistic behaviour and response of structures of various types arising out of repetitive loading approaching fatigue conditions in structural members, joints, materials, etc.

8.5 Structural Safety During Construction

All loads required to be carried by the structures or any part of it due to storage or positioning of construction materials and erection equipment including all loads due to operation of such equipment, shall be considered as erection loads. Proper provision shall be made, including temporary bracings, to take care of all stresses due to erection loads. The conjunction with the temporary bracings shall be capable of sustaining these erection loads, without exceeding the permissible stresses specified in respective Codes of practice. Dead load, wind load and such parts of imposed load, as would be imposed on the structure during the period of erection, shall be taken as acting together with erection loads.

8.6 Accidental Loads

The occurrence of which, with a significant value, is unlikely on a given structure over the period of time under consideration and also in most cases, is of short duration. The occurrence of an accidental load could, in many cases, be expected to cause severe consequences, unless special measures are taken.

The accidental loads arising out of human action include the following:

a) Impacts and collisions;
b) Explosions; and
c) Fire.

Characteristic of the above stated loads are that they are not a consequence of normal use and that they are undesired and that extensive effects are made to avoid them. As a result, the probability of occurrence of an accidental load is small whereas the consequences may be severe.

The causes of accidental loads may be:

a) inadequate safety of equipment (due to poor design or poor maintenance); and
b) wrong operation (due to insufficient teaching or training, indisposition, negligence or unfavourable external circumstances).

In most cases, accidental loads only develop under a combination of several unfavourable occurrences. In practical applications, it may be necessary to neglect the most unlikely loads. The probability of occurrence of accidental loads, which are neglected, may differ for different consequences of a possible failure. A data base for a detailed calculation of the probability will seldom be available.

8.6.1 *Impact and Collisions*

8.6.1.1 *General*

During an impact, the kinetic impact energy has to be absorbed by the vehicle hitting the structure and by the structure itself. In an accurate analysis, the probability of occurrence of an impact with a certain energy object hitting the structure and the structure itself at the actual place must be considered. Impact energies for dropped object should be based on the actual loading capacity and lifting height.

Common sources of impact are:

a) vehicles;

b) dropped objects from cranes, fork lifts, etc;

c) cranes out of control, crane failures; and

d) flying fragments.

The codal requirements regarding impact from vehicles and cranes are given in **8.6.1.2** and **8.6.1.3**.

8.6.1.2 The requirements for loads as a result of collision between vehicle and structural or non-structural elements shall be as per **8.6.1.2.1** and **8.6.1.2.2**.

8.6.1.2.1 *Collisions between vehicles and structural elements*

In road traffic, the requirement that a structure shall be able to resist collision may be assumed to be fulfilled, if it is demonstrated that the structural element is able to stop a fictitious vehicle, as described below. It is assumed that the vehicle strikes the structural element at a height of 1.2 m in any possible direction and at a speed of 10 m/s (36 km/h).

The fictitious vehicle shall be considered to consist of two masses m_1 and m_2 which during compression of the vehicle, produce an impact force increasing uniformly from zero, corresponding to the rigidities C_1 and C_2. It is assumed that the mass m_1 is broken completely before the breaking of mass m_2 begins.

The following numerical values should be used:

a) $m_1 = 400$ kg, $C_1 = 10\ 000$ kN/m, the vehicle is compressed; and

b) $m_2 = 12\ 000$ kg, $C_2 = 300$ kN/m, the vehicle is compressed.

NOTE — The described fictitious collision corresponds in the case of a non-elastic structural element to a maximum static force of 630 kN for the mass m_1 and 600 kN for the mass m_2 irrespective of the elasticity, it will therefore be on the safe side to assume the static force to be 630 kN.

In addition, breaking of the mass m_1 will result in an impact wave, the effect of which will depend, to a great extent, on the kind of structural element concerned. Consequently, it will not always be sufficient to design for the static force.

8.6.1.2.1.1 *For structural elements in stilts and car parking levels*

For structural elements in stilts and car parking levels, where driveways and car parking are provided in the buildings which have limited vehicle speeds, the design shall take care of the following considerations:

a) Speed of the vehicle to be 20 km/h maximum (since within a building and inside the car parks, speed of the vehicle may not generally be more than 20 km/h); and

b) Impact to be considered at a height of 450 mm to 600 mm.

Structural elements such as columns, RC walls or vertical load resisting elements shall be designed for loads due to the above unless protected by separate resisting system.

8.6.1.2.2 *Collision between vehicles and non-structural elements:*

Non-structural elements, such as vehicle barriers for car parks shall be designed to resist the impact and the momentum as outlined below:

a) The horizontal force F (in kN), normal to and uniformly distributed over any length of 1.5 m of a barrier for a car park, required to withstand the impact of a vehicle shall be as given below:

$$F = \frac{0.5mv^2}{\delta_c + \delta_b}$$

where

m = gross mass of the vehicle, in kg;

v = velocity of the vehicle normal to the barrier, in m/s;

δ_c = deformation of the vehicle, in mm; and

δ_b = deflection of the barrier, in mm.

b) Where the car park has been designed on the basis that the gross mass of the vehicles using it will not exceed 2500 kg, the following values shall be used to determine the force F:

m = 1500 kg;
v = 4.5 m/s;
δ_c = 100 mm;

For a rigid barrier, for which δ_b may be taken as zero, the force, F, appropriate to vehicles up to 2500 kg gross mass, shall be taken as 150 kN.

c) Where the car park has been designed for vehicles whose gross mass exceeds 2500 kg, the following values shall be used to determine the force F:

m = actual mass of the vehicle for which the car park is designed, in kg;

v = 4.5 m/s;

δ_c = 100 mm;

d) The force determined as in (b) or (c) may be considered to act at bumper height. In the case of car parks intended for motor cars whose gross mass does not exceed 2500 kg, this height may be taken as 375 mm above the floor level.

e) Barriers to access ramps of car parks have to withstand one-half of the force determined in (b) or (c) acting at a height of 610 mm above the ramp.

Opposite to the ends of straight ramps intended for downward travel, which exceed 20 m in length, the barrier shall be designed to withstand twice the force determined in (b) or (c) acting at a height of 610 mm above the ramp.

NOTE – The mass of 1500 kg is taken as being more representative of the vehicle population than the extreme value of 2500 kg.

8.6.1.3 *Safety railings*

With regard to safety, railings put up to protect structures against collision due to road traffic, it should be shown that the railings are able to resist the impact as described in 8.6.1.2.

NOTE — When a vehicle collides with safety railings, the kinetic energy of the vehicle will be absorbed partly by the deformation of the railings and partly by the deformation of the vehicle. The part of the kinetic energy which the railings should be able to absorb without breaking down may be determined on the basis of the assumed rigidity of the vehicle during compression.

8.6.1.4 *Crane impact load on buffer stop*

The basic horizontal load P_y (tonne), acting along the crane track produced by impact of the crane on the buffer stop, is calculated by the following formula:

$$P_y = MV^2/F$$

where

V = speed at which the crane is traveling at the moment of impact (assumed equal to half the nominal value) (m/s).

F = maximum shortening of the buffer, assumed equal to 0.1 m for light duty, mediuL-duty and heavy-duty cranes with flexible load suspension and loading capacity not exceeding 50 t and 0.2 m in every other cranes.

M = reduced crane mass, (t.s^2/m); and is obtained by the formula:

$$M = \frac{1}{g}\left[\frac{P_h}{2} + \left(P_t + kQ\right)\frac{L_k - l}{L_k}\right]$$

where

P_h = crane bridge weight (*t*);

P_t = crab bridge weight (*t*);

k = coefficient, assumed equal to zero for cranes with flexible load suspension and to one for cranes with rigid suspension;

Q = crane loading capacity (*t*);

L_k = crane span (m); and

ℓ = nearness of crab (m); and

g = acceleration due to gravity (9.81 m/s^2).

8.6.2 *Explosions*

8.6.2.1 *General*

Explosions may cause impulsive loading on a structure. The following types of explosions are particularly relevant:

a) Internal gas explosions which may be caused by leakage of gas piping (including piping outside the room), evaporation from volatile liquids or unintentional evaporation from surface material (for example, fire);

b) Internal dust explosions;

c) Boiler failure;

d) External gas cloud explosions; and

e) External explosions of high explosives (TNT, dynamite).

The codal requirement regarding internal gas explosions is given in 8.6.2.2.

8.6.2.2 *Explosion effect in closed rooms*

Gas explosion may be caused, for example by leaks in gas pipes (inclusive of pipes outside for room), evaporation from volatile liquids or unintentional evaporation of gas from wall sheathings (for example, caused by fire).

NOTES

1 The effect of explosions depends on the exploding medium, the concentration of the explosion, the shape of the room, possibilities of ventilation of the explosion and the ductility and dynamic properties of the structure. In rooms with little possibility for relief of the pressure from the explosion, very large pressures may occur.

2 Internal over pressure from an internal gas explosion in rooms of sizes comparable to residential rooms and with ventilation areas consisting of window glass breaking at a pressure of 4 kN/m^2 (3 mm to 4 mm machine made glass) may be calculated from the following method:

a) The over pressure is assumed to depend on a factor A/V, where A is the total windows area, in m^2 and V is the volume, in m^3, of the room considered;

b) The internal pressure is assumed to act simultaneously upon all walls and floors in one closed room; and

c) The action q_o may be taken as static action.

3 If account is taken of the time curve of the action, the schematic correspondence between pressure and time is assumed (*see* Fig. 12), where t_1 is the time from the start of combustion until maximum pressure is reached and t_2 is the time from maximum pressure to the end of combustion. For t_1 and t_2, the most unfavourable values should be chosen in relation to the dynamic properties of the structures. However, the values should be chosen within the intervals as given in Fig. 13.

Figure 12 is based on tests with gas explosions in room corresponding to ordinary residential flats and should, therefore, not be applied to considerably different conditions. The figure corresponds to an explosion caused by town gas and it might, therefore, be somewhat on the safe side in rooms where there is only the possibility of gases with a lower rate of combustion.

The pressure may be applied solely in one room or in more rooms at the same time. In the latter case, all rooms are incorporated in the volume V. Only windows or other similarly weak and light weight structural elements may be taken to be ventilation areas even though certain limited structural parts break at pressures less than q_o.

Figure 12 is given purely as guide and probability of occurrence of an explosion should be checked in each case using appropriate values.

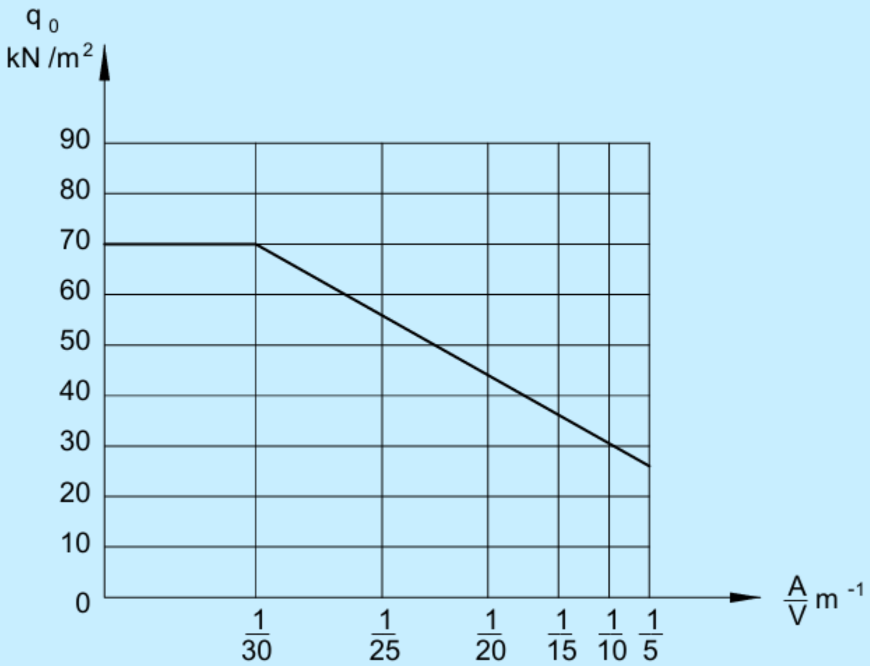


FIG. 12 SKETCH SHOWING RELATION BETWEEN PRESSURE AND TIME

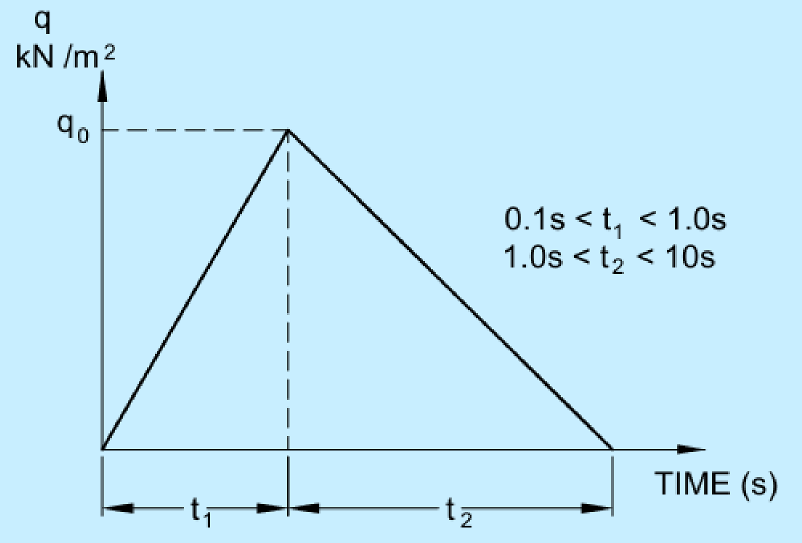


FIG. 13 SKETCH SHOWING TIME INTERVAL AND PRESSURE

8.6.3 *Vertical Load on Air Raid Shelters*

8.6.3.1 *Characteristic values*

As regards buildings in which the individual floors are acted upon by a total characteristic imposed action of up to 5.0 kN/m^2, vertical actions on air raid shelters generally located below ground level, for example, basement, etc, should be considered to have the following characteristic values:

a) Buildings with up to 2 storeys : 28 kN/m^2

b) Buildings with 3-4 storeys : 34 kN/m^2

c) Buildings with more than 4 storeys : 41 kN/m^2

d) Buildings of particularly stable construction irrespective of the number of storeys : 28 kN/m^2

In the case of buildings with floors that are acted upon by a characteristic imposed action larger than 5.0 kN/m^2, the above values should be increased by the difference between the average imposed action on all storeys above the one concerned and 5.0 kN/m^2.

NOTES

1 By storeys it is understood, every utilizable storey above the shelter.

2 By buildings of a particular stable construction, it is understood, buildings in which the load- bearing structures are made from reinforced *in-situ* concrete.

8.6.4 *Fire*

8.6.4.1 *General*

Possible extraordinary loads during a fire may be considered as accidental actions. Examples are loads from people along escape routes and loads on another structure from structure failing because of a fire.

8.6.4.2 *Thermal effects during fire*

The thermal effect during fire may be determined from one of the following methods:

a) Time-temperature curve and the required fire resistance (in min); and

b) An energy balance method.

If the thermal effect during fire is determined from an energy balance method, the fire load is taken to be:

$$q = 12\ t_b$$

where

q = fire action (KJ/m^2 floor); and

t_b = required fire resistance (in min) {*see* [C-1(12)]}.

NOTE — The fire action is defined as the total quantity of heat produced by complete combustion of all combustible material in the fire compartment, inclusive of stored goods and equipment together with building structures and building materials.

8.7 Vibrations

For general details on loads due to vibrations, reference may be made to Annex K.

8.8 Blast Loads

For provisions related to blast loads, *see* Annex L.

8.9 Other Loads

Other loads not included in this Section, such as special loads due to technical process, moisture and shrinkage effects, etc, should be taken into account where stipulated by building design codes or established in accordance with the performance requirement of the structure.

8.10 Landslide Control Measures

Mountainous and hilly terrains are prone to slope instability arising from geological, hydrological and seismic factors, further aggravated by unplanned developmental activities. The following good practices address the specific aspects towards hazard assessment, design and construction:

Sl No. (1)	*Aspects* (2)	*Accepted Standard*(*s*) (3)
i)	Guidelines for preparation of landslide hazard zonation maps	[C-1(13)]
ii)	Preparation of landslide risk assessment maps, combining hazard probability with potential damage through a risk assessment matrix	[C-1(13)]
iii)	Site-specific investigation and stability analysis, including geological mapping, subsurface exploration, laboratory testing and numerical modelling	[C-1(13)]
iv)	Landslide control measures with emphasis on drainage management, slope modification, reinforcement, bio-engineering and protective works	[C-1(13)]
v)	Design and construction of different types of retaining walls	[C-1(13)]
vi)	Micropiles for slope stabilization	[C-1(13)]
vii)	Surface water management in hilly areas	[C-1(13)]
viii)	Siting, design and selection of materials for residential buildings in hilly areas	[C-1(13)]

8.11 Cyclone Resistant Buildings

Cyclone-prone regions are vulnerable to high wind speeds, wind-borne debris and storm surges, which can cause extensive damage to buildings, particularly low-rise and kutcha houses. The following good practices address aspects of loads, design, construction and assessment for improving resilience:

Sl No.	*Aspect*	*Accepted Standard*
(1)	(2)	(3)
i)	Guidelines for improving the cyclonic resistance of low-rise houses and other buildings	[C-1(14)]
ii)	Guidelines for survey of housing and building typology in cyclone prone areas for assessment of vulnerability of regions and post-cyclone damage estimation	[C-1(14)]
iii)	Guidelines for design and construction of cyclone shelters	[C-1(14)]
iv)	Method for determination of performance relating to safety of external building envelope impacted by wind-borne debris	[C-1(14)]
v)	Guidelines for improving the cyclonic resistance capacity of kutcha houses	[C-1(14)]

9 LOAD COMBINATIONS

9.1 General

A judicious combination of the loads keeping in view the probability of:

a) their acting together; and

b) their disposition in relation to other loads and severity of stresses or deformations caused by the combinations of the various loads is necessary to ensure the required safety and economy in the design of a structure.

9.2 Load Combinations

Keeping the aspect specified in **9.1**, the various loads should, therefore, be combined in accordance with the stipulation in the relevant design Codes. In the absence of such recommendations, the following loading combinations, whichever combination produces the most unfavourable effect in the building, foundation or structural member concerned may be adopted (as a general guidance). It should also be recognized in load combinations that the simultaneous occurrence of maximum values of wind, earthquake, imposed and snow loads is not likely.

a) *DL*;

b) *DL* and *IL*;

c) *DL* and W*L*;

d) *DL* and E*L*;

e) *DL* and T*L*;

f) *DL*, *IL* and *WL*;

g) *DL*, *IL* and *EL*;

h) *DL*, *IL* and *TL*

j) *DL*, W*L* and *TL*;

k) *DL*, *EL* and *TL*;

m) *DL*, *IL*, *WL* and *TL*; and

n) *DL*, *IL*, *EL* and *TL*

(*DL* = dead load, *IL* = imposed load, *WL* = wind load, *EL* = earthquake load and *TL* = temperature load).

NOTES

1 When snow load is present on roofs, replace imposed load by snow load for the purpose of above load combinations.

2 The relevant design codes shall be followed for permissible stresses when the structure is designed by working stress method and for partial safety factors when the structure is designed by limit state design method for each of the above load combinations.

3 Whenever imposed load (*IL*) is combined with earthquake load (*EL*), the appropriate part of imposed load as specified in **5** should be used, both for evaluating earthquake effect and also for combined load effects used in such combination.

4 For the purpose of stability of the structure as a whole against overturning, the restoring moment shall be not less than 1.2 times the maximum overturning moment due to dead load plus 1.4 times the maximum overturning moment due to imposed loads. In cases where dead load provides the restoring moment, only 0.9 times the dead load shall be considered. The restoring moments due to imposed loads shall be ignored. In case of high water table, the effects of buoyancy have to be suitably taken into consideration.

5 In case of high water able, the factor of safety of 1.2 against uplift alone shall be provided.

6 The structure shall have a factor against sliding of not less than 1.4 under the most adverse combination of the applied loads/forces. In this case, only 0.9 times the dead load shall be taken into account.

7 Where the bearing pressure on soil due to wind alone is less than 25 percent of that due to dead load and imposed load, it may be neglected in design where this exceeds 25 percent, foundation may be so proportioned that the pressure due to combined effect of dead load, imposed load and wind load does not exceed the allowable bearing pressure by more than 25 percent. When earthquake effect is included, the permissible increase in allowable bearing pressure in the soil shall be in accordance with 5.

8 Reduced imposed load specified in 3 for the design of supporting structures should not be applied in combination with earthquake forces.

9 Other loads and accidental load combination not included should be dealt with appropriately.

10 Crane load combinations are covered in **3.6.4**.

10 MULTI-HAZARD RISK IN VARIOUS DISTRICTS OF INDIA

10.1 Multi-hazard Risk Concept

The commonly encountered hazards are:

a) Earthquake;

b) Cyclone;

c) Wind storm;

d) Floods;

e) Landslides;

f) Liquefaction of soils;

g) Extreme winds;

h) Cloud bursts; and

j) Failure of slopes.

A study of the earthquake, wind/cyclone and flood hazard maps of India indicate that there are several areas in the country which run the risk of being affected by more than one of these hazards.

Further there may be instances where one hazard may cause occurrence or accentuation of another hazard such as landslides may be triggered/accelerated by earthquakes and wind storms and floods by the cyclones.

It is important to study and examine the possibility of occurrence of multiple hazards, as applicable to an area. However, it is not economically viable to design all the structures for multiple hazards. The special structures such as nuclear power plants and life line structures such as hospitals and emergency rescue shelters may be designed for multiple hazards. For such special structures, site specific data have to be collected and the design be carried out based on the accepted levels of risk. The factors that have to be considered in determining this risk are:

a) The severity of the hazard characterized by M.M. (or M.S.K.) intensity in the case of earthquake; the duration and velocity of wind in the storms; and unprotected or protected situation of flood prone areas; and

b) The frequency of occurrence of the severe hazards.

Till such time that risk evaluation procedures are formalized, the special structures may be designed for multiple hazards using the historical data, that can be obtained for a given site and the available code for loads already covered. The designer may have to consider the loads due to any one of the hazards individually or in combination as appropriate.

10.2 Multi-hazard Prone Areas

10.2.1 At a site, more than one hazard may be prominent. In general, the natural hazards are not considered to act together, but need to be considered one at a time. Also, the proportion of combining the man-made hazards with natural hazards also are specified in the NBC. The NBC provides a minimum set of combinations of loads that need to be considered in the design of structures along with the corresponding partial safety factor of the loads in each of the said combinations.

10.2.2 The criteria adopted for identifying multi hazard prone areas may be as follows:

a) *Earthquake and flood risk prone* — Districts which have seismic zone of intensity 7 or more and also flood prone unprotected or protected area. Earthquake and flood can occur separately or simultaneously.

b) *Cyclone and flood risk prone* — Districts which have cyclone and flood prone areas. Here floods can occur separately from cyclones, but simultaneous also along with possibility of storm surge too.

c) *Earthquake, cyclone and flood risk prone* — Districts which have earthquake zone of intensity 7 or more, cyclone prone as well as flood prone (protected or unprotected) areas. Here the three hazards can occur separately and also simultaneously as in (a) and (b) above but earthquake and cyclone will be assumed to occur separately only.

d) *Earthquake and cyclone risk prone* — Districts which have earthquake zone of intensity 7 or more and prone to cyclone hazard too. The two will be assumed to occur separately.

Based on the approach given above, the districts with multi-hazard risk are given in Annex M.

10.3 Use of the List of the District with Multi-Hazard Risk

The list provides some ready information for use of the authorities involved in the task of disaster mitigation, preparedness and preventive action. This information gives the districts which are prone to high risk for more than one hazard. This information will be useful in establishing the need for developing housing design to resist such multi-hazard situation.

11 DOCUMENTATION

11.1 For the successful planning, design and construction of buildings, adequate documentation covering structural design sufficiency, sub-surface investigations, supervision, etc may be required. In particular, compliance with the structural safety requirements of this NBCS shall be demonstrated through appropriate documentation, including the preparation of a Structural Design Basis Report (SDBR), which establishes the basis and assumptions adopted in the structural design.

11.2 Structural Design Basis Report (SDBR)

The Structural design basis report (SDBR) is a document that establishes the basis and assumptions adopted for the structural design of high rise and special buildings, demonstrating that the structure has been designed to ensure safety against various loads, actions and effects, including those arising from natural hazards such as earthquakes, landslides, cyclones and floods, in accordance with the provisions of this NBCS, particularly Part C 'Structural Design' and other relevant Indian Standards.

The preparation and submission of an SDBR provides transparency and traceability of design decisions and enables verification that the structural system, materials, loading criteria and analysis methods adopted are consistent with the applicable provisions. It also serves as a reference document for reviewing authorities and stakeholders and ensures that the registered engineer/structural engineer maintains adequate documentation to substantiate the structural design.

The SDBR (Annex N) sets out the basis for designing the building and consists of the following parts:

a) Part 1 — General information/Data;

b) Part 2 — Load-bearing masonry buildings;
c) Part 3 — Reinforced concrete buildings; and
d) Part 4 — Steel and steel–concrete composite buildings.

For demonstrating compliance with Part C ‘Structural Design’ of this NBCS and the relevant Indian Standards referenced therein, the registered engineer/structural engineer shall submit an SDBR for structures of different complexities along with the drawings and other documents required to be submitted with the application.

ANNEX A

[*Foreword*, *Clause* 2.2]

DEAD LOADS — UNIT WEIGHTS OF CONSTRUCTION MATERIAL AND STORED MATERIALS

A-1 BUILDING MATERIALS

The unit weight of materials used in construction of buildings and structures are specified in Table 40. Also mentioned alongside are the corresponding Indian Standards, if applicable

Table 40 Unit Weight of Building Materials

(*Clause* A-1)

Sl No.	**Materials**	**Nominal Size or Thickness** mm	**Weight**	
			kN	per
(1)	(2)	(3)	(4)	(5)
i)	**Acoustical Material (*see* IS 2526) [C-1(15)]**			
	Eelgrass	10	0.57 to 0.765 × 10^{-2}	m^{2}
	Glass fibre, min	10	0.38 × 10^{-2}	m^{2}
	Hair	10	1.91 × 10^{-2}	m^{2}
	Mineral wool	10	1.345 × 10^{-2}	m^{2}
	Slag wool		2.65	m^{3}
	Cork		2.35	m^{3}
	Wood fibre board		5.9 to 6.15	m^{3}
	Wood particle Board			
	As per IS 3129 [C-1(15)]		3.92	m^{3}
	As per IS 12823 [C-1(15)]		4.9 to 9.9	m^{3}
	As per IS 3478 [C-1(15)]		8.9 to 11.8	m^{3}
	Compressed wood wool	-	3.95 to 4.45	m^{3}
	Mineral/glass wool quilts and mats	-	0.157 to 0.314	m^{3}
	Mineral compressed glass wool tiles	-	1.87 to 2.06	m^{3}
	Polyester board	-	1.87 to 2.06	m^{3}
ii)	**Aggregate, Coarse**			
	Broken stone ballast			
	Dry, well-shaken	–	15.70 to 18.35	m^{3}
	Perfectly wet	–	18.85 to 21.95	m^{3}
	Shingles, 3 to 38 mm	–	14.35	m^{3}
	Broken bricks:			
	Fine	–	14.20	m^{3}

	Coarse	–	9.90	m^3
	Foam slag (foundry pumice)	–	6.85	m^3
	Cinder	–	7.85	m^3
	Slag			
	Iron slag		32.4	m^3
	Steel Slag		31 to 36	m^3
	Copper slag		31 to 36	m^3
	River pebbles		15	m^3
iii)	**Aggregate, Fine**			
	Sand			
	Dry, clean	–	15.10 to 15.70	m^3
	River	–	18.05	m^3
	Wet	–	17.25 to 19.60	m^3
	Brick dust (*SURKHI*)	–	9.90	m^3
	Crushed stone sand (*see* IS 383) [C-1(15)]		19 to 20	m^3
	Quarry dust		14 to 20	m^3
iv)	**Aggregate, Organic**			
	Saw dust, loose	–	1.55	m^3
	Peat			
	Dry	–	5.50 to 6.30	m^3
	Sandy, compact	–	7.85	m^3
	Wet, compact	–	13.35	m^3
v)	**Asbestos**			
	Felt	10	0.145	m^2
	Fibres:			
	Pressed	–	9.40	m^3
	Sprayed	10	0.02	m^2
	Natural	–	29.80	m^3
	Raw	–	5.90 to 8.85	m^3
vi)	**Asbestos Cement Building Pipes** (*see* Sl No. xliii ‘pipes’ in this Table)			
vii)	**Asbestos Cement Gutters** [*see* IS 1626 (Part 2)] [C-1(15)]			
	Boundary wall gutters			
	510 mm × 150 mm × 255 mm	12.5	0.180	m
	455 mm × 150 mm × 305 mm	12.5	0.158	m
	305 mm × 150 mm × 225 mm	12.5	0.129	m
	280 mm × 125 mm × 180 mm	12.5	0.106	m
	Valley gutters			

	915 mm × 205 mm × 230 mm	12.5	0.250	m
	610 mm × 150 mm × 230 mm	12.5	0.162	m
	455 mm × 125 mm × 150 mm	12.5	0.146	m
	405 mm × 125 mm × 255 mm	12.5	0.131	m
	Half round gutters			
	150 mm	9.5	0.043	m
	230 mm	9.5	0.073	m
	305 mm	9.5	0.088	m
viii)	**Asbestos Cement Pressure Pipes** (*see* Sl No. xliii 'Pipes' in this Table)			
ix)	**Asbestos Cement Sheeting** (*see* IS 459) [C-1(15)]			
	Corrugated (pitch – 146 mm)	6	0.118 to 0.130	m^2
	Semi-corrugated (pitch 388 mm)	6	0.118 to 0.127	m^2
	Plain	5	0.09	m^2
x)	**Bitumen**	–	0.8-1	m^3
xi)	**Binders**			
	Fly Ash loose		5.05 to 7.05	m^3
	Fly Ash compacted		16.00	m^3
	Ground Granulated blast furnace slag		14.9	m^3
	Silica fume		3.5 to 7	m^3
	Rice husk ash		1.0 to 3.5	m^3
	Metakaolin		8 to 10	m^3
xii)	**Blocks**			
	Lime-based solid blocks (*see* IS 3115) [C-1(15)], *min*	–	9.8	m^3
	concrete blocks [*see* IS 2185 (Part 1)] [C-1(15)]			
	Grade A (hollow)	–	15	m^3
	Grade B (hollow)	–	11 to 15	m^3
	Grade C (Solid)	–	18	m^3
	Autoclaved cellular concrete blocks [*see* IS 2185 (Part 3)] [C-1(15)]		4.42 to 9.81	m^3
xiii)	**Boards**			
	Cork boards [*see* IS 4253 (Part 1 and Part 2)] [C-1(15)]			
	Compressed		2.16 to 3.73	m^3
	Ordinary		2.15 to 3.72	m^3
	Fibre hard boards (*see* IS 1658) [C-1(15)]			

	Medium hardboard		3.43 to 7.84	m^3
	Standard hardboard		7.84 to 10.05	m^3
	Tempered hardboard		7.84 to 10.05	m^3
	Fibre cement boards (*see* IS 14862) [C-1(15)]		13 to 16	m^3
	Fibre insulation board, ordinary or flame-retardant type bitumen-bounded fibre insulation board (*see* IS 3348*)* [C-1(15)], *Max*	9, 12, 18, 25	3.924	M^3
	Plain gypsum plaster boards [*see* IS 2095 (Part 1)] [C-1(15)]			
	Type A	9.5, 12.5, 15	5.39	m3
	Type H1 and H2	9.5, 12.5, 15	5.88	m3
	Type D	9.5, 12.5, 15	7.84	m3
	Type F and FH	9.5, 12.5, 15	7.84	m3
	Type R1	9.5, 12.5, 15	8.33	m3
	Type R2	9.5, 12.5, 15	9.31	m3
	Type W	9.5, 12.5, 15	8.33	m3
	Coated/laminated gypsum plaster boards [*see* IS 2095 (Part 2)] [C-1(15)]	9.5, 12.5, 15	11.27	M^3
	Reinforced gypsum plaster boards and ceiling tiles [*see* IS 2095 (Part 3)] [C-1(15)], *min*			
	Fibre reinforced Gypsum		7.84	m^3
	Glass reinforced Gypsum plaster board		24.52	m^3
	Glass reinforced Gypsum plaster tiles		5.88	m^3
	Insulating board (*fibre*) (*see* IS 3348) [C-1(15)], *mean*		0.981	m^3
	Laminated board (*fibre*) Medium density (*see* IS 14587) [C-1(15)]		5.88 to 8.82	m^3
	Wood particle boards (*see* IS 3087) [C-1(15)]	–	4.90 to 8.85	m^3
	Low density wood particles boards for insulation purposes (*see* IS 3129) [C-1(15)]	–	3.52	m^3
	High density wood particle boards (*see* IS 3478) [C-1(15)]			
	Type 1 & 2, Grade A	–	11.30	m^3
	Type 1 & 2, Grade B	–	7.94	m^3

xiv)	**Bricks**			
	Common burnt clay bricks (*see* IS 1077) [C-1(15)]	–	15.70 to 18.85	m^3
	Engineering bricks	–	21.20	m^3
	Heavy duty bricks (*see* IS 2180) [C-1(15)]	–	24.50	m^3
	Pressed bricks	–	17.25 to 18.05	m^3
	Refractory bricks	–	17.25 to 19.60	m^3
	Sand cement bricks	–	18.05	m^3
	Sand lime bricks	–	20.40	m^3
	Pulverized fuel-ash lime bricks (*see* IS 12894) [C-1(15)]		12 to 15	m^3
	Pulverized fuel-ash cement bricks (*see* IS 16720) [C-1(15)]		10.8 to 19.6	m^3
	Acid resistance bricks (*see* IS 4860) [C-1(15)]		22.5 to 24.83	m^3
	Soil based bricks (*see* IS 1725) [C-1(15)]		17.5	m^3
	Perforated building bricks (*see* IS 2222) [C-1(15)]		6.8 to 7.75	m^3
	Calcium silicate bricks (*see* IS 4139) [C-1(15)]		25 to 29	m^3
xv)	**Brick Chips and Broken Bricks** (*see* under Sl No. ii 'Broken Bricks' in this Table)			
xvi)	**Brick dust (*SURKHI*)**	–	9.00	m^3
xvii)	**Cast Iron, Manhole Covers** (*see* IS 1726) [C-1(15)]			
	Double triangular (HD)	500	1.16	Cover
		560	1.37	Cover
	Circular (HD)	500	1.16	Cover
		560	1.37	Cover
	Circular (MD)	500	0.57	Cover
		560	0.63	Cover
	Rectangular (MD)	–	0.78	Cover
	Rectangular (LD) :			
	Single seal (Pattern 1)	–	0.23	Cover
	Single seal (Pattern 2)	–	0.15	Cover
	Double seal	–	0.28	Cover
	Square (LD):			
	Single seal	455	0.13	Cover
		610	0.25	Cover
	Double seal	455	0.23	Cover
		610	0.36	Cover

xviii)	**Cast Iron, Manhole Frames** (*see* IS 1726) [C-1(15)]			
	Double triangular (HD)	500	1.09	Frame
		560	1.13	Frame
	Circular (HD)	500	0.83	Frame
		560	1.06	Frame
	Circular (MD)	500	0.57	Frame
		560	0.63	Frame
	Rectangular (MD)	–	0.63	Frame
	Rectangular (LD):			
	Single seal (Pattern 1)	–	0.15	Frame
	Single seal (Pattern 2)	–	0.10	Frame
	Double seal	–	0.23	Frame
	Square (LD):			
	Single seal	455	0.07	Frame
		610	0.13	Frame
	Double seal	455	0.15	Frame
		610	0.18	Frame
xix)	**Cast Iron Pipes** (*see* under Sl No. xliii 'Pipes' in this Table)			
xx)	**Cement**			
	Ordinary (*see* IS 269) and other types	–	14.10	m^3
	Rapid-hardening (*see* IS 8041) [C-1(15)]	–	12.55	m^3
xxi)	**Ceilings**			
	Plaster on tile or concrete	13 mm thick	0.25	m^2
	Plaster on wood lath	25 mm thick	0.39	m^2
	Suspended metal lath and cement plaster	25 mm thick	0.74	m^2
	Suspended metal lath and gypsum plaster	25 mm thick	0.49	m^2
xxii)	**Cement Concrete, Plain**			
	Aerated		7.45	m^3
	No-fines, with heavy aggregate	–	15.70 to 18.80	m^3
	No-fines, with light aggregate	–	8.65 to 12.55	m^3
	With burnt clay aggregate	–	17.25 to 21.20	m^3
	With expanded clay aggregate	–	9.40 to 16.50	m^3
	With clinker aggregate	–	12.55 to 17.25	m^3
	With pumice aggregate	–	5.50 to 11.00	m^3
	With sand and gravel or crushed natural stone aggregate	–	22.00 to 23.50	m^3

	With saw dust	–	6.30 to 16.50	m^3
	With foamed slag aggregate	–	9.40 to 18.05	m^3
	With light weight cinder aggregate		6.4	m^3
	Light weight concrete		8 to 20	m^3
	Cellular concrete (Foam concrete) (*see* IS 6598) [C-1(15)]		3 to 5	m^3
	Grade A, *max*		3.13	m^3
	Grade B		3.13 to 3.92	m^3
	Grade C		3.93 to 4.9	m^3
	Transparent concrete		15	m^3
	Glass fiber reinforced concrete		18 to 22	m^3
	Alkali activated (Geopolymer) concrete (*see* IS 17452) [C-1(15)]		24 to 25	m^3
	Shotcrete (*see* IS 9012) [C-1(15)]		22 to 25	m^3
	Ferro cement		22 to 25	m^3
	Roller compacted concrete		22 to 25	m^3
	Controlled low strength mix		22 to 25	m^3
	Plum concrete (*see* IS 457) [C-1(15)]		22 to 25	m^3
	Autoclaved Aerated Concrete		4.42 to 9.81	m^3
	Vermiculite concrete		6 to 9	m^3
xxiii)	**Cement Concrete, Prestressed** (conforming to IS 1343) [C-1(15)]	–	23.50	m^3
xxiv)	**Cement Concrete, Reinforced:**			
	With 1 percent steel	–	22.75 to 24.20	m^3
	With 2 percent steel	–	23.25 to 24.80	m^3
	With 5 percent steel	–	24.80 to 26.50	m^3
xxv)	**Damp-proofing** (*see* Sl No. xxviii 'Felt bituminous for waterproofing and damp proofing')			
xxvi)	**Earth filling** (*see* Sl No. xlviii 'Soils and gravels in Table 1)			
xxvii)	**Expanded Metal** (conforming to IS 412) [C-1(15)]			
	Size of Mesh, Nominal			
	SWM	LWM		
	mm	mm		
	100	250	0.030	m^2
	100	250	0.024	m^2
	100	250	0.016	m^2

	75	200	0.042	m^2
	75	200	0.032	m^2
	75	200	0.021	m^2
	40	115	0.080	m^2
	40	115	0.060	m^2
	40	75	0.060	m^2
	40	75	0.028	m^2
	40	115	0.039	m^2
	40	75	0.039	m^2
	40	115	0.020	m^2
	40	75	0.020	m^2
	25	75	0.054	m^2
	25	75	0.038	m^2
	25	75	0.028	m^2
	25	75	0.021	m^2
	20	60	0.070	m^2
	20	50	0.070	m^2
	20	60	0.050	m^2
	20	50	0.050	m^2
	20	60	0.036	m^2
	20	50	0.036	m^2
	20	50	0.021	m^2
	20	60	0.021	m^2
	12.5	50	0.050	m^2
	12.5	50	0.050	m^2
	12.5	40	0.040	m^2
	12.5	50	0.030	m^2
	12.5	40	0.030	m^2
	12.5	50	0.025	m^2
	12.5	40	0.025	m^2
	10	40	0.050	m^2
	10	40	0.035	m^2
	10	40	0.028	m^2
	95	285	0.050	m^2
	95	285	0.028	m^2
	95	285	0.020	m^2
	6	25	0.074	m^2
	6	25	0.048	m^2

	6	25	0.038	m^2
	5	20	0.050	m^2
	3	15	0.041	m^2
xxviii)	**Felt, Bituminous for Waterproof and Damp–proofing** (*see* IS 1322) [C-1(15)]			
	Fibre base			
	Type 1 (under lay)	–	7.6×10^{-3}	m^2
	Type 2 (self-finished felt)	-	2.6×10^{-2}	m^2
	Hessian base			
	Type 3 (self-finished felt)			
	Grade 1	–	2.26×10^{-2}	m^2
	Grade 2	–	3.64×10^{-2}	m^2
xxix)	**Finishing** (*see* also 'Floor finishes' given under Sl No. xxxi 'Flooring' and xlv 'Roofing'in Table 1)			
	Plaster:			
	Acoustic	10	0.08	m^2
	Anhydrite	10	0.21	m^2
	Barium Sulphate	10	0.28	m^2
	Fibrous	10	0.09	m^2
	Gypsum or lime	10	0.19	m^2
	Hydraulic lime or cement	10	0.23	m^2
	Plaster ceiling on wire netting	10	0.26	m^2
	NOTE – When wood or metal lathing is used, add	–	0.06	
xxx)	**Float Glass** (*see* IS 2835) **and Safety Glass** [*see* IS 2553 (Part 1)] [C-1(15)]			
	Sheet	2	0.049	m^2
		2.5	0.062	m^2
		3	0.074	m^2
		4	0.098	m^2
		5	0.123	m^2
		5.5	0.134	m^2
		6.5	0.167	m^2
		8	0.200	m^2
		10	0.250	m^2
		12	0.300	m^2
		15	0.375	m^2
		19	0.475	m^2
xxxi)	**Flooring**			
	Asphalt flooring	10	0.22	m^2
	NOTE — For macadam finish, add	10	0.26	m^2

	Compressed cork	10	0.04	m^2
	Floors, structural:			
	Hollow clay blocks including reinforcement and mortar jointing between blocks, but excluding any concrete topping	100	1.47	m^2
		125	1.67	m^2
		150	1.86	m^2
		175	2.16	m^2
		200	2.55	m^2
	NOTE — Add extra for concrete topping			
	Hollow clay blocks including reinforcement and concrete ribs between blocks, but excluding any concrete topping	100	1.18	m^2
		115	1.27	m^2
		125	1.37	m^2
		140	1.47	m^2
		150	1.57	m^2
		175	1.76	m^2
		200	1.96	m^2
	NOTE — Add extra for concrete topping.			
	Hollow concrete units including any concrete topping necessary for constructional purposes	100	1.67	m^2
		125	1.96	m^2
		150	2.16	m^2
		175	2.35	m^2
		200	2.65	m^2
		230	3.14	m^2
	Floors, wood:			
	Hard wood	22	0.16	m^2
		28	0.20	m^2
	Soft wood	22	0.11	m^2
		28	0.13	m^2
	Weight of mastic used in laying wood block flooring	–	0.015	m^2
	NOTE — All thicknesses are ‘finished thicknesses’.			
	Floor finishes:			
	Clay floor tiles (*see* IS 1478) [C-1(15)]	12.5 to 25.4	0.10 to 0.2	m^2
	NOTE – This weight is ‘as laid’ but excludes screeding.			
	Magnesium oxychloride:			
	Normal type (saw dust filler)	10	0.142	m^2
	Heavy duty type (mineral filler)	10	0.216	m^2
	Parquet flooring	–	0.08 to 0.12	m^2
	Rubber (*see* IS 809) [C-1(15)]	3.2	0.048 to 0.062	m^2

		4.8	0.070 to 0.09	m^2
		6.4	0.093 to 0.130	m^2
	Terra cotta, filled 'as laid'	–	5.54 to 7.06	m^2
	Terrazzo paving 'as laid'	10	0.23	m^2
xxxii)	**Foam Slag, Foundry Pumice**	–	6.85	m^3
xxxiii)	**Gutters, Asbestos Cement** (*see* under vii '**Asbestos cement gutter**' in this Table)			
xxxiv)	**Gypsum**			
	Gypsum mortar [*see* IS 2547 (Part 1 and Part 2)] [C-1(15)]	–	18.6	m^3
	Gypsum powder (*see* IS 12679) [C-1(15)]	–	13.89 to 17.25	m^3
xxxv)	**Iron**			
	Pig	–	70.60	m^3
	Gray, cast	–	68.95 to 69.90	m^3
	White, cast	–	74.30 to 75.70	m^3
	Wrought	–	75.70	m^3
xxxvi)	**Lime**			
	Lime concrete with burn clay Aggregate (*see* IS 2541) [C-1(15)]	–	18.80	m^3
	Lime mortar	–	15.70 to 18.05	m^3
	Lime plaster (*see* IS 2394) [C-1(15)]	–	17.25	m^3
	Lime stored in lumps, uncalcined	–	12.55 to 14.10	m^3
	Lime, unslaked, freshly burnt in pieces	–	8.60 to 10.20	m^3
	Lime slaked, fresh	–	5.70 to 6.30	m^3
	Lime slaked, after 10 days	–	7.85	m^3
	Lime, unslaked (KANKAR)	–	11.55	m^3
	Lime, slaked (KANKAR)	–	10.00	m^3
xxxvii)	**Linoleum** (*see* IS 653) [C-1(15)]			
	Sheets and tiles	4.5	0.0569	m^2
		3.2	0.0402	m^2
		2.0	0.0265	m^2
		1.65	0.0215	m^2
xxxviii)	**Masonry**			
	Brick Masonry (excluding plaster)			
	With common burnt clay bricks (*see* IS 1077) [C-1(15)]	–	19.25	m^3

	Engineering bricks	–	21.2	m^3
	Glazed bricks	–	20.40	m^3
	Pressed bricks	–	18.65	m^3
	Block Masonry			
	With lime based solid blocks		13.55	m^3
	Hollow concrete blocks			
	Grade A		15.4	m^3
	Grade B		12.00	m^3
	Solid Concrete Blocks		18.15	m^3
	Autoclaved cellular concrete blocks		9.1 to 11.1	m^3
xxxix	**Masonry, Stone**			
	Cast	–	21.75	m^3
	Dry rubble	–	20.40	m^3
	Granite ashlar	–	25.00	m^3
	Granite rubble	–	23.55	m^3
	Lime stone ashlar	–	25.10	m^3
	Marble dressed	–	26.50	m^3
	Sand stone	–	22.00	m^3
xl)	**Mastic asphalt**	10	0.216	m^2
xli)	**Metal sheeting, protected galvanized steel sheets, plain** (*see* IS 277) [C-1(15)]			
	Class A (corrugated)	1.60	0.131	m^2
		1.00	0.104	m^2
		0.9	0.084	m^2
		0.80	0.069	m^2
		0.63	0.056	m^2
	Class B (corrugated)	1.60	0.129	m^2
		1.00	0.102	m^2
		0.9	0.083	m^2
		0.80	0.067	m^2
		0.63	0.054	m^2
	Class C (corrugated)	1.60	0.128	m^2
		1.00	0.101	m^2
		0.9	0.081	m^2
		0.80	0.066	m^2
		0.63	0.053	m^2
	Class D (corrugated)	1.60	0.127	m^2
		1.00	0.100	m^2
		0.9	0.081	m^2

		0.80	0.065	m^2
		0.63	0.052	m^2
xlii)	**Mortar**			
	Cement	–	20.40	m^3
	Gypsum	–	11.75	m^3
	Lime	–	15.70 to18.05	m^3
xliii)	**Pipes**			
	Asbestos cement pipes [*see* IS 1626 (Part 1)] [C-1(15)]	50	0.032 to 0.034	m
		60	0.032 to 0.043	m
		80	0.051 to 0.054	m
		90	0.052 to 0.060	m
		100	0.058 to 0.065	m
		125	0.072 to 0.086	m
		150	0.086 to 0.108	m
	Asbestos cement pressure pipes [(*see* IS 1592) [C-1(15)]	50	0.056	m
		80	0.067	m
		100	0.090	m
		125	0.139	m
		150	0.175	m
		200	0.264	m
		250	0.380	m
		300	0.539	m
	Cast iron pipes (*see* IS 1729) [C-1(15)]			
	Standard overall length 1.8 m with socket	50	0.073	pipe
		75	0.108	pipe
		100	0.137	pipe
		125	0.196	pipe
		150	0.255	pipe
	Standard overall length 1.5 m with socket	50	0.064	pipe
		75	0.093	pipe
		100	0.123	pipe
		125	0.172	pipe
		150	0.230	Pipe
	Pressure pipes for water, gas and sewage:			
	a) Centrifugally cast (*see* IS 1536) [C-1(15)]			
	Socket and spigot pipes			
	Barrel:			
	Class LA	80	0.145	m

		100	0.182	m
		125	0.237	m
		150	0.297	m
		200	0.432	m
		250	0.582	m
		300	*0.750*	m
		350	0.944	m
		400	1.146	m
		450	1.383	m
		500	1.620	m
		600	2.156	m
		700	2.718	m
		750	3.111	m
	Class A	80	0.151	m
		100	0.201	m
		125	0.259	m
		150	0.326	m
		200	0.472	m
		250	0.637	m
		300	0.824	m
		350	1.030	m
		400	1.262	m
		450	1.530	m
		500	1.775	m
		600	2.367	m
		700	3.056	m
		750	3.422	m
	Class B	80	0.172	m
		100	0.216	m
		125	0.281	m
		150	0.352	m
		200	0.511	m
		250	0.692	m
		300	0.896	m
		350	1.112	m
		400	1.368	m
		450	1.657	m
		500	1.929	m

		600	2.578	m
		700	3.317	m
		750	3.733	m
	Sockets for Class LA, Class A and Class B barrels	80	0.054	Socket
		100	0.069	Socket
		125	0.090	Socket
		150	0.113	Socket
		200	0.165	Socket
		250	0.225	Socket
		300	0.292	Socket
		350	0.368	Socket
		400	0.454	Socket
		450	0.549	Socket
		500	0.647	Socket
		600	0.876	Socket
		700	1.145	Socket
		750	1.292	Socket
	b) Flanged pipe with screwed flanges			
	Barrel:			
	Class A	80 to 300	Same as for centrifugally cast socket and spigot piles, Class A	
	Class B	80 to 300	Same as for centrifugally cast socket and spigot piles, Class B	
	Flanges for Class A and Class B barrels	80	0.042	Flange
		100	0.049	Flange
		125	0.065	Flange
		150	0.080	Flange
		200	0.112	Flange
		250	0.144	Flange
		300	0.182	Flange
	c) Vertically cast socket and spigot pipes (*see* IS 1537) [C-1(15)]			
	Barrel: Class A	80 to 750	Same as for centrifugally cast socket and spigot pipes, Class A	
		800	3.82	m
		900	4.65	m
		1000	5.59	m
		1100	6.59	m
		1200	7.67	m
		1500	11.98	m

	Class B	80 to 750	–	–
		800	–	m
		900	5.07	m
		1000	6.07	m
		1100	7.23	m
		1200	8.35	m
		1500	13.07	m
	Socket of Class A and Class B barrels	80 to 750	–	–
		800	–	Socket
		900	179	Socket
		1000	218	Socket
		1100	260	Socket
		1200	360	Socket
		1500	491	Socket
	d) Sand cast (flanked pipes)			
	Barrel:			
	Class A	80 to 750	Same as for centrifugally cast socket and spigot pipes, Class A	
		800 to 1500	–	
	Class B	80 to 750	Same as for vertically cast socket and spigot pipes, CIass B	
		800 to 1500		
	Flanges for Class A and Class B barrels	80	0.036	Flange
		100	0.041	Flange
		125	0.052	Flange
		150	0.066	Flange
		200	0.091	Flange
		250	0.117	Flange
		300	0.145	Flange
		350	0.186	Flange
		400	0.229	Flange
		450	0.250	Flange
		500	0.315	Flange
		600	0.431	Flange
		750	0.587	Flange
		700	0.685	Flange
		800	0.792	Flange
		900	0.928	Flange
		1000	1.18	Flange

		1100	1.38	Flange
		1200	1.70	Flange
		1500	2.71	Flange
	Concrete pipes (*see* IS 458) [C-1(15)]			
	Class NP 1 (unreinforced non-pressure pipes)	80	0.19	m
		100	0.22	m
		150	0.30	m
		250	0.40	m
		300	0.69	m
		350	0.84	m
		400	0.95	m
		450	1.17	m
	Class NP 2 (reinforced concrete, light duty, non-pressure pipes)	80	0.196	m
		100	0.215	m
		150	0.324	m
		250	0.510	m
		300	0.736	m
		350	0.902	m
		400	1.02	m
		450	1.26	m
		500	1.38	m
		600	1.89	m
		700	2.19	m
		800	2.81	m
		900	3.51	m
		1000	4.30	m
		1100	5.15	m
		1200	6.09	m
		1400	8.18	m
		1600	9.93	m
		1800	12.58	m
	Class NP 3 (reinforced concrete, heavy duty, non-pressure pipes)	350	2.35	m
		400	2.63	m
		450	2.91	m
		500	3.19	m
		600	4.02	m
		700	4.61	m
		800	5.92	m

		900	7.39	m
		1000	8.13	m
		1100	10.34	m
		1200	11.18	m
	Class P1 (reinforced concrete pressure pipes safe for 20 MPa pressure tests)	80	0.196	m
		100	0.235	m
		150	0.324	m
		250	0.510	m
		300	0.736	m
		350	0.902	m
		400	1.02	m
		450	1.26	m
		500	1.38	m
		600	1.89	m
		700	2.19	m
		800	2.81	m
		900	3.51	m
		1000	4.30	m
		1100	5.15	m
		1200	6.09	m
	Class P2 (reinforced concrete pressure pipes safe for 40 MPa pressure tests)	80	0.196	m
		100	0.235	m
		150	0.324	m
		250	0.608	m
		300	1.01	m
		350	1.31	m
		400	1.67	m
		450	1.84	m
		500	1.56	m
		600	3.20	m
	Class P3 (reinforced concrete pressure pipes safe for 60 MPa pressure tests)	80	0.196	m
		100	0.235	m
		150	0.324	m
		250	0.736	m
		300	1.15	m
		350	1.65	m
		400	2.04	m

	Lead pipes [*see* IS 404 (Part 1)] [C-1(15)] (service and distribution pipes 10 be laid underground) :			
	For working 40 MPa	10	0.018	m
		13	0.031	m
		20	0.042	m
		25	0.060	m
		30	0.074	m
		40	0.091	m
		50	0.142	m
	For working 70 MPa	10	0.022	m
		15	0.038	m
		20	0.050	m
		25	0.069	m
		32	0.126	m
		40	0.175	m
	For working 100 MPa	10	0.029	m
		15	0.048	m
		20	0.067	m
		25	0.105	m
	Service pipes to be fixed or laid above ground:			
	For working pressure 40 MPa	10	0.014	m
		15	0.021	m
		20	0.027	m
		25	0.036	m
		32	0.059	m
		40	0.091	m
		50	0.142	m
	For working pressure 70 MPa	10	0.018	m
		15	0.024	m
		20	0.030	m
		25	0.069	m
		32	0.126	m
		40	0.175	m
	For working pressure 100 MPa	10	0.029	m
		15	0.048	m
		20	0.067	m
		25	0.105	m

	Cold water distribution pipes to be fixed or laid above ground:			
	For working pressure 25 MPa	10	0.014	m
		15	0.021	m
		20	0.027	m
		25	0.036	m
		32	0.048	m
		40	0.067	m
		50	0.084	m
	For working pressure 40 MPa	10	0.014	m
		15	0.021	m
		20	0.027	m
		25	0.036	m
		32	0.059	m
		40	0.091	m
		50	0.142	m
	Hot water distribution pipes to be fixed or laid above ground:			
	For working pressure 20 MPa	10	0.015	m
		15	0.023	m
		20	0.031	m
		25	0.041	m
		32	0.062	m
		40	0.082	m
		50	0.142	m
	For working pressure 35 MPa	10	0.015	m
		15	0.027	m
		20	0.045	m
		25	0.085	m
		32	0.132	m
	Soil, waste and soil and waste ventilation pipes	50	0.050	m
		75	0.073	m
		100	0.097	m
		150	0.160	m
	Flushing and warning pipes	20	0.020	m
		25	0.025	m
		32	0.032	m
		40	0.039	m
		50	0.049	m
	Gas pipes:			
	Heavy weight gas pipes	10	0.008	m

		15	0.017	m
		20	0.025	m
		25	0.034	m
		32	0.045	m
		40	0.061	m
		50	0.071	m
	Light weight gas pipes	10	0.008	m
		15	0.012	m
		20	0.020	m
		25	0.029	m
		32	0.037	m
		40	0.047	m
		50	0.058	m
	Stoneware, salt-glazed pipes (*see* IS 651) [C-1(15)]	100	0.137	m
		150	0.216	m
		200	0.324	m
		230	0.412	m
		250	0.510	m
		300	0.775	m
		350	0.980	m
		400	1.26	m
		450	1.44	m
		500	1.77	m
		600	2.35	m
xliv)	**Plaster**			
	Cement	10	0.204	m^2
	Lime	10	0.172	m^2
	Acoustic	10	0.078	m^2
	Anhydrite	10	0.206	m^2
	Barium sulphate	10	0.284	m^2
	Fibrous	10	0.088	m^2
	Gypsum	10	0.186	m^2
xlv)	**Roofing**			
	Asbestos cement sheeting			
	(*see* 'Asbestos cement sheeting' in Table 1)			
	Allahabad tiles (single) including battens (*see* Note below)	–	0.83	m^2

	Allahabad tiles (double) including battens (*see* Note below)	–	1.67	m^2
	Country tiles (single) including battens (*see* Note below)	–	0.69	m^2
	Country tiles (double) including battens (*see* Note below)	–	1.18	m^2
	Mangalore tiles battens (*see* Note below)	–	0.64	m^2
	Mangalore tiles bedded in mortar over flat tiles (*see* Note below)	–	1.08	m^2
	Mangalore tiles with flat tiles (*see* Note below)	–	0.78	m^2
	Copper sheet roofing including laps and rolls	0.56	0.08	m^2
	Flat roofs	0.72	0.10	m^2
	Clay tiles- hollow clay blocks/clay floor tiles (*see* Sl No. xxxi 'Flooring')			
	Concrete hollow units (*see* Sl No. xxxi 'Flooring' in this Table)			
	Galvanized iron sheeting (*see* Sl No. 'xli Metal sheeting, protected')			
	Glazed Roofing:			
	Glazing with aluminum alloy bars for spans up to 3 m	6.4	0.19	m^2
	Glazing with lead-covering steel bars at 0.6 m centres	6.4	0.25 to 0.28	m^2
	States on battens	–	0.34 to 0.49	m^2
	Thatch with battens	–	0.34 to 0.49	m^2
	NOTE – Weights acting vertically on horizontally projection to be multiplied by cosine of roof angle to obtain weights normal to the roof surface.			
	Roof finished			
	Bitumen macadam	10	0.22	m^2
	Felt roofing (*see* 28 'Felt bituminous for water-proofing and damp-proofing' in Table 1)	10	0.008	m^2
	Glass silk quilted	0.5	0.05	m^2
	Lead sheet	0.8	0.07	m^2
	Mortar screeding	10	0.21	m^2
xlvi)	**Sheeting**			
	Asbestos (*see* under Sl No. ix 'asbestos cement sheeting' in this Table)			
	Galvanized iron (*see* under Sl No. xli 'metal sheeting, protected' in this table)			
	Glass (*see* under Sl No. xxx 'Glass' in this table)			
	Plywood (*see* IS 303) [C-1(15)]	1	0.007	m^3

xlvii)	**Slugwool**	–	2.65	m^3
xlviii)	**Soils and Gravels**			
	Alluvial ground, undisturbed	–	15.69	m^3
	Broken stone ballast:			
	Dry, well-shaken	–	15.70 to 18.35	m^3
	Perfectly wet	–	18.85 to 21.95	m^3
	Chalk		15.70 to 18.85	m^3
	Clay:			
	China, compact	–	21.95	m^3
	Clay fills:			
	Dry, lumps	–	10.20	m^3
	Dry, compact	–	14.10	m^3
	Damp, compact	–	17.25	m^3
	Wet , compact	–	20.40	m^3
	Undisturbed	–	18.85	m^3
	Undisturbed, gravelly	–	20.40	m^3
	Crush stone sand (Msand)	–	–	–
	Earth:			
	Dry	–	13.85 to 18.05	m^3
	Moist	–	15.70 to 19.60	m^3
	Gravel:			
	Loose	–	15.70	m^3
	Rammed	–	18.85 to 21.20	m^3
	Kaolin, compact	–	25.50	m^3
	Loam:			
	Dry, loose	–	11.75	m^3
	Dry, compact	–	15.70	m^3
	Wet, compact	–	18.85	m^3
	Loess, dry	–	14.10	m^3
	Marl, compact	–	17.25 to 18.85	m^3
	Mud, river, wet	–	17.25 to 18.85	m^3
	Peat:			
	Dry	–	5.50 to 6.30	m^3
	Sandy, compact	–	7.85	m^3
	Wet, compact	–	13.35	m^3
	Rip-rap	–	12.55 to 14.10	m^3
	Sand:			
	Dry, clean	–	15.10 to 15.70	m^3

	River	–	18.05	m^3
	Wet	–	17.25 to 19.60	m^2
	Shingles:			
	Aggregate 3 to 38 mm	–	13.75	m^2
	Fine sand:			
	Dry	–	15.70	m^2
	Saturated	–	20.40	m^2
	Silt, wet	–	17.25 to 18.85	m^2
xlix)	**Steel sections**			
	Density of steel sections shall be taken as 78.50 kg/m^3			
	Weight of hot rolled sections (ISJB, ISLB, ISMB, ISWB, ISNPB, ISWPB, ISSC, ISHB, ISJC, ISLC, ISMC, ISMPC, ISA, ISPBP) shall be referred from (*see* IS 808) [C-1(15)]			
	Weight of hollow steel sections shall be referred from (*see* IS 4923) [C-1(15)]			
	Weight of cold formed light gauge structural steel sections shall be referred from (*see* IS 811) [C-1(15)]			
	Weight of rolled and slit T bars shall be referred from (*see* IS 1173) [C-1(15)]			
	Weight of steel sheet piling sections shall be referred from (*see* IS 2314) [C-1(15)]			
l)	**Stone**			
	Agate	–	25.50	m^3
	Aggregate	–	15.70 to 18.85	m^3
	Basalt	–	27.95 to 29.05	m^3
	Cast	–	21.95	m^3
	Chalk	–	21.50	m^3
	Dolomite	–	28.25	m^3
	Emery	–	39.25	m^3
	Flint	–	25.40	m^3
	Gneiss	–	23.55 to 26.40	m^3
	Granite	–	25.90 to 27.45	m^3
	Gravel:			
	Loose	–	15.70	m^3
	Moderately rammed, dry	–	18.85	m^3
	Green stone	–	28.25	m^3
	Gypsum	–	21.95 to 23.55	m^3
	Kota			
	Laterite	–	20.40 to 23.55	m^3
	Lime stone	–	23.55 to 25.90	m^3
	Marble	–	26.70	m^3
	Pumice	–	7.85 to 11.00	m^3
	Quartz rock	–	25.90	m^3

	Sand stone	–	21.95 to 23.54	m^3
	Slate	–	27.45	m^3
	Soap stone	–	26.45	m^3
li)	**Tar, Coal**			
	Crude (*see* IS 212) [C-1(15)]	–	9.90	m^3
	Naphtha, light	–	9.90	m^3
	Naphtha, heavy	–	9.90	m^3
	Road tar	–	9.90	m^3
	Pitch (*see* IS 216) [C-1(15)]	–	9.90	m^3
lii)	**Thermal Insulation**			
	Unbonded glass wool	–	12.75 to 23.55	m^3
	Unbonded rock and slag wool	–	11.30 to 19.60	m^3
	Cellular concrete			
	Grade A	–	Up to 29.40	m^3
	Grade B	–	29.50 to 39.20	m^3
	Grade C	–	39.30 to 49.00	m^3
	Performed calcium silicate Insulation (for temperature up to 650°C)	–	19.60 to 34.30	m^3
liii)	**Tiles and stone cladding**			
	Terra-cotta	–	18.35 to 23.25	m^2
	Terrozzo			
	Paving	10	0.24	m^2
	Cast partitions	40	0.93	m^2
	Tiles			
	Mangalore pattern (*see* IS 654) [C-1(15)]	–	0.02 to 0.03	Tile
	Polystyrene wall tiles	99 x 99	0.013	m^2
		148.5 x 148.5	0.013	m^2
	Pressed ceramic tiles, glazed and unglazed (*see* IS 15622) [C-1(15)]		22	m^3
	Concrete paving blocks (*see* IS 15658) [C-1(15)]		24	m^3
liv)	**Timber**			
	Typical Indian timbers (*see* IS 399) [C-1(15)]			
	Aglaia	–	8.34	m^3
	Aini	–	5.83	m^3
	Alder	–	3.63	m^3
	Amari	–	6.13	m^3

	Amla	–	7.85	m^3
	Amra	–	4.41	m^3
	Anjan	–	8.33	m^3
	Arjun	–	7.99	m^3
	Ash	–	7.06	m^3
	Axlewood	–	8.82	m^3
	Babul	–	7.70	m^3
	Baen	–	7.70	m^3
	Bahera	–	7.99	m^3
	Bakota	–	4.21	m^3
	Balasu	–	7.55	m^3
	Ballagi	–	11.13	m^3
	Bamboo			
	Banati	–	4.41	m^3
	Benteak	–	6.62	m^3
	Ber	–	6.91	m^3
	Bhendi	–	7.55	m^3
	Bijasal	–	7.85	m^3
	Black chuglam	–	6.13	m^3
	Birch	–	7.85	m^3
	Black locust	–	8.34	m^3
	Blue gum	–	8.34	m^3
	Blue pine	–	5.05	m^3
	Bola	–	6.42	m^3
	Bonsum	–	5.20	m^3
	Bullet wood	–	8.78	m^3
	Casuarina	–	8.34	m^3
	Cettis	–	6.42	m^3
	Champ	–	4.85	m^3
	Chaplash	–	5.05	m^3
	Chatian	–	4.07	m^3
	Chikrassy	–	6.62	m^3
	Chilauni	–	6.42	m^3
	Chilla	–	7.85	m^3
	Chir	–	5.64	m^3
	Chuglam:			
	Black	–	7.85	m^3
	White (silver grey-wood)	–	6.91	m^3

	Cinnamon	–	6.42	m^3
	Cypress	–	5.05	m^3
	Debdaru	–	6.28	m^3
	Deodar	–	5.35	m^3
	Devdam	–	7.06	m^3
	Dhaman:			
	Grewia tiliofolia	–	7.70	m^3
	Grewia vestita	–	7.40	m^3
	Dhup	–	6.42	m^3
	Dilenia	–	6.13	m^3
	Dudhi	–	5.49	m^3
	Ebony	–	8.19	m^3
	Elim	–	5.20	m^3
	Eucalyptus	–	8.33	m^3
	Figs	–	4.56	m^3
	Fir	–	4.14	m^3
	Frash	–	6.62	m^3
	Gamari	–	5.05	m^3
	Gardenia	–	7.40	m^3
	Garuga	–	5.98	m^3
	Geon	–	4.07	m^3
	Gluta	–	7.06	m^3
	Gokul	–	4.07	m^3
	Grewia sp.	–	7.55	m^3
	Gurjan	–	7.70	m^3
	Gutel	–	4.41	m^3
	Haldu	–	6.62	m^3
	Hathipaila	–	5.84	m^3
	Hiwar	–	7.70	m^3
	Hollock	–	5.98	m^3
	Hollong	–	7.21	m^3
	Hoom	–	7.21	m^3
	Horse chestnut	–	5.05	m^3
	Imli	–	8.97	m^3
	Indian Chestnut	–	6.28	m^3
	Indian Hemlock	–	3.92	m^3
	Indian Oak	–	8.48	m^3
	Indian Olive	–	10.35	m^3

	Irul	–	8.33	m^3
	Jack	–	5.83	m^3
	Jaman	–	7.70	m^3
	Jarul	–	6.13	m^3
	Jathtkai	–	5.05	m^3
	Jhingan	–	5.63	m^3
	Jutili	–	7.85	m^3
	Kadam	–	4.85	m^3
	Kail	–	5.05	m^3
	Kaim	–	6.42	m^3
	Kambli	–	4.07	m^3
	Kanchan	–	6.62	m^3
	Kanjuj	–	5.84	m^3
	Karada	–	8.34	m^3
	Karal	–	7.99	m^3
	Karani	–	6.28	m^3
	Karar	–	5.34	m^3
	Kardahi	–	9.27	m^3
	Karimgotta	–	3.92	m^3
	Kasi	–	5.83	m^3
	Kasum	–	10.84	m^3
	Kathal	–	5.85	m^3
	Keora	–	6.13	m^3
	Khair	–	9.00	m^3
	Khasipine	–	5.05	m^3
	Kindal	–	7.55	m^3
	Kokko	–	6.28	m^3
	Kongoo	–	9.76	m^3
	Kuchla	–	8.63	m^3
	Kumbi	–	7.70	m^3
	Kurchi	–	5.20	m^3
	Kurung	–	9.76	m^3
	Kusum	–	11.28	m^3
	Kuthan	–	4.71	m^3
	Lakooch	–	6.28	m^3
	Lambapatti	–	5.34	m^3
	Lampati	–	5.05	m^3
	Laurel	–	8.33	m^3

	Lendi	–	7.40	m^3
	Machilus:			
	Gamblei	–	5.05	m^3
	Macrantha	–	5.20	m^3
	Maharukh	–	4.07	m^3
	Mahogany	–	6.62	m^3
	Mahua	–	8.97	m^3
	Maina	–	5.64	m^3
	Makai	–	3.14	m^3
	Malabar neem	–	4.41	m^3
	Mango	–	6.77	m^3
	Maniawga	–	7.40	m^3
	Maple	–	5.64	m^3
	Mesua	–	9.76	m^3
	Milla	–	9.12	m^3
	Mokha	–	7.99	m^3
	Mulberry	–	6.62	m^3
	Mullilam	–	7.21	m^3
	Mundani	–	6.77	m^3
	Murtenga	–	7.70	m^3
	Myrabolan	–	9.27	m^3
	Narikel	–	5.49	m^3
	Nedunar	–	5.05	m^3
	Oak	–	8.48	m^3
	Padauk	–	7.06	m^3
	Padri	–	7.06	m^3
	Palang	–	5.98	m^3
	Pali	–	6.28	m^3
	Papita	–	3.28	m^3
	Parrotia	–	8.48	m^3
	Persian lilac	–	5.84	m^3
	Piney	–	6.13	m^3
	Ping	–	8.97	m^3
	Pinus insignis	–	6.13	m^3
	Pipli	–	5.83	m^3
	Pitraj	–	6.77	m^3
	Poon	–	6.42	m^3
	Poplar	–	4.41	m^3

	Pula	–	3.78	m^3
	Pyinma	–	3.98	m^3
	Rajbrikh	–	8.48	m^3
	Red sanders	–	10.84	m^3
	Rohini	–	11.33	m^3
	Rosewood (black wood)	–	8.19	m^3
	Rudrak	–	4.71	m^3
	Sal	–	8.48	m^3
	Salai	–	5.64	m^3
	Sandal wood	–	8.97	m^3
	Sadan	–	8.34	m^3
	Satin wood	–	9.41	m^3
	Saykaranji	–	7.40	m^3
	Seleng	–	4.85	m^3
	Semul	–	3.78	m^3
	Silver oak	–	6.28	m^3
	Siris	–	3.92	m^3
	Kala-siris	–	7.21	m^3
	Safed- siris	–	6.28	m^3
	Siaso	–	7.70	m^3
	Spruce	–	4.71	m^3
	Suji	–	2.65	m^3
	Sundri	–	9.41	m^3
	Talauma	–	5.64	m^3
	Tanaku	–	2.09	m^3
	Teak	–	6.28	m^3
	Toon	–	5.05	m^3
	Udal	–	2.50	m^3
	Upas	–	3.14	m^3
	Uriam	–	7.40	m^3
	Vakai	–	9.41	m^3
	Vellapine	–	5.83	m^3
	Walnut	–	5.64	m^3
	White bombwe	–	5.98	m^3
	White cedar	–	7.06	m^3
	White chuglam (silver grey-wood)	–	6.91	m^3
	White dhup	–	4.22	m^3
	Yon	–	8.33	m^3

	NOTE — The unit of timbers correspond to average unit of typical Indian timbers at 12 percent moisture content.			
lv)	**Water**			
	Fresh	–	10.0	m³
	Salt	–	10.05	m³
lvi)	**Wood – Wool Building Slabs**	10mm	0.059	m²
lvii)	**Walling** (*see* IS 6072) [C-1(15)]			
	Autoclaved reinforced cellular concrete wall slabs			
	Class A	–	8.35 to 9.80	m²
	Class B	–	7.35 to 8.35	m²
	Class C	–	6.35 to 7.35	m²
	Class D	–	5.40 to 6.35	m²
	Class E	–	4.40 to 5.40	m²
	Brick masonry (*see* xxxviii 'Masonry Brick' in Table 1)			
	Blocks masonry (*see* xii 'Block' in Table 1)			
	Stone masonry (*see* xxxix 'Masonry Stone' in Table 1)			
	Partitions 39			
	Brick wall	100	1.91	m²
	Cinder concrete	75	1.13	m²
	Galvanized on sheet	–	0.15	m²
	Hollow glass block (bricks)	100	0.88	m²
	Hollow blocks per 200 mm of thickness			
	Ballast or stone concrete	200	0.201	m²
	Clay	200	0.201	m²
	Clinker concrete	200	0.220	m²
	Coke breeze concrete	200	9.176	m²
	Diatomaceous earth	200	0.093	m²
	Gypsum	200	0.137	m²
	Pumice concrete	200	0.177	m²
	Slag concrete, air-cooled	200	0.196	m²
	Slag concrete foamed	200	0.186	m²
	Lath and plaster	–	0.392	m²
	Solid blocks per 20 mm of thickness			
	Ballast or stone	20	0.451	m²
	Clinker concrete	20	0.300	m²
	Coke breeze concrete	20	0.221	m²
	Pumice concrete	20	0.221	m²
	Slag concrete, foamed	20	0.250	m²
	Terrazzo cast partitions	40	0.932	m²
	Timber studding plastered	–	9.981	m²
NOTE — For unit weight of fixtures and fittings required to buildings including builder's hardware, reference may be made to appropriate Indian standards.				

A-2 STORED AND MISCELLANEOUS MATERIALS

A-2.1 Units weights of stored and miscellaneous materials intended for dead load calculation and other general purposes are given in Table 41.

Table 41 Unit Weights of Stored and Miscellaneous Materials

(*Clause* A-2.1)

Sl No.	Materials	Weight KN/m^3	Angle of Friction, Degrees
(1)	(2)	(3)	(4)
i)	**Agriculture and Food Products**		
	Butter	8.45	–
	Coffee in bags	5.50	–
	Drinks in bottle, in boxes	7.35	–
	Eggs, packed	2.95	–
	Fats, oil	5.80	–
	Fish meal	4.90	45
	Flour in sacks up to 1 m height	2.20 to 5.90	–
	Forage (bales)	1.25	–
	Fruits	3.45	–
	Grains:		
	Barley	6.75	27
	Corn, shelled	7.55	27
	Flax seed	7.35	30
	Oats	5.30	30
	Rice	6.55	33
	Soyabeans	7.35	30
	Wheat	8.15	28
	Wheat flour	6.85	30
	Grain sheaves up to 4 m stack height	0.98	30
	Grain sheaves over 4 m stack height	1.45	30
	Grass and clover	3.45	–
	Hay:		–
	Compressed	1.65	–
	Loose up to about 3 m stack height	0.69	–
	Honey	14.10	–
	Hops:		
	In stacks	1.65	–
	In cylinder hop bins	4.60	–

Table 41 (*Continued*)

Sl No.	Materials	Weight KN/m^3	Angle of Friction, Degrees
(1)	(2)	(3)	(4)
	Sewn up or compressed in cylindrical shape in hop cloth	2.85	–
	Malt:		
	Crushed	3.90	20
	Germinated	1.85	–
	Meat and meat products	7.05	–
	Milk	10.05	–
	Molasses	4.40	–
	Onion in bags	5.40	0
	Oil cakes, crushed	5.80	0
	Potatoes	7.05	30
	Preserves (tins in cases)	4.90 to7.85	–
	Bags	7.05	–
	Bulk	9.40	–
	Seeds:		
	Heaps	4.90 to 7.85	25
	Sacks	3.90 to 6.85	–
	Straw and chaff:		
	Loose up to about 3 m stack height	0.45	–
	Compressed	1.65	–
	Sugar:		
	Crystal	7.35	30
	Cube sugar in boxes	7.85	–
	Sugar beet, pressed out	7.85	–
	Tobacco bundles	3.45	–
	Vinegar	10.40	–
ii)	**Chemicals and Allied Materials**		
	Acid, hydrochloric	11.75	–
	Acid, nitric 91 percent	14.80	–
	Acid, sulphuric 87 percent	17.55	–
	Alcohol	7.65	–
	Alum, pearl in barrel	5.20	–
	Ammonia, liquid	8.85	–
	Ammonium, chloride, crystalline	8.15	30 to 40
	Ammonium nitrate	7.05 to 9.80	25
	Ammonium sulphate	7.05 to 9.00	32 to 45
	Beeswax	9.40	–
	Benzole	8.90	–
	Benzene hexachloride	8.75	–
	Bicarbonate of soda	6.40	–

Table 41 (*Continued*)

Sl No.	Materials	Weight KN/m^3	Angle of Friction, Degrees
(1)	(2)	(3)	(4)
	Bone	18.65	–
	Borax	17.15	–
	Calcite	26.50	–
	Camphor	9.70	–
	Carbon disulphide	12.75	–
	Casein	13.25	–
	Caustic soda	13.85	–
	Creosole	10.50	–
	Dicalcium phosphate	6.65	–
	Disodium phosphate	3.90 to 4.80	30 to 45
	Iodine	48.55	–
	Oils in bottle or barrels	5.70 to 8.90	–
	Oil, linsee:		
	In barrels	5.70	–
	In drums	7.05	–
	Oil, turpentine	8.50	–
	Paints	9.40	–
	Paraffin wax	7.85 to 9.40	–
	Petroleum	9.90	–
	Phosphorus	17.85	–
	Plastics and polymers:		
	Cellulose acetate	12.25 to 13.35	–
	Cellulose nitrate	13.25 to 15.70	–
	Methyl methacrylate (IS 14753) [C-1(15)]	11.57 to 11.77	–
	Phenol formaldehyde	12.55	–
	Expanded Polystyrene (IS 4671) [C-1(15)]	0.15 to 0.35	–
	Extruded polystyrene	0.21	
	Polyvinyl chloride (Perspex)	11.75 to 13.25	–
	Resin bonded sheet	12.85 to 13.55	–
	Urea formaldehyde	13.25 to 13.55	–
	Extruded polystyrene	0.21	
	Polyurethane	0.59 to 0.66	
	Polyethylene (IS 2508) [C-1(15)]	9.81 to 19.6	
	Polyvinyl Butaryl	11	
	Polycarbonate (IS 14443) [C-1(15)]	12	
	Ethylene tetrafluoroethylene	17	
	Polytetrafluoroethylene [IS 14635 (part 2)] [C-1(15)]	22	
	Potash	14.40	–
	Potassium	8.65	–

Table 41 (*Continued*)

Sl No.	Materials	Weight KN/m^3	Angle of Friction, Degrees
(1)	(2)	(3)	(4)
	Potassium nitrate	9.90	–
	Red lead, dry	20.70	–
	Red lead, paste	87.30	–
	Rosin in barrels	6.75	–
	Rubber:		
	Raw	8.90 to 9.40	–
	Vulcanized	8.90 to 9.10	–
	Saltpeter	9.91	–
	Sodium silicate in barrels	8.35	–
	Sulphur	20.10	–
	Talc	27.45	–
	Varnishes	9.40	–
	Vitriol, blue, in barrels	7.05	–
iii)	**Fuels**		
	Brown coal	6.83	–
	Brown coal briquettes heaped	7.85	35
	Brown coal briquettes stacked	12.75	–
	Charcoal	2.95	–
	Coal:		
	Untreated, mine-moist	9.80	35
	In washeries	11.75	0
	Dust	6.85	25
	All other sorts	8.35	35
	Coke:		
	Furnace or gas	4.90	35
	Brown coal, low-temperature	9.80	35
	Hard, raw coal	8.35	35
	Hard, raw coal, mine-damp	9.80	35
	Diesel oil	9.40	0
	Firewood, chopped	3.90	45
	Petrol	6.75	0
	Wood in chips	1.95	45
	Wood shaving, loose	1.45	35
	Wood shaving, shaken down	2.45	35
iv)	**Manures**		
	Animal manures:		
	Loosely heaped	11.75	45
	Stacked dung up to 25 m stack height	17.65	45
	Artificial manures	11.75	24 to 30
v)	**Metals and Alloys**		

Table 41 (*Continued*)

Sl No.	Materials	Weight KN/m^3	Angle of Friction, Degrees
(1)	(2)	(3)	(4)
	Aluminium	25.30 to 26.60	
	Cast	25.30 to 26.60	–
	Wrought	25.90 to 27.45	–
	Sheet per mm of thickness per m^2	0.028	–
	Antimony, pure:		
	Amorphous	60.90	–
	Solid	65.70	–
	Bismuth:		
	Liquid	98.07	–
	Solid	95.02 to 97.9	–
	Cadmium:		
	Cast	83.75 to 84.05	–
	Wrought	85.03	–
	Calcium	15.60	–
	Chromium	63.95 to 66.00	–
	Cobalt:		
	Cast	83.25 to 85.10	–
	Wrought	88.45	–
	Copper:		
	Cast	86.20 to 87.65	–
	Wrought	86.70 to 87.65	–
	Sheet per mm of thickness	0.09	–
	Gold:		
	Cast	188.75 to 189.55	–
	Wrought	189.55	–
	Iron:		
	Pig	70.60	–
	Grey, cast	68.95 to 69.90	–
	White, cast	74.35 to 75.70	–
	Wrought	75.50	–
	Lead:		
	Cast	111.20	–
	Liquid	105.00	–
	Wrought	111.40	–
	Sheet per mm of thickness	0.11	–
	Magnesium	16.45 to 17.15	–
	Manganese	72.55	–
	Mercury	133.35	–
	Nickel	81.20 to 87.20	–
	Platinum	210.25	–

Table 41 (*Continued*)

Sl No.	**Materials**	**Weight** KN/m^3	**Angle of Friction, Degrees**
(1)	(2)	(3)	(4)
	Silver:		
	Cast	102.0 to 102.85	–
	Liquid	93.15	–
	Wrough	103.35 to 103.55	–
	Sodium:		
	Liquid	9.10	–
	Solid	9.30	–
	Tungsten	188.30	–
	Uranium	180.45	–
	Zinc		
	Cast	68.95 to 70.20	–
	Wrought	70.50	–
	Sheet per mm of thickness	0.07	–
	Alloys:		
	Aluminium and copper		
	Aluminium 10 percent copper 90 percent	75.40	–
	Aluminium 5 percent copper 95 percent	82.00	–
	Aluminium 3 percent copper 97 percent	85.10	–
	Aluminium 91 percent zinc 9 percent	27.45	–
	Babbit metal tin 90 percent	71.70	–
	Lead 5 percent copper 5 percent		
	Wood's metal bismuth 50 percent	95.00	–
	Lead 25 percent cadmium 12.5 percent		
	Tin 12.5 percent		
	Brasses:		
	Muntz metal (copper 60 percent, zinc 40 percent)	80.60	–
	Red (copper 90 percent, zinc 10 percent)	84.25	–
	White (copper 50 percent, zinc 50 percent)	80.30	–
	Yellow (copper 70 percent, zinc 30 percent)		
	Cast	82.75	–
	Drawn	85.10	–
	Rolled	83.85	–
	Bronzes:		
	Bell metal (copper 80 percent, tin 20 percent)	85.60	–

Table 41 (*Continued*)

Sl No.	**Materials**	**Weight** KN/m^3	**Angle of Friction, Degrees**
(1)	(2)	(3)	(4)
	Gun metal (copper 90 percent, tin 10 percent)	86.10	–
	Cadmium and tin	75.40	–
	German Silver:		
	Copper 52 percent, zinc 26 percent, nickel 22 percent	82.75	–
	Copper 59 percent, zinc 30 percent, nickel 11 percent	81.70	–
	Copper 63 percent, zinc 30 percent, nickel 7 percent	81.40	–
	Gold and Copper:		
	Gold 98 percent, copper 2 percent	184.75	–
	Gold 90 percent, copper 10 percent	168.20	–
	Lead and Tin:		
	Lead 87.5 percent, tin 12.5 percent	103.85	–
	Lead 30.5 percent, tin 69.5 percent	81.10	–
	Monel metal cast (nickel 70 percent, copper 30 percent)	87.00	–
	Steel:		
	Cast	77.00	–
	Wrought	76.30	–
	Black plate per mm of thickness	0.08	–
	Steel sections (*see* 46 'steel sections' in Table 1)		
vi)	**Miscellaneous Materials**		
	Aggregate, coarse	10.80 to 15.70	30
	Ashes, coal, dry, 12 mm and under	5.50 to 6.30	40
	Ashes, coal, dry, 75 mm and under	5.50 to 6.30	38
	Ashes, coal, wet 12 mm and under	7.05 to 7.85	52
	Ashes, coal, wet 75 mm and under	7.05 to 7.85	50
	Asphalt, crushed 12 mm and under	7.05	30 to 45
	Ammonium nitrate, polls	3.55 to 8.35	27
	Bone	18.65	–
	Books and files, stacked	8.35	–
	Calcium ammonium nitrate	9.80	28
	Copper sulphate, ground	11.75	30
	Chalk	21.95	–
	Chinaware, earthenware, stacked (including cavities)	10.80	–
	Clinker, furnace, clean	7.85	30
	Diammonium phosphate	7.85 to 8.50	29

Table 41 (*Continued*)

Sl No.	Materials	Weight KN/m^3	Angle of Friction, Degrees
(1)	(2)	(3)	(4)
	Double salt (ammonium sulphate nitrate)	7.05 to 9.30	34
	Filling cabinet and cupboards with contents in records offices, libraries, archives	5.90	–
	Flue dust, boiler house, dry	5.50 to 7.05	30
	Fly ash, pulverised	5.50 to 7.05	–
	Glass, solid	23.50 to 26.70	–
	Wool	0.16 to 1.18	–
	In sheets	25.50	–
	Glue	12.55	–
	Gypsum, calcined, 12mm and under	8.60 to 9.40	40
	Gypsum, calcined, powdered	9.40 to 12.55	45
	Gypsum, raw, 25 mm and under	14.10 to 15.70	30 to 45
	Hides:		
	Dry } Only green	8.65	–
	Salted } Only green	8.90	–
	Ice } Only green		
	Leather put in rows	7.85	–
	Lime, ground 3 mm and under	9.40	> 45
	Lime, hydrated 3 mm and under	6.30	30 to 45
	Lime, hydrated, pulverized	5.00 to 6.30	30 to 45
	Lime pebble	8.25 to 8.75	
	Limestone, agricultural 3 mm and under	10.60	
	Limestone, crushed	13.30 to 14.10	30 to 45
	Limestone dust	8.65 to 14.90	30 to 45
	Magnesite, caustic, in powder form	7.85	–
	Magnesite sinter and Magnesite granular	19.60	–
	Phosphate, rock, pulverized	9.40	40 to 52
	Phosphate rock	11.75 to 13.35	30 to 45
	Phosphate sand	14.10 to 15.70	30 to 45
	Potassium carbonate	7.95	30 to 45
	Potassium chloride, pellets	18.85 to 20.40	30 to 45
	Potassium nitrate	4.85	> 30
	Potassium sulphate	6.55 to 7.45	45
	Pyrites, pellets	18.85 to 20.40	30 to 45
	Pumice	5.80 to 9.90	–
	Rubbish:		
	Building	13.80	–
	General	6.30	–
	Salt, common, dry, coarse	6.30 to 10.00	30 to 45
	Salt, common, dry, fine	11.00 to 12.55	30 to 45

Table 41 (*Concluded*)

Sl No.	Materials	Weight KN/m³	Angle of Friction, Degrees
(1)	(2)	(3)	(4)
	Salt cake, dry, coarse	13.35	30
	Salt cake, dry, pulverized	11.20 to 13.35	35
	Sand, bank. damp	17.25 to 20.40	45
	Sand, bank, dry	14.10 to 17.25	30
	Sand, silica, dry	14.10 to 15.70	30 to 45
	Saw dust	1.57	30
	Silica gel	4.40	30 to 45
	Soda ash, heavy	8.67 to 10.20	35
	Soda ash, light	4.70 to 6.00	37
	Sodium nitrate, granular	11.00 to 12.55	24
	Sulphur, crushed, 12 mm and under	7.85 to 8.25	35 to 45
	Sulphur, 76 mm and under	8.65 to 13.35	32
	Sulphur, powdered	7.85 to 9.40	30 to 45
	Single superphosphate (S.S.P), granulated	7.65 to 8.25	37
	Slag, furnace, crushed	14.90	35
	Steel goods:		
	Cylinders, usually stored for Carbonic acid, etc	13.80	
	Sheets, railway rails, etc, usually stored	44.00	
	Trisodium phosphate	9.40	30 to 45
	Triple superphosphate	7.85 to 8.65	30 to 45
	Turf	2.85 to 5.70	–
	Urea, prills	6.40	23 to 26
vii)	**Ores**		
	Antimony	29.80	–
	Ferrous sulphide	26.50	–
	Ferrous sulphide ore waste after roasting	13.85	–
	Iron ore, compact storing	29.80	–
	Magnesium ore	19.60	–
viii)	**Textiles, Paper and Allied Materials**		
	Cellulose in bundles	7.35	–
	Cotton, compressed	12.75	–
	Flax, piles and compressed in bales	2.95	–
	Furs	8.80	–
	Jute in bundles	6.85	–
	Paper:		
	In bundles and rolls	6.85	–
	Newspaper in bundles	3.90	–
	Put in rows	10.80	–
	Thread in bundles	4.90	–
	Wood, compressed	12.75	–

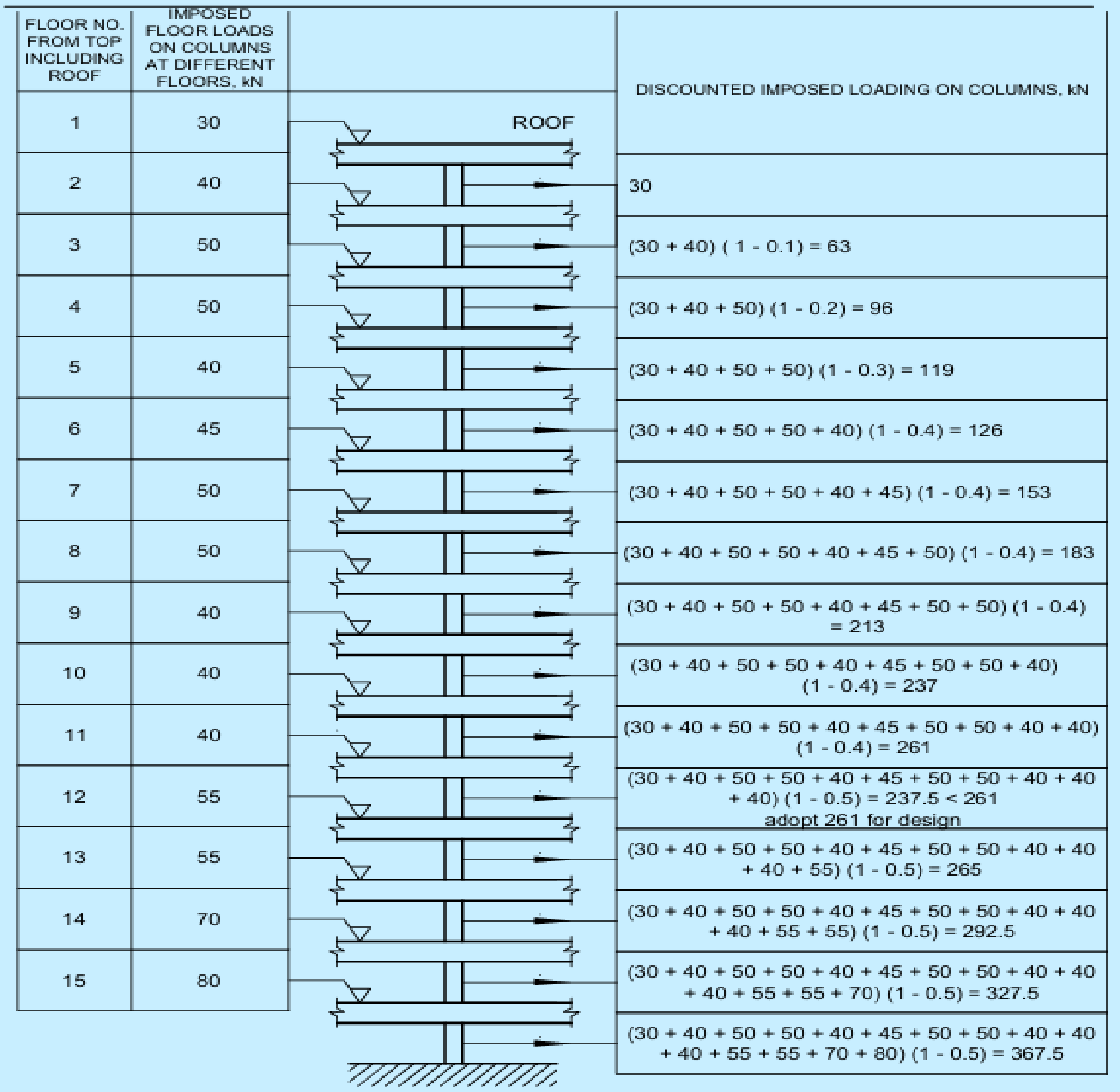
ANNEX B

[*Clause* 3.3.2.1(b)]

ILLUSTRATIVE EXAMPLE SHOWING REDUCTION OF UNIFORMLY DISTRIBUTED IMPOSED FLOOR LOADS IN MULTI-STOREYED BUILDINGS FOR DESIGN OF COLUMNS

B-1 The total imposed loads from different floor levels (including the roof) coming on the central column of a multi-storeyed building (with mixed occupancy) is shown in Fig. 14. Calculate the reduced imposed load for the design of column members at different floor levels using **3.3.2.1**. Floor loads do not exceed 5.0 kN/m^2.

B-1.1 Applying reduction coefficients in accordance with **3.3.2.1**, total reduced floor loads on the column at different levels is indicated along with Fig. 14.



FLOOR NO. FROM TOP INCLUDING ROOF	IMPOSED FLOOR LOADS ON COLUMNS AT DIFFERENT FLOORS, kN	DISCOUNTED IMPOSED LOADING ON COLUMNS, kN
1	30	
2	40	30
3	50	(30 + 40) (1 - 0.1) = 63
4	50	(30 + 40 + 50) (1 - 0.2) = 96
5	40	(30 + 40 + 50 + 50) (1 - 0.3) = 119
6	45	(30 + 40 + 50 + 50 + 40) (1 - 0.4) = 126
7	50	(30 + 40 + 50 + 50 + 40 + 45) (1 - 0.4) = 153
8	50	(30 + 40 + 50 + 50 + 40 + 45 + 50) (1 - 0.4) = 183
9	40	(30 + 40 + 50 + 50 + 40 + 45 + 50 + 50) (1 - 0.4) = 213
10	40	(30 + 40 + 50 + 50 + 40 + 45 + 50 + 50 + 40) (1 - 0.4) = 237
11	40	(30 + 40 + 50 + 50 + 40 + 45 + 50 + 50 + 40 + 40) (1 - 0.4) = 261
12	55	(30 + 40 + 50 + 50 + 40 + 45 + 50 + 50 + 40 + 40 + 40) (1 - 0.5) = 237.5 < 261 adopt 261 for design
13	55	(30 + 40 + 50 + 50 + 40 + 45 + 50 + 50 + 40 + 40 + 40 + 55) (1 - 0.5) = 265
14	70	(30 + 40 + 50 + 50 + 40 + 45 + 50 + 50 + 40 + 40 + 40 + 55 + 55) (1 - 0.5) = 292.5
15	80	(30 + 40 + 50 + 50 + 40 + 45 + 50 + 50 + 40 + 40 + 40 + 55 + 55 + 70) (1 - 0.5) = 327.5
		(30 + 40 + 50 + 50 + 40 + 45 + 50 + 50 + 40 + 40 + 40 + 55 + 55 + 70 + 80) (1 - 0.5) = 367.5

FIG. 14 LOADING DETAILS

ANNEX C

(*Clauses* 4.2)

NOTATIONS

C-1 The following notations to be followed unless otherwise specified in relevant clauses under wind loads:

A = Surface area of a structure or part of a structure
A_e = Effective frontal area
A_z = Effective frontal area of the building at height z
b = Breadth of a structure or structural member normal to the wind stream in the horizontal plane
B_s = Background factor
C_d = Drag coefficient
C_f = Force coefficient
C_{fn} = Normal force coefficient
C_{ft} = Transverse force coefficient
C_f' = Frictional drag coefficient
C_p = Pressure coefficient
C_{pe} = External pressure coefficient
C_{pi} = Internal pressure coefficient
C_{fs} = Cross-wind force spectrum coefficient
$C_{f,z}$ = Drag force coefficient of the building corresponding to the area A_z
C = Coefficient, which depends on θ_s, used in the evaluation of k_3 factor
d = Depth of a structure or structural member parallel to wind stream in the horizontal plane
d_w = Wake width
D = Diameter of cylinder or sphere
E = Wind energy factor
F_z = Along wind load on the building/structure at any height z
F = Force normal to the surface
f_a = First mode natural frequency of the building/structure in along wind direction, in Hz
f_c = First mode natural frequency of the building/structure in across wind direction, in Hz
f_s = Vortex shedding frequency
F_n = Normal force
F_t = Transverse force
F' = Frictional force
G = Gust factor
g_R = Peak factor for resonant response
g_v = Peak factor for upwind velocity fluctuations
h = Height of structure above mean ground level
h_x = Height of development of a velocity profile at a distance x down wind from a change in terrain category
H_s = Height factor for resonant response

H = Height above mean ground level on the topography feature

I = Turbulence intensity

$I_{h,i}$ = Turbulence intensity at height h in terrain category i

$I_{z,i}$ = Turbulence intensity at height z in terrain category i

IF = Interference factor

k = Mode shape power exponent

k_1, k_2, k_3, k_4 = Wind speed modification factors

$\overline{k}_{2,i}$ = Hourly mean wind speed factor

K = Force coefficient multiplication factor for individual members of finite length

K_a = Area averaging factor

K_c = Combination factor

K_d = Wind directionality factor

l = Length of the member or larger horizontal dimension of a building

L = Actual length of upwind slope

L_e = Effective length of upwind slope

L_h = Integral turbulence length scale at the height, h

m_0 = Average mass per unit height of the structure

M_a = Design peak along wind base bending moment

M_c = Design peak across wind base bending moment

N = Effective reduced frequency

p_d = Design wind pressure

p_z = Wind pressure at height z

$\overline{P}_d$ = Design hourly mean wind pressure corresponding to $\overline{V}_{z,d}$

p_e = External pressure

p_i = Internal pressure

r = Roughness factor which is twice the longitudinal turbulence intensity at height h, $I_{h\,i}$

R_e = Reynolds number

s = Level on a building/structure for the evaluation of along wind load effects

s_0 = Factor, which depends on H and X, used for the evaluation of k_3 factor

S_t = Strouhal number

S = Size reduction factor

V_b = Regional basic wind speed

V_z = Design wind speed at height z

$\overline{V}_d$ = Design hourly mean wind speed

$\overline{V}_{z,d}$ = Design hourly mean wind speed at height z

$\overline{V}_{z,H}$ = Hourly mean wind speed at height z

w = Lesser horizontal dimension of a building, or a structural member

w' = Bay width in multi-bay building

$\hat{\ddot{x}}$ = Peak acceleration at the top of the building/structure in along wind direction, in m/s^2;

x = Distance down wind from a change in terrain category

X = Distance from the summit or crest of topography feature relative to the effective length, L_e

$\hat{y}$ = Peak acceleration at the top of the building/structure in across wind direction

z = Height or distance above the ground

$z_{0,i}$ = Aerodynamic roughness height for i^{th} terrain

Z = Effective height of the topography feature

α = Inclination of the roof to the horizontal

β = Damping coefficient of the building/structure

η = Shielding factor

ϕ = Factor to account for the second order turbulence intensity

Φ = Solidity ratio

Φ_e = Effective solidity ratio

ε = Average height of the surface roughness

θ_s = Upwind slope of the topography feature in the wind direction

θ = Wind angle from a given axis

ANNEX D

(*Clause* 4.4.2)

BASIC WIND SPEED AT 10 m HEIGHT FOR SOME IMPORTANT CITIES/TOWNS

City/Town	Basic Wind Speed m/s	City/Town	Basic Wind Speed m/s
Agra	47	Kanpur	47
Ahmedabad	39	Kohima	44
Ajmer	47	Kolkata	50
Almora	39	Kozhikode	39
Amritsar	50	Kurnool	39
Asansol	47	Lakshadweep	39
Aurangabad	39	Lucknow	50
Bahraich	50	Ludhiana	50
Bengaluru	33	Madurai	39
Barauni	47	Mandi	39
Bareilly	50	Mangaluru	39
Bhatinda	47	Moradabad	50
Bhilai	44	Mumbai	44
Bhopal	47	Mysuru	33
Bhubaneshwar	50	Nagpur	44
Bhuj	50	Nainital	47
Bikaner	47	Nasik	39
Bokaro	39	Nellore	50
Chandigarh	50	Panaji	39
Chennai	50	Patiala	50
Coimbatore	39	Patna	47
Cuttack	50	Puducherry	50
Darbhanga	47	Port Blair	44
Darjeeling	47	Pune	39
Dehra Dun	39	Raipur	44
Delhi	50	Rajkot	39
Durgapur	47	Ranchi	39
Gangtok	47	Roorkee	50
Guwahati	50	Rourkela	39
Gaya	39	Simla	39
Gorakhpur	47	Srinagar	39
Hyderabad	44	Surat	44
Imphal	44	Tiruchirrappalli	47

City/Town	Basic Wind Speed m/s	City/Town	Basic Wind Speed m/s
Jabalpur	39	Thiruvananthapuram	39
Jaipur	47	Udaipur	47
Jamshedpur	47	Vadodara	39
Jhansi	47	Varanasi	47
Jodhpur	47	Vijaywada	50
		Visakhapatnam	50

ANNEX E

[*Clause* 4.4.3.2.4(b)(2)]

CHANGES IN TERRAIN CATEGORIES

E-1 LOW TO HIGH TERRAIN CATEGORY NUMBER

In cases of transition from a low terrain category number (corresponding to a low terrain roughness) to a higher terrain category number (corresponding to a rougher terrain), the velocity profile over the rougher terrain shall be determined as follows:

a) Below height h_x, the velocities shall be determined in relation to the rougher terrain; and

b) Above height h_x, the velocities shall be determined in relation to the less rough (more distant) terrain.

E-2 HIGH TO LOW TERRAIN CATEGORY NUMBER

In cases of transition from a more rough to a less rough terrain, the velocity profile shall be determined as follows:

a) Above height h_x, the velocities shall be determined in accordance with the rougher (more distant) terrain; and

b) Below height h_x, the velocity shall be taken as the lesser of the following:

   1) That determined in accordance with the less rough terrain; and

   2) The velocity at height h_x as determined in relation to the rougher terrain.

NOTE — Examples of determination of velocity profiles in the vicinity of a change in terrain category are shown in Fig. 15(A) and Fig. 15(B).

E-3 MORE THAN ONE CATEGORY

Terrain changes involving more than one category shall be treated in similar way to that described in **E-1** and **E-2**.

NOTE — Examples involving three terrain categories are shown in Fig. 15(B).

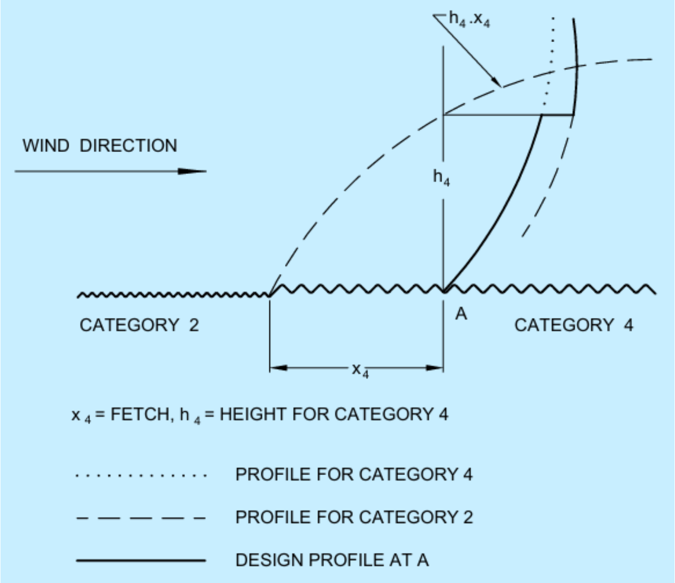

h4.x4
WIND DIRECTION
h4
CATEGORY 2
A
CATEGORY 4
x4
x4 = FETCH, h4 = HEIGHT FOR CATEGORY 4
PROFILE FOR CATEGORY 4
PROFILE FOR CATEGORY 2
DESIGN PROFILE AT A

Fig. 15(A) Determination of Velocity Profile Near a Change in Terrain Category (Less rough to more rough)

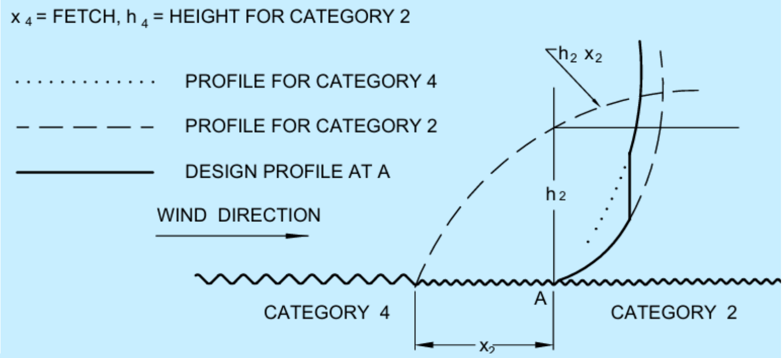

x4 = FETCH, h4 = HEIGHT FOR CATEGORY 2
PROFILE FOR CATEGORY 4
PROFILE FOR CATEGORY 2
DESIGN PROFILE AT A
WIND DIRECTION
h2 x2
h2
CATEGORY 4
A
CATEGORY 2
x2

Fig. 15(B) Determination of Velocity Profile Near a Change in Terrain Category (More rough to less rough)

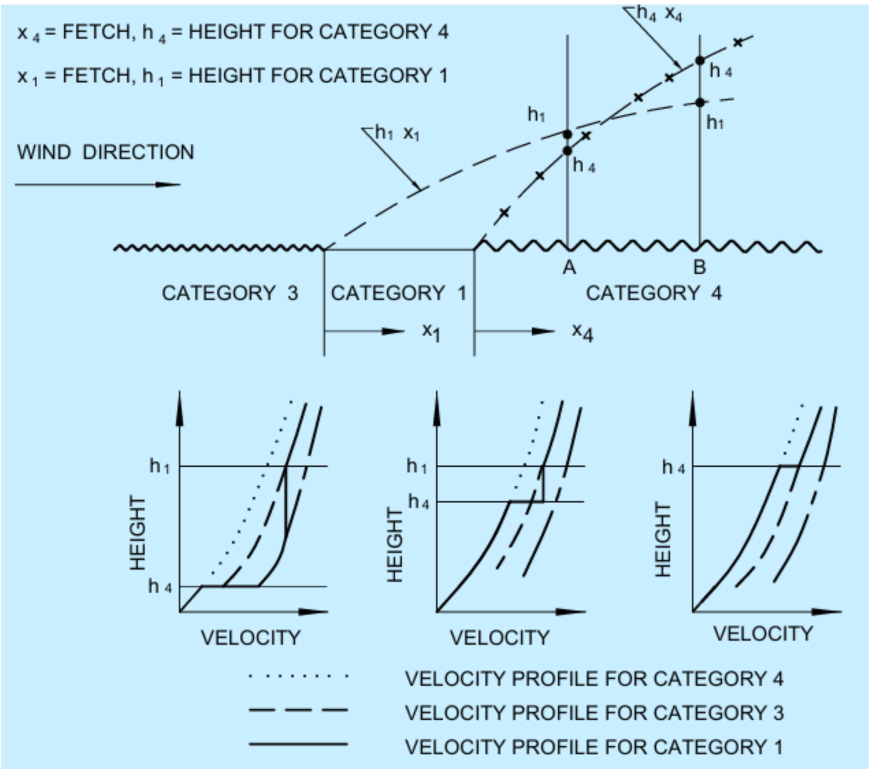

x₄ = FETCH, h₄ = HEIGHT FOR CATEGORY 4
x₁ = FETCH, h₁ = HEIGHT FOR CATEGORY 1
WIND DIRECTION
h₁ x₁
h₄ x₄
h₁
h₄
h₄
h₁
A
B
CATEGORY 3
CATEGORY 1
CATEGORY 4
x₁
x₄
HEIGHT
h₁
h₄
VELOCITY
HEIGHT
h₁
h₄
VELOCITY
HEIGHT
h₄
VELOCITY
VELOCITY PROFILE FOR CATEGORY 4
VELOCITY PROFILE FOR CATEGORY 3
VELOCITY PROFILE FOR CATEGORY 1

FIG. 15(C) DETERMINATION OF DESIGN PROFILE INVOLVING MORE THAN ONE CHANGE IN TERRAIN CATEGORY

FIG. 15 VELOCITY PROFILES IN THE VICINITY OF A CHANGE IN TERRAIN CATEGORY

ANNEX F

(*Clause* 4.4.3.3)

EFFECT OF A CLIFF OR ESCARPMENT ON EQUIVALENT HEIGHT ABOVE GROUND (k_3 FACTOR)

F-1 The influence of the topographic feature is considered to extend 1.5 L_e upwind and 2.5 L_e downwind of the summit of crest of the feature where Le is the effective horizontal length of the hill depending on slope as indicated below (*see* Fig. 16):

Slope	L_e
$3° < \theta_s \leq 17°$	L
$\theta_s > 17°$	$Z / 0.3$

where

L = actual length of the upwind slope in the wind direction,

Z = effective height of the topography feature and

θ_s = upwind slope in the wind direction.

In case, the zone in downwind side of the crest of the feature is relatively flat ($\theta_s < 3°$) for a distance exceeding L_e, then the feature should be treated as an escarpment. Otherwise, the feature should be treated as a hill or ridge. Examples of typical features are given in Fig. 16.

NOTES

1 No difference is made, in evaluating k_3 between a three dimensional hill and two dimensional ridge.

2 In undulating terrain, it is often not possible to decide whether the local topography to the site is significant in terms of wind flow. In such cases, the average value of the terrain upwind of the site for a distance of 5 km should be taken as the base level from wind to assess the height, Z and the upwind slope θ, of the feature.

F-2 TOPOGRAPHY FACTOR, k_3

The topography factor k_3 is given by the following:

$$k_3 = 1 + C\, s_0$$

where C has the following values:

Slope	*C*
$3° < \theta_s \leq 17°$	$1.2\,(Z/L)$
$\theta_s > 17°$	0.36

and s_0 is a factor derived in accordance with **F-2.1** appropriate to the height, H above mean ground level and the distance, X, from the summit or crest relative to the effective length, L_e.

F-2.1 The factor, s_0 should be determined from:

a) Fig. 17 for cliffs and escarpments; and

b) Fig.18 for ridges and hills.

NOTE — Where the downwind slope of a hill or ridge is more than 3°, there will be large regions of reduced accelerations or even shelter and it is not possible to give general design rules to cater for these circumstances. Values of s_0 from Fig. 18 may be used as upper bound values.

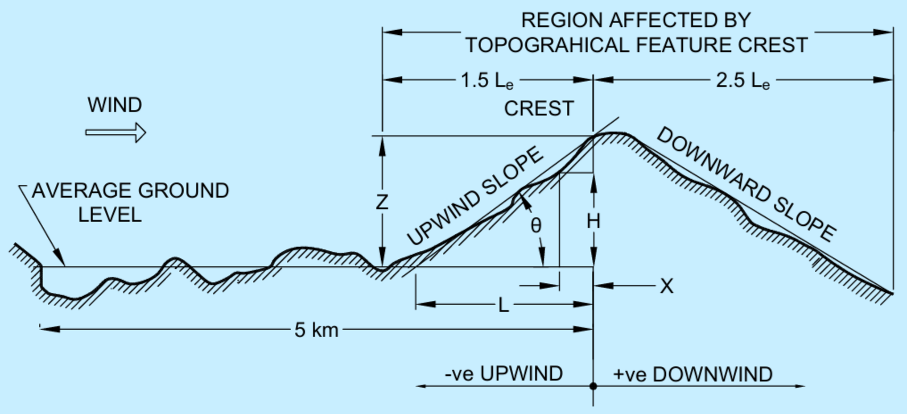
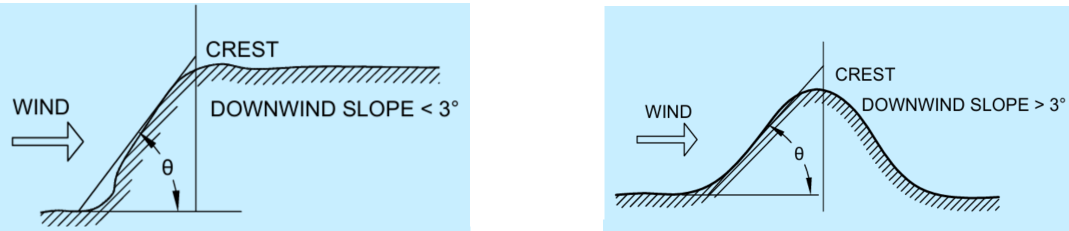

REGION AFFECTED BY
TOPOGRAHICAL FEATURE CREST
1.5 L_e
2.5 L_e
CREST
WIND
AVERAGE GROUND LEVEL
DOWNWARD SLOPE
UPWIND SLOPE
Z
θ
H
X
L
5 km
-ve UPWIND
+ve DOWNWIND

FIG. 16(A) GENERAL NOTATIONS


WIND
CREST
DOWNWIND SLOPE < 3°
θ
WIND
CREST
DOWNWIND SLOPE > 3°
θ

16(B) CLIFF AND ESCARPMENT

16(C) HILL AND RIDGE

FIG. 16 TOPOGRAPHICAL DIMENSIONS

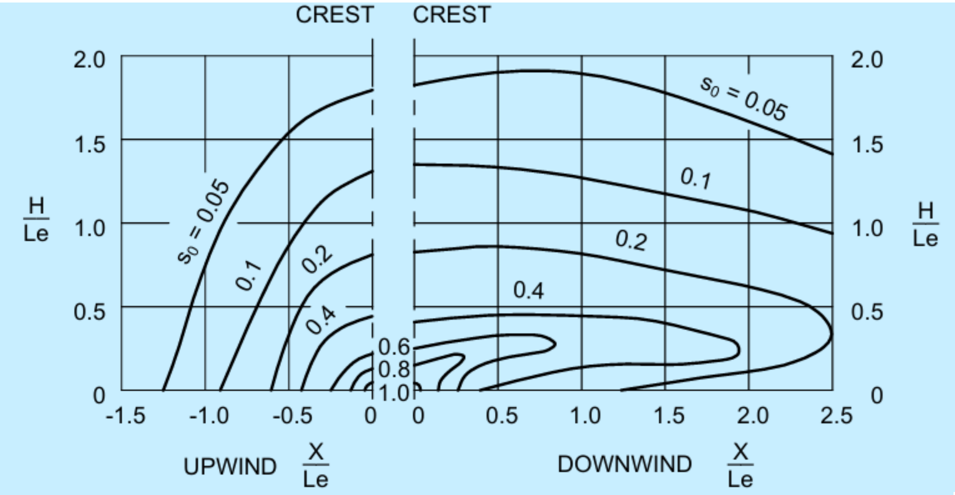


FIG. 17 FACTOR s_0 FOR CLIFF AND ESCARPMENT

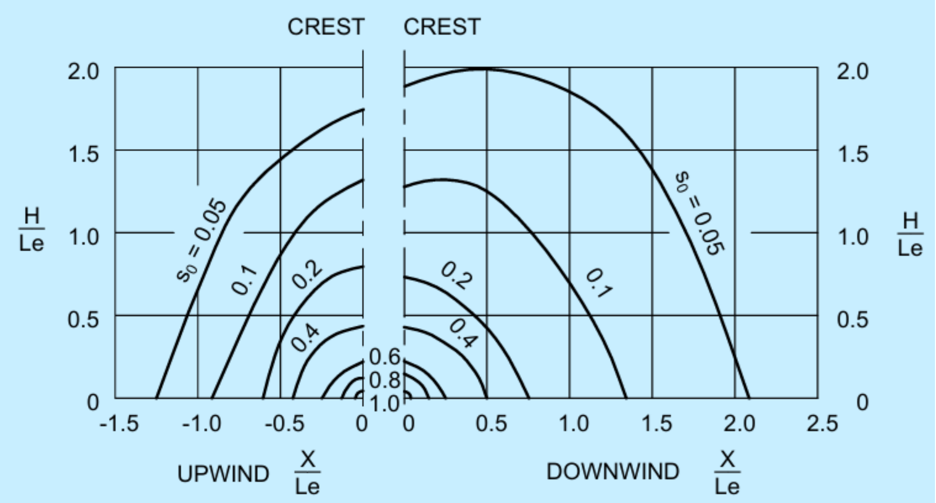


FIG. 18 FACTOR s_0 FOR RIDGE AND HILL

ANNEX G

[*Clauses* 4.5.4.2.2, 4.5.4.3.2(c) *and* 4.5.4.3.3]

WIND FORCE ON CIRCULAR SECTIONS

G-1 The wind force on any object is given by:

$$F = C_f A_e p_d$$

where

C_f = force coefficient;
A_e = effective area of the object normal to the wind direction; and
p_d = design pressure of the wind.

For most shapes, the force coefficient remains approximately constant over the whole range of wind speeds likely to be encountered. However, for objects of circular cross section, it varies considerably.

For a circular section, the force coefficient depends on the way in which the wind flows around it and is dependent upon the velocity and kinematic viscosity of the wind and diameter of the section. The force coefficient is usually quoted against a non-dimensional parameter, called the Reynolds number, which takes into account of the velocity and viscosity of the flowing medium (in this case the wind) and the member diameter.

$$\text{Reynolds number, } R_e = \frac{D\overline{V}_d}{\nu}$$

where

D = diameter of the member;
$\overline{V}_d$ = design hourly mean wind speed; and
ν = kinematic viscosity of the air which is 1.46×10^{-5} m^2/s at 15° and standard atmospheric pressure.

Since in most natural environments likely to be found in India, the kinematic viscosity of the air is fairly constant, it is convenient to use $D\overline{V}_d$ as the parameter instead of Reynolds number and this has been done in this Section.

The dependence of a circular section's force coefficient on Reynolds number is due to the change in the wake developed behind the body.

At a low Reynolds number, the wake is as shown in Fig. 19 and the force coefficient is typically 1.2. As Reynolds number is increased, the wake gradually changes to that shown in Fig. 20, that is, the wake width d_w decreases and the separation point, denoted as s_p, moves from front to the back of the body.

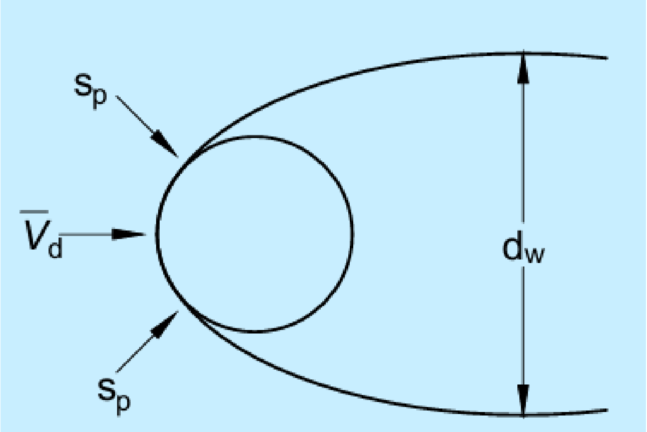


FIG. 19 WAKE IN SUB-CRITICAL FLOW

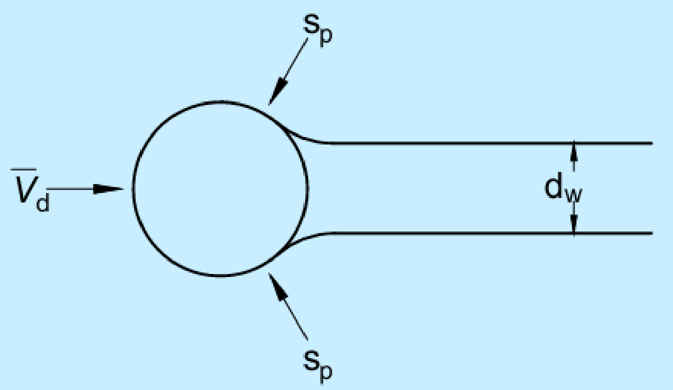


FIG. 20 WAKE IN SUPER-CRITICAL FLOW

As a result, the force coefficient shows a rapid drop at a critical value of Reynolds number followed by a gradual rise as Reynolds number is increased still further.

The variation of C_f with parameter $D\overline{V}_d$ is shown in Fig. 5 for infinitely long circular cylinders having various values of relative surface roughness (ε/D) when subjected to wind having an intensity and scale of turbulence typical of built-up urban areas. The curve for a smooth cylinder (ε/D) = 1×10^{-5} in a steady air stream, as found in a low-turbulence wind tunnel, is also shown for comparison.

It can be seen that the main effect of free-stream turbulence is to decrease the critical value of the parameter $D\overline{V}_d$. For subcritical flows, turbulence can produce a considerable reduction in C_f below the steady air-stream values. For supercritical flows, this effect becomes significantly smaller.

If the surface of the cylinder is deliberately roughened, such as by incorporating flutes, riveted construction, etc, then the data given in Fig. 5 for appropriate value of $\varepsilon/D > 0$ shall be used.

NOTE — In case of uncertainty regarding the value of ε to be used for small roughness, ε/D shall be taken as 0.001.

ANNEX H

(*Foreword* *and clause* 7.3.2)

CHARACTERISTIC GROUND SNOW LOAD

H-1 This annex presents the characteristic ground snow load computation procedure for the union territory of Jammu and Kashmir, union territory of Ladakh, Himachal Pradesh, Uttarakhand and Sikkim which is the result of scientific work carried out by Defence Geoinformatics Research Establishment (DGRE), Chandigarh under Defence Research and Development Organization (DRDO).

H-2 The characteristic value of the ground snow load at any site is defined with a 3.4 percent annual exceedance probability or, equivalently, with a mean recurrence interval, MRI = 30 years. The site altitude is the altitude at which the structure is or will be located, measured from mean sea level. The procedure shall be used for the computation of characteristic ground snow load on sites with an altitude higher than 1000 m and lower than 4000 m from mean sea level.

H-3 The characteristic ground snow load, s_0 (kPa) to be used for any site in the union territory of Jammu and Kashmir, union territory of Ladakh, Himachal Pradesh, Uttarakhand should be obtained from the zone map shown in Fig. 21 and equation given below:

$$s_0 = 1.624 \times [Z - 0.5] \times \left[1 + \left(\frac{A}{2677}\right)^2\right] \text{ kPa}$$

where

s_0 = characteristic ground snow load (kPa);

Z = zone number (for example 1, 2, 3, 4 or 5) obtained from the zone; and

A = map in Fig. 21.

H-4 The characteristic ground snow load s_0 (kPa) to be used for any site in Sikkim should be directly obtained from the characteristic ground snow load map shown in Fig. 22.

H-5 The ground snow loads for any mean recurrence interval of n years, different to that for the characteristic snow load, s_0, (which by definition is based on annual probability of exceedance of 0.034 that is MRI = 30 years) shall be calculated by the equation given below:

$$s_n = s_0 \left\{ \frac{1 - C_{\mathrm{v}} \frac{\sqrt{6}}{\pi} \left[ln\left(-ln(1 - P_{\mathrm{n}})\right) + 0.577\,22 \right]}{(1 + 2.188\,7 C_{\mathrm{v}})} \right\}$$

where

s_0 = characteristic snow load on the ground with MRI = 30 years

s_n = characteristic snow load on the ground with MRI = 30 years

P_{n} = annual probability of exceedance (equivalent to $1/n$, where n is the corresponding recurrence interval in years)

C_{v} = coefficient of variation of annual maximum snow load.

H-5.1 The coefficient of variation of maximum snow load at different snow-meteorological observatories of DGRE located in union territory of J and K, union territory of Ladakh, HP and UK ranges between 0.35 to 0.65. For application of above equation, a constant value of $C_{\mathrm{v}} = 0.5$ is recommended for all the zones to calculate snow loads on the ground for other probability of exceedance (for example, MRI of 50 years for structures where a higher risk of exceedance is deemed acceptable). The above equation is shown graphically in Fig. 23.

NOTES

1 The characteristic ground snow load *versus* altitude relation as given above in equation and Fig. 21 is determined based on the snow depth observations at more than 70 field observatories of DGRE located in different parts of union territory of Jammu and Kashmir, union territory of Ladakh and states of Himachal Pradesh and Uttarakhand as well as High Asia Refined analysis (HAR10) dataset (HAR, Maussion et al., 2014).

2 Since adequate snow depth measurements are not available for Sikkim region, hence the characteristic ground snow load map for Sikkim given in Fig. 22 is generated based solely on high Asia refined analysis (HAR10) dataset (HAR, Maussion et al., 2014).

3 Annex H does not apply for sites at altitudes above 4000 m. For altitudes greater than 4000 m specialist advice should be sought from DGRE on the characteristic ground snow loads likely to occur at the site.

4 Unusual local effects have not been accounted for in the analysis undertaken to produce the characteristic ground snow load map given in Annex H. These include local shelter from the wind, which can result in increased local snow loads and local configurations in mountainous areas, which may funnel the snow and give increased local loading. Annex H is also not applicable for sites with permanent snow/ice cover throughout the year. If the designer suspects that there are unusual local conditions that need to be taken into account, DGRE may be consulted.

5 In special cases where more refined data is needed, the characteristic value of snow load on the ground (s_0) may be refined using an appropriate statistical analysis of long term records taken in a well sheltered area near the site.

6 Ground characteristics snow load at any place depends on the critical combination of maximum depth of undisturbed aggregate cumulative snowfall and its density. In due course the characteristics snow load for states of Arunachal Pradesh will be included based on studies. Till such time the users of this section are advised to consult DGRE for the specific information relating to the state of Arunachal Pradesh.

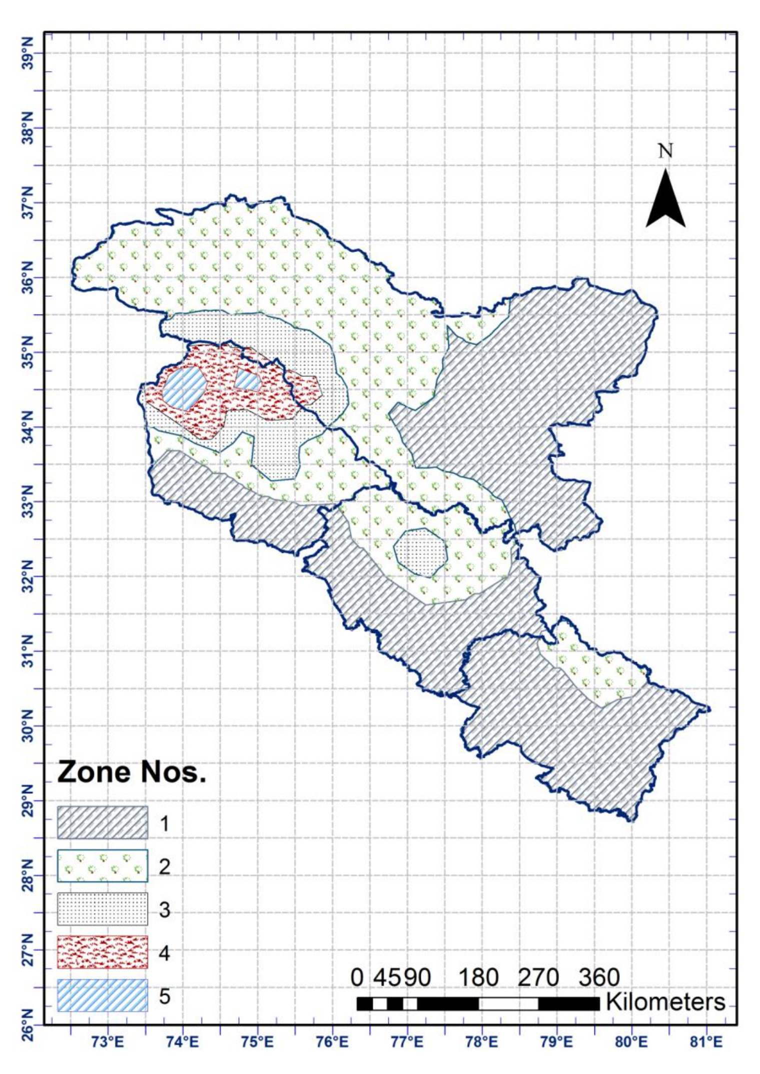

N
Zone Nos.
1
2
3
4
5
0 45 90 180 270 360
Kilometers
39°N
38°N
37°N
36°N
35°N
34°N
33°N
32°N
31°N
30°N
29°N
28°N
27°N
26°N
73°E
74°E
75°E
76°E
77°E
78°E
79°E
80°E
81°E

FIG. 21 ZONE MAP FOR J AND K, LADAKH, HP AND UK AT 10 KM RESOLUTION

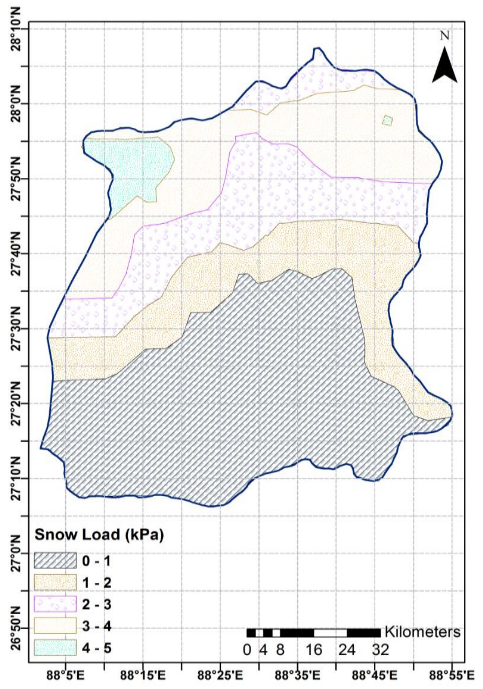

28°10'N
28°0'N
27°50'N
27°40'N
27°30'N
27°20'N
27°10'N
27°0'N
26°50'N
N
Snow Load (kPa)
0 - 1
1 - 2
2 - 3
3 - 4
4 - 5
Kilometers
0 4 8 16 24 32
88°5'E
88°15'E
88°25'E
88°35'E
88°45'E
88°55'E

FIG. 22 CHARACTERISTIC GROUND SNOW LOAD MAP FOR SIKKIM AT 10 KM RESOLUTION

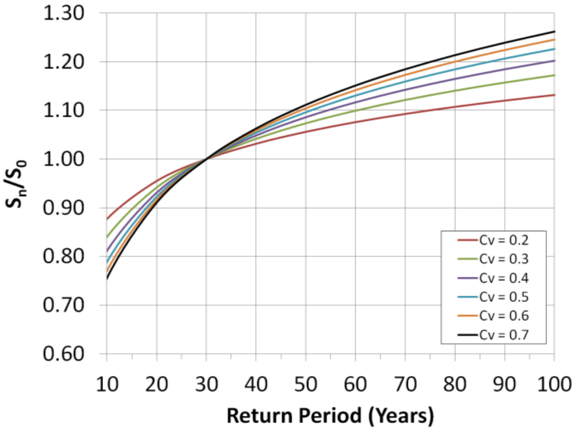


FIG. 23 ADJUSTMENT OF THE GROUND SNOW LOAD ACCORDING TO THE RETURN PERIOD

ANNEX J

(*Clauses* 7.4.2.4 *and* 7.4.3)

SHAPE COEFFICIENTS FOR MULTILEVEL ROOFS

J-1 A more comprehensive formula for the shape coefficient for multilevel roofs than that given in **7.4.2** is as follows:

$$\mu_w = 1 + \frac{1}{h}\left(m_1 l_1 + m_2 l_2\right)\left(l_2 - 2h\right)$$

$$\mu_1 = 0.8$$

$$l_3 = 2h$$

$$(h \text{ and } l \text{ in m})$$

Restriction:

$$\mu_w \leq \frac{kh}{S_o}$$

where

S_0 = kilopascals (kilonewtons per square metre)

k = newtons per cubic metre

l_3 = $\leq 15\ m$

Values of $m_1(m_2)$ for the higher (lower) root depend on its profile and are taken as equal to:

0.5 for plane roofs with slopes $\beta \leq 20°$ and vaulted roofs with $\frac{f}{l} \leq \frac{1}{18}$

0.3 for plane roofs with slopes $\beta \leq 20°$ and vaulted roofs with $\frac{f}{l} \leq \frac{1}{18}$

The coefficient m_1 and m_2 may be adjusted to take into account conditions for transfer of snow on the roof surface (that is wind, temperature, etc).

NOTE — The other condition of loading shall also be tried.

ANNEX K

(*Clause* 8.7)

VIBRATIONS IN BUILDINGS

K-1 GENERAL

In order to design the buildings safe against vibrations, it is necessary to identify the source and nature of vibration. Vibrations may be included in the buildings due to various actions, such as:

a) human induced vibrations, for example, the walking or running or a single person or a number of persons or dancing or motions in stadia or concert halls;

b) machine induced vibrations;

c) wind induced vibrations;

d) blast induced vibrations;

e) traffic load, for example, due to rail, fork-lift, trucks, cars, or heavy vehicles;

f) airborne vibrations;

g) crane operations; and

h) other dynamic actions such as wave loads or earthquake actions.

The dynamic response of buildings for the above mentioned causes of vibration of buildings may have to be evaluated by adopting standard mathematical models and procedures.

The severity or otherwise of these actions have to be assessed in terms of the limits set for dynamic response (frequencies and amplitude of motion) of the buildings related to (a) human comfort, (b) serviceability requirements such as deflections and drifts and separation distances to avoid damage due to pounding and (c) limits set on the frequencies and amplitude of motion for machines and other installations.

In order to verify that the set limits are not exceeded, the actions may be modelled in terms of force-time histories for which the structural responses may be determined as time histories of displacements or accelerations by using appropriate analytical/numerical methods.

K-2 SERVICEABILITY LIMIT STATE VERIFICATION OF STRUCTURE SUSCEPTIBLE TO VIBRATIONS

K-2.1 While giving guidance for serviceability limit state verification of structure susceptible to vibrations, here it is proposed to deal with the treatment of the action side, the determination of the structural response and the limits to be considered for the structural response to ensure that vibrations are not harmful or do not lead to discomfort.

K-2.2 Source of Vibrations

Vibrations may be included by the following sources:

a) by the movement of persons as in pedestrian bridges, floors where people walk, floors meant for sport or dancing activities and floors with fixed seating and spectator galleries;

b) by working of machines as in machine foundations and supports, vibrations transmitted through the ground and pile driving operations;

c) by wind blowing on buildings, towers, chimneys and masts, guyed masts, pylons, bridges, cantilevered roofs, airborne vibrations;

d) induced by traffic on rail or road bridges and car park structures and exhibition halls; and

e) by earthquakes.

K-2.3 Modelling of Actions and Structures

For serviceability limit states, the modelling of these actions and of the structure depends on how the serviceability limits are formulated. The serviceability limit states may refer to:

a) human comfort;

b) limits for the proper functioning of machines and other installations; and

c) maximum deformation limits to avoid damage or pounding.

In order to verify that these limits are not exceeded, the actions may be modeled in terms of force-time histories, for which the structural responses may be determined as time histories of displacements or accelerations by using appropriate analytical/numerical methods. Where the structural response may significantly influence the force-time histories to be applied, these interactions have to be considered either in modeling a combined load-structure vibration system or by appropriate modifications of the force time histories. In addition to the levels of vibration for which presently limits have been specified, the possible deformations of structural members and systems using different clauses in the relevant codes have to be evaluated by adopting standard mathematical models and procedures.

K-2.4 Force-Time Histories

The force-time histories used in the dynamic analysis should adequately represent the relevant loading situations for which the serviceability limits are to be verified. The force-time histories may model:

a) human induced vibrations, for example the walking or running of a single person or a number of persons or dancing or motions in stadia or concert halls;

b) machine induced vibrations, for example by force vectors due to mass eccentricities and frequencies, that may be variable with time;

c) wind induced vibrations;

d) blast induced vibrations;

e) traffic load, for example rail, fork-lift, trucks, cars, or heavy vehicles;

f) airborne vibrations;

g) crane operations; and

h) other dynamic actions such as wave loads or earthquake actions.

ANNEX L

(*Foreword and clause* 8.8)

BLAST LOAD

L-1 BLAST LOAD

L-1.1 This annex prescribes the minimum criteria for analysis and design of new structures for blast effects of above-ground explosions of high-explosives under three different detonation scenarios: surface burst, free-air burst and air burst. The primary objective of this annex is to minimize human casualties and safeguard assets due to above ground explosions. The performance expectation of a structure designed as per the provisions of this annex would depend on the type of protection category selected for that structure and the blast loading determined through threat assessment.

L-1.2 This annex shall be used in conjunction with other applicable standards for analysis and design of structures. This annex does not supersede or replace other design standards. This annex shall be applicable if design against malevolent or accidental blast loading is determined to be a credible threat to a structure.

L-1.3 The owner of a structure is the competent authority who can determine the necessity of blast-resistant design. In the scenario of accidental and malevolent blast event which may pose public health and safety issue, competent authorities other than the owner of building that govern or regulate the construction, operation and maintenance of the structural facility, can specify the requirement of blast-resistant design.

L-1.4 The provisions of this annex do not address the following:

a) Estimation of structural loads due to nuclear detonations, pressure vessel explosions, dust and vapour cloud explosions;

b) Effects of cased explosives and shaped charges;

c) Threats emanating from fragmentation, induced fire or thermal effects, biological or chemical radiations, electromagnetic pulse (EMP) and deflagration events; and

d) Detonations in contact with structural elements.

L-2 TERMINOLOGY

For the purpose of this annex, the following definitions shall apply.

L-2.1 Arrival Time — Time taken by the shock after the explosion to reach the location of interest.

L-2.2 Charge Mass — Mass of the explosive material responsible for generating blast effects.

L-2.3 Clearance Time — Time in which the reflected pressure decays down to the sum of the side on overpressure and the dynamic pressure.

L-2.4 Close-in Detonation — Detonation at a scaled distance (Z) below which the resulting blast pressure distribution is non-uniform over the reflecting surface of the element being considered. It corresponds to a value of Z less than 1.2 m/kg1/3.

L-2.5 Decay Parameter — The coefficient of the negative power of exponent e governing the fall of pressure with time in the pressure-time curves.

L-2.6 Detonation — Fast and sudden release of huge amount of energy through a stable chemical reaction in which reaction front propagates into unreacted substance at supersonic speed resulting in formation of shock waves.

L-2.7 Drag Force — Force on a structure or structural element due to the dynamic pressure of the blast wave. On any structural element, the drag force equals dynamic pressure multiplied by the drag coefficient and the area of the element.

L-2.8 Ductility Ratio — Ratio of the maximum deflection to the deflection corresponding to the elastic limit.

L-2.9 Dynamic Increase Factor (DIF) — A factor applied to material strength to account for high strain rate loading effects.

L-2.10 Dynamic Pressure — The pressure due to air mass movement behind the shock front.

L-2.11 Exponential Blast Pressure History — The variation of blast pressure with time at a point represented through an exponential decaying function, which considers positive and negative phase of blast overpressures.

L-2.12 Far-Field Detonation — Detonation at a scaled distance (Z) above which the resulting blast pressure distribution is uniform over the reflecting surface of element being considered. It corresponds to a value of Z greater than 1.2 $m/kg^{1/3}$.

L-2.13 High-Explosives — Chemical explosive that undergoes detonation to produce shock waves with high pressure and short duration.

L-2.14 Impulse — The integral of the pressure-time curve per unit projected area due to explosion (*see* specific impulse).

L-2.15 Mach Number — The ratio of the speed of the shock front propagation to the speed of sound in standard atmosphere at sea level.

L-2.16 Negative Phase — The duration of reflected overpressure when it is below the ambient atmospheric pressure.

L-2.17 Overpressure — The rise in pressure above atmospheric pressure due to the shock wave from an air blast.

L-2.18 Positive Phase —The duration of overpressure when it is above the ambient atmospheric pressure.

L-2.19 Protection Category — Category assigned to different structures that correlates its importance to the performance goals through qualitative estimate of damage.

L-2.20 Reflected Overpressure —The overpressure resulting due to reflection of a shock wave front striking any surface. If the shock front is parallel to the surface, the reflection is normal.

L-2.21 Regular Shaped Structure — A structure that does not have any spatial geometric irregularity.

L-2.22 Scaled Distance — The distance between the centre of explosion to the point of interest divided by the cube root of the charge mass expressed in equivalent TNT. The unit for scaled distance is $m/kg^{1/3}$.

L-2.23 Shape Function — The displaced shape of the component as a function of its length normalized to the maximum deflection.

L-2.24 Shock Wave Front — The discontinuity between the blast wave and the surrounding atmosphere. It propagates away from the point of explosion in all directions at a speed greater than the speed of sound in the undisturbed atmosphere.

L-2.25 Side-on (Incident) Overpressure — Overpressure if it is not reflected by any surface.

L-2.26 Simplified Overpressure History — A triangular representation of the overpressure history obtained by equating the impulse and the peak overpressure of the exponential representation of the overpressure history.

L-2.27 Specific Impulse — The area under the pressure-time curve due to explosion. This is often referred to as impulse (*see* **L-2.13**).

L-2.28 Standoff Distance — The shortest distance between the centre of detonation and the point of interest at which the effects of explosion need to be considered.

L-2.29 Support Rotation — The angle formed by a flexural member in its deflected shape with respect to the chord adjoining the two support ends (*see* Fig. 45).

L-2.30 Transit Time — Time required for the shock front to travel across the structure or its element under consideration.

L-3 SYMBOLS

For the purpose of this annex, the following notations shall apply.

b	Decay parameter/coefficient
C_d	Drag coefficient
C_r	Velocity of sound in air
$C_{r\alpha}$	Reflection coefficient
E	Modulus of elasticity of material
H	Height of the structure
I	Moment of inertia of member
i_e	Equivalent specific impulse of a uniformly distributed load
i_{ro}	Peak reflected specific impulse
j	Number of concentrated load points
K_L	Load factor
K_{LM}	Load mass factor
K_M	Mass factor
k_E	Effective stiffness of equivalent single spring-mass system
L	Length of structure in the direction of motion of blast wave (*see* Fig. 39)
M	Charge mass/weight
M_p	Plastic moment of section
M_{pm}	M_p at mid-span
M_{ps}	M_p at support
M_{pfa}	Total positive ultimate moment capacity along mid-span section parallel to short edge
M_{pfb}	Total positive ultimate moment capacity along mid-span section parallel to long edge

m	Distributed mass intensity per unit length
n	Number of concentrated masses
p_a	Ambient atmospheric pressure
P_r	Concentrated dynamic force at point *r*
p_ro	Peak reflected overpressure
p_s	Side-on overpressure
p_so	Peak side-on overpressure
P_t	Total dynamic load (at any instant of time)
$p(x)$	Intensity of distributed dynamic load per unit length
p_o1	Peak reflected overpressure on a surface including the effects of clearing
p_o2	Intercept of the reflected overpressure history on the y-axis corresponding to the clearing phase
q	Dynamic pressure
q_o	Peak dynamic pressure
R	Standoff distance
R_m	Peak resistance of a structural member against a given load distribution
S	W or H whichever is less
T	Elastic time-period of structural member
t_c	Clearance time
t_d	Duration of the equivalent triangular pulse
t_m	Time to the peak displacement of an SDOF system
t_o	Time for positive phase of side-on overpressure
t_t	Transit time
t_d1	Time at which clearing starts on a finite reflecting surface (*see* Fig. 47B)
t_d2	Total time duration of blast loading on a finite reflecting surface (*see* Fig. 47B)
U	Shock front velocity
u	Peak particle velocity
V_A	Total dynamic reaction along a short edge
V_B	Total dynamic reaction along a long edge
y_E	Displacement corresponding to the elastic limit of an equivalent bilinear representation of idealised resistance-deflection curve
y_el	Displacement corresponding to the first onset of yielding (elastic limit) of the idealized resistance-deflection curve of a structural member
y_m	Maximum deflection/deformation permitted in the design of the structure
y_o	Peak static displacement of an SDOF system without inertial effects
W	Span or width of structure across the direction of shock wave propagation
Z	Scaled distance

μ	Ductility ratio = $\frac{y_m}{y_E}$
φ_r	Deflection at point *r* of an assumed deflected shape for concentrated loads
$\varphi_{(x)}$	Deflection at point *x* of an assumed deflected shape for distributed loads
$\varphi_{(x,y)}$	Deflected shape function of blast-loaded component

L-4 GENERAL PRINCIPLES

L-4.1 Blast Resistant Design Attributes

The design process of a building against blast should start with planning of building layout and arrangements. The distance between the explosive and the building shall be maximized through a combination of site-access controls, landforms, anti-ram structures, street and site landscaping and perimeter walls. The building should preferably have short-face oriented towards blast source. Also, it shall be located uphill and placed upstream of wind direction and away from congestion. The structures and their contents that need protection against an explosion event should be decided and all possible scenarios need to be considered which can cause damage or occupant injuries. The overall design of a structure shall aim to incorporate following attributes in the overall planning and design of a facility against explosion threats:

a) *Security* — Discourage potential terrorist attacks on a structure through visible security personnel deployment and defences to reduce chance of such attacks;

b) *Deception* — Disguise the critical area or content of structure so that the focus of the attack is misdirected. Such attacks, even if successfully completed, may not deliver intended impact and realize its goals;

c) *Shielding* — Shield the target structure through physical barriers, including but not limited to blast walls, bollards, anti-ram elements, vehicle and pedestrian entry controls and landforms. The objective of shielding is to increase the standoff distance between the charge and the target structure and components; and

d) *Design* — The attack must be blunted through appropriate design and detailing of the structure to absorb the energy of the attack and safeguard valuable assets.

L-4.2 Blast Source

L-4.2.1 *Charge Shape*

The provisions of this annex shall be applicable for:

a) explosives of spherical shape; and

b) non-spherical charges if the detonation effects are considered at scaled distances greater than 3 m/kg$^{1/3}$.

In case of non-spherical charges at scaled distances smaller than 3 m/kg$^{1/3}$, the provisions of **L-8.3.3** shall be applicable with explicit modelling of the detonation process.

L-4.2.2 *Detonation Scenarios*

The standard addresses three scenarios of unconfined explosions based on the location of the detonation with respect to the point of interest:

a) Spherical (free-air) burst (*see* Fig. 24);

b) Hemispherical (surface) burst (*see* Fig. 25); and

c) Air-burst (*see* Fig. 26).

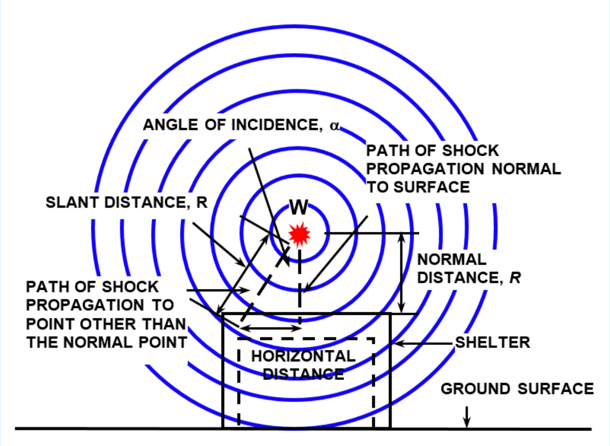

ANGLE OF INCIDENCE, α
PATH OF SHOCK PROPAGATION NORMAL TO SURFACE
SLANT DISTANCE, R
W
NORMAL DISTANCE, R
PATH OF SHOCK PROPAGATION TO POINT OTHER THAN THE NORMAL POINT
HORIZONTAL DISTANCE
SHELTER
GROUND SURFACE

FIG. 24 SPHERICAL (FREE-AIR) BURST

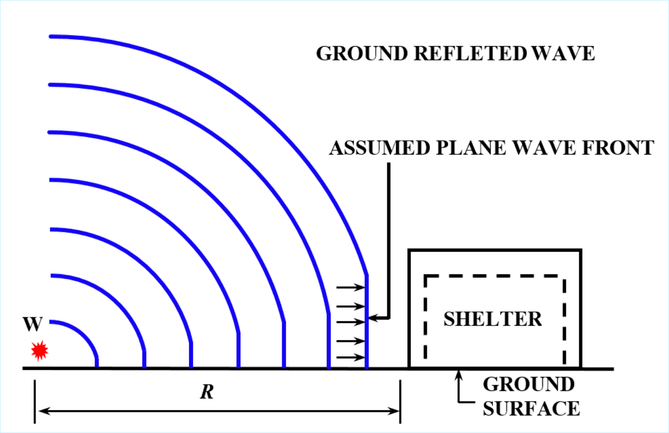

GROUND REFLETED WAVE
ASSUMED PLANE WAVE FRONT
W
SHELTER
R
GROUND SURFACE

FIG. 25 HEMISPHERICAL (SURFACE) BURST

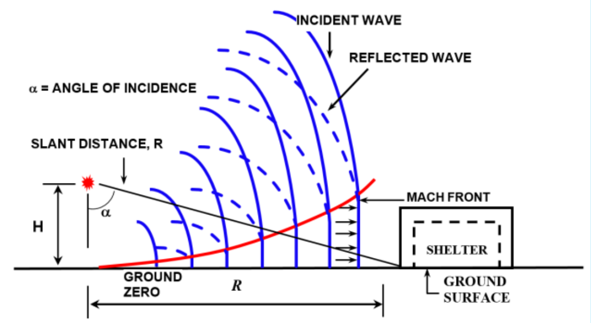

INCIDENT WAVE
REFLECTED WAVE
α = ANGLE OF INCIDENCE
SLANT DISTANCE, R
α
H
MACH FRONT
SHELTER
GROUND ZERO
R
GROUND SURFACE

FIG. 26 AIR-BURST

L-4.2.3 *Standoff Distance*

The standoff distance (*R*) shall be estimated as the distance between the centre of detonation and the point of interest. If the location of interest is not directly in the line of the sight from the centre of detonation, then Fig. 27 shall be referred to estimate the effective standoff distance.

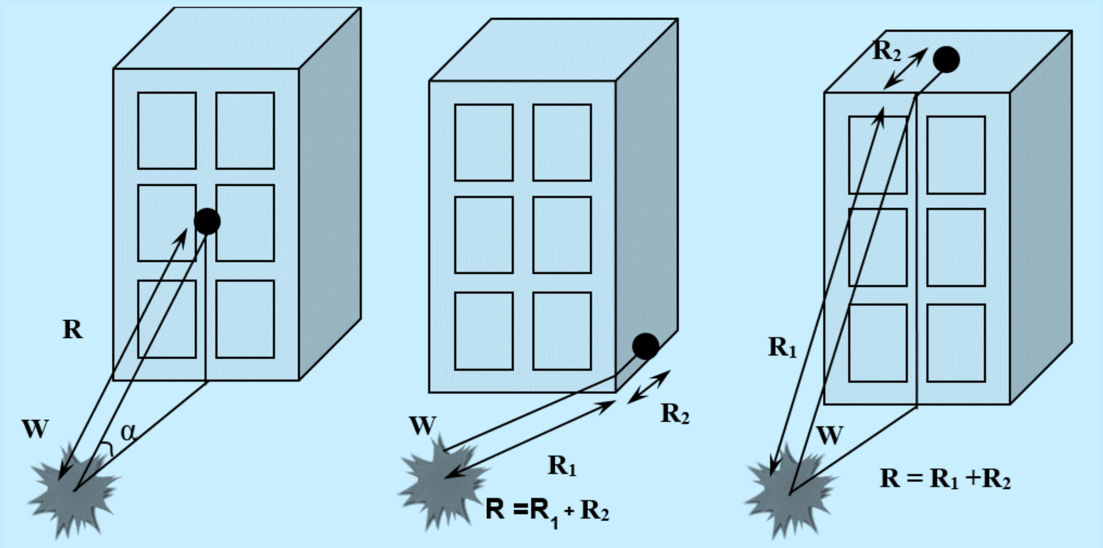


FIG. 27(A) FRONT FACE FIG. 27(B) SIDE FACE FIG. 27(C) TOP FACE

FIG. 27 CALCULATION OF STANDOFF DISTANCES AT DIFFERENCE FACES OF A BUILDING STRUCTURE

L-4.2.4 *Equivalent TNT Charge*

Trinitrotoluene (TNT) shall be used to benchmark all types of explosives. To quantify blast wave parameters (pressure, impulse) from explosives other than TNT, the actual mass of the explosive (M_{EXP}) shall be converted into a TNT-equivalent mass. The TNT equivalent weight (M_{TNT}) of any explosive shall be estimated as:

$$M_{\mathrm{TNT}}=\left(\frac{\Delta E_{\mathrm{EXP}}}{\Delta E_{\mathrm{TNT}}}\right) M_{\mathrm{EXP}}$$

where

ΔE_{EXP} and ΔE_{TNT} are the specific energies of the explosive and the TNT, respectively.

The factors presented in Table 42 shall be utilized to obtain equivalent mass of TNT corresponding to the listed explosives.

Table 42 Equivalent TNT Mass of Different Explosives

(*Clause* L-4.2.4)

Sl No. (1)	**Explosive** (2)	**Density** Mg/m^3 (3)	**Equivalent Mass for Pressure** (4)	**Equivalent Mass for Impulse** (5)
i)	Ammonia dynamite (50 percent strength)	NA[*]	0.90	0.90[Ɨ]
ii)	Ammonia dynamite (20 percent strength)	NA[*]	0.70	0.70[Ɨ]
iii)	ANFO (94/6 ammonium nitrate/fuel oil)	NA[*]	0.87	0.87[Ɨ]
iv)	Composition C-4	1.59	1.20	1.19
		1.59	1.37	1.19
v)	Cycloid (75/25 RDX/TNT) (70/30) (60/40)	1.71	1.11	1.26
		1.73	1.14	1.09
		1.74	1.04	1.16
vi)	Gelatine dynamite (50 percent strength)	NA[*]	0.80	0.80[Ɨ]
vii)	Gelatine dynamite (20 percent strength)	NA[*]	0.70	0.70[Ɨ]
viii)	HMX	NA[*]	1.25	1.25[Ɨ]
ix)	Nitrocellulose	1.65 to 1.70	0.50	0.50[Ɨ]
x)	Nitroglycerine dynamic (50 percent strength)	NA[*]	0.90	0.90[Ɨ]
xi)	Nitroglycerine (NQ)	1.72	1.00	1.00[Ɨ]
xii)	PETN	1.77	1.27	1.27[Ɨ]
xiii)	Picrotol (52/48 Ex D/TNT)	1.63	0.90	0.93
xiv)	RDX	NA[*]	1.10	1.10[Ɨ]
xv)	RDX/wax (98/2)	1.92	1.16	1.16[Ɨ]
xvi)	RDX/AL/wax (74/21/5)	NA[*]	1.30	1.30[Ɨ]
xvii)	Tetryl	1.73	1.07	1.07[Ɨ]
xviii)	Tetrytol (75/25 tetryl/TNT)	1.59	1.06	1.06[Ɨ]
xix)	TNT	1.63	1.00	1.00

NOTE

[*] NA — Data not available.

[Ɨ] Value is estimated.

L-4.2.5 *Cube Root Scaling*

Cube root scaling shall be used to relate blast parameters from different sources and standoff distances. The cube-root scaling shall be valid if the conditions specified in **L-4.2.1** are satisfied.

The blast load parameters can be obtained in scaled form as function of scaled distance, *Z*, as:

$$Z = \frac{R}{M^{1/3}}$$

where

R = standoff distance of the point of interest from the centre of charge mass; and

M = Mass in equivalent TNT.

The unit for scaled distance shall be m/kg$^{1/3}$, for standoff distance in m and charge mass in kg.

L-4.3 Performance Expectations

L-4.3.1 *Categorization of Structures*

Structures shall be categorized based on their importance as per the specification of Table 43.

The categorisation of structures as per Table 43, does not automatically require them to be designed for explosion threats. Only, if the threat assessment carried as per the provisions of **L-5.1** identifies blast loading due to explosion as a potential threat, the categorisation in Table 43 shall be used to define the importance of a structure.

Table 43 Categories of Structures

(*Clause* L-4.3.1)

Sl No. (1)	Importance (2)	Structure Type (3)
i)	Low	Residential buildings with 50 or less occupants
ii)	Medium	a) Residential buildings with more than 50 occupants b) Buildings with large congregation, such as schools, public offices and cinemas c) Industrial buildings with continuous human occupancy
iii)	High	a) Lifeline structures (water, power, communication, transportation, hospital) b) Structures housing essential services that are required for disaster management (for example, emergency relief stores, data centres, governance continuity buildings) c) Financial and commercial establishments of strategic importance

L-4.3.2 *Structural Performance*

A protection category shall be decided by the building owner based on the importance of the building and required performance. The performance goals for each protection category are listed in Table 44.

Table 44 Protection Category and Associated Performance Goals

(*Clause* L-4.3.2)

Sl No. (1)	Protection Category (2)	Performance Goal (3)
i)	1	Minimal damage, resumption after brief halt of operations
ii)	2	Limited damage, operational after repairs and retrofit
iii)	3	Extensive damage, safe replacement, or demolition

Structures of high, medium and low importance shall be provided with protection categories 1, 2 and 3 respectively, as at least a minimum as specified in Table 45.

The facility owner may specify a protection category higher than the minimum protection category specified in Table 45 based on the realistic assessment of threat.

Table 45 Protection Category and Associated Category of Structures

(*Clause* L-4.3.2)

Sl No.	Building Category	Minimum Protection Category
(1)	(2)	(3)
i)	Low	3
ii)	Medium	2
iii)	High	1

The protection categories specified in shall comply with the deformation limits of structural elements provided in **L-8.1.4** when using simplified single degree of freedom (SDOF) and multi degree of freedom (MDOF) methods of analysis as per requirements of **L-8.3.1** and **L-8.3.2** respectively. Accordingly, all elements shall be designed and detailed to provide deformation limits specified for different protection categories.

If advanced methods of analysis are used as per **L-8.3.3**, the response and damage in structure and elements for the performance goals of each protection category mentioned in can be independently established. In such case, deformation limits specified in **L-8.3.1** and **L-8.3.2** need not to be used.

L-5 THREAT ASSESSMENT

L-5.1 Threat Assessment Parameters

A threat assessment shall be carried out to determine all potential sources of detonation.

The threat assessment shall identify two parameters for the purpose of calculation of blast load parameters, namely:

a) charge mass; and

b) standoff distance.

If threat assessment identifies multiple sources of detonation, the effect of blast on the structure shall be assessed considering individual, as well as combinations of all identified detonation threats.

L-5.2 Design Blast (Reference Explosion)

L-5.2.1 *Design TNT Equivalence*

If the threat scenario results in identification of one of the detonation sources listed in Table 46, then the associated charge mass may be used for determination of equivalent TNT capacity.

L-5.2.2 *Standoff Distance*

The standoff distance (*R*) is site specific and shall be estimated as per the actual geometry and access control of the target structure.

L-6 BLAST LOAD

L-6.1 Blast Wave Propagation

The blast loads for design of structures and components shall be determined from blast pressure history.

Table 46 Detonation Source and the Associated Charge Mass

(*Clause* L-5.2.1 *and* Table 60)

Sl No.	Threat Description		Explosive Capacity (TNT Equivalent)
(1)	(2)	(3)	(4)
i)		Pipe bomb	2.5 kg
ii)		Suitcase	25 kg
iii)		Hatchback	250 kg
iv)		Sedans/SUV	500 kg
v)		Passenger van/small cargo truck	2 000 kg
vi)		Delivery truck	5 000 kg
vii)		Water tanker/diesel truck/gas truck	15 000 kg

The variation of pressure at a fixed location away from the centre of detonation shall be obtained using following assumptions:

a) the shock wave due to explosion moves away from the centre of detonation at a speed, U;

b) when the shock wave reaches a point at the arrival time t_a, the pressure rises instantaneously from the ambient pressure (p_a) to a peak pressure. This peak pressure, p_{so}, is known as side-on overpressure or peak incident overpressure;

c) the time needed for the pressure to reach its peak value is very small and for design purposes it is assumed to be zero;

d) the overpressure decreases exponentially from its peak value to the ambient pressure over the positive phase duration (t_o). After the positive phase of the pressure-time profile, the pressure becomes smaller than the ambient value (referred to as negative pressure) and finally returns to the ambient pressure, p_a;

e) the movement of air caused by the shock wave induces dynamic pressure, in addition to blast pressure. Air dynamic pressure q_o and peak particle velocity u shall be obtained using peak incident pressure, p_{so} (*see* Fig. 32 and Fig. 33); and

f) shock wave upon reflection from a rigid surface would apply reflected overpressure, p_r, to the reflecting surface. The variation of reflected overpressure with time for normal reflection follows the same trend as the incident overpressure but characterized by significantly higher peak overpressure.

L-6.2 Decay of Blast Overpressure with Time

The blast overpressure is assumed to vary with time, t according to the following exponential relationship (*see* Fig. 28):

$$p_s(t) = p_o\left(1-\frac{t}{t_o}\right)e^{-b(t/t_o)}$$

where

p_o = peak blast overpressure, which is interpreted as the peak incident and reflected overpressures for the incident and the reflected blast wave, respectively; and

b = decay coefficient; and t_o is the positive phase duration. Special literature is to be referred for the calculation of the blast wave decay parameter, b.

L-6.3 Blast Overpressure History Parameters

The maximum values of the positive side-on overpressure p_{so}, incident impulse i_s, reflected over pressure p_r, reflected impulse i_r, positive phase duration t_o, shock wave front velocity U and wave length L_w, for varying scaled distances, are to be obtained for a spherical TNT explosion in free air and a hemispherical TNT explosion on the surface using Fig. 30 and Fig. 31, respectively. Further, air dynamic pressure q_o and peak particle velocity u, are to be obtained using Fig. 32 and Fig. 33, respectively.

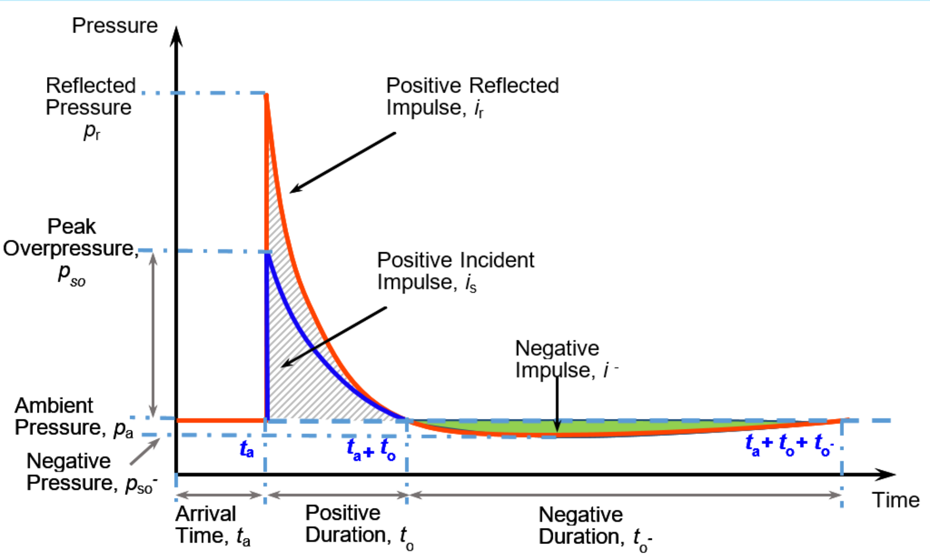

Pressure
Reflected Pressure p_r
Positive Reflected Impulse, i_r
Peak Overpressure, p_{so}
Positive Incident Impulse, i_s
Negative Impulse, i^-
Ambient Pressure, p_a
Negative Pressure, p_{so}^-
t_a
$t_a + t_o$
$t_a + t_o + t_o^-$
Time
Arrival Time, t_a
Positive Duration, t_o
Negative Duration, t_o^-

FIG. 28 INCIDENT AND REFLECTED BLAST PRESSURE HISTORY

L-6.4 Oblique Reflection of Blast Wave

The clauses of this section are applicable to determine the peak reflected overpressure for scenarios where the angle between the wave front and the interacting surface is α (≤ 90°) as shown in Fig. 29. In such case, the peak reflected overpressure (p_{ro}) is to be determined as multiplication of peak incident overpressure (p_{so}) with a reflection coefficient ($C_{r\alpha}$). The reflection coefficient at any angle is to be determined from Fig. 34 for given incident overpressure.

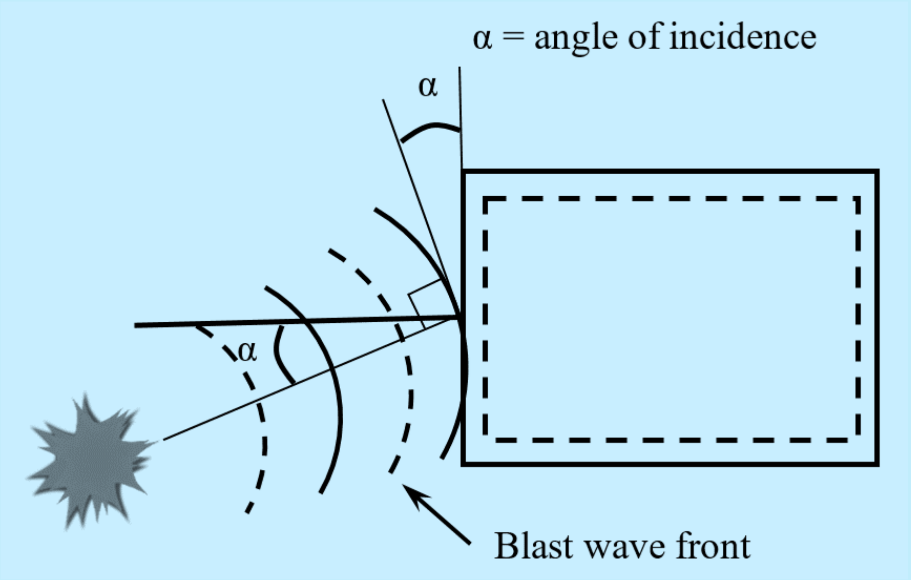


FIG. 29 OBLIQUE REFLECTION OF A BLAST WAVE

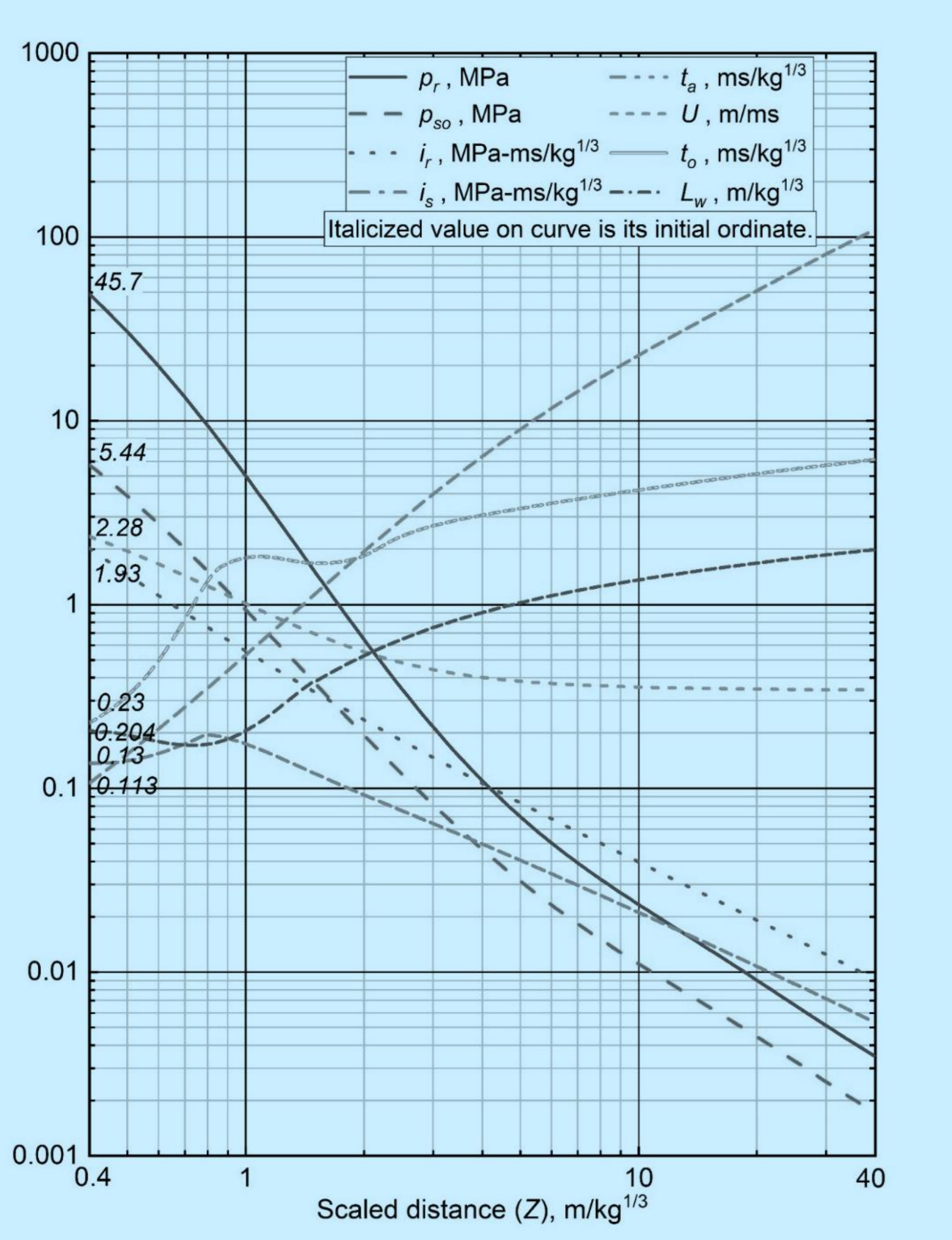


FIG. 30 POSITIVE PHASE SHOCK WAVE PARAMETERS FOR A SPHERICAL TNT EXPLOSION IN FREE AIR

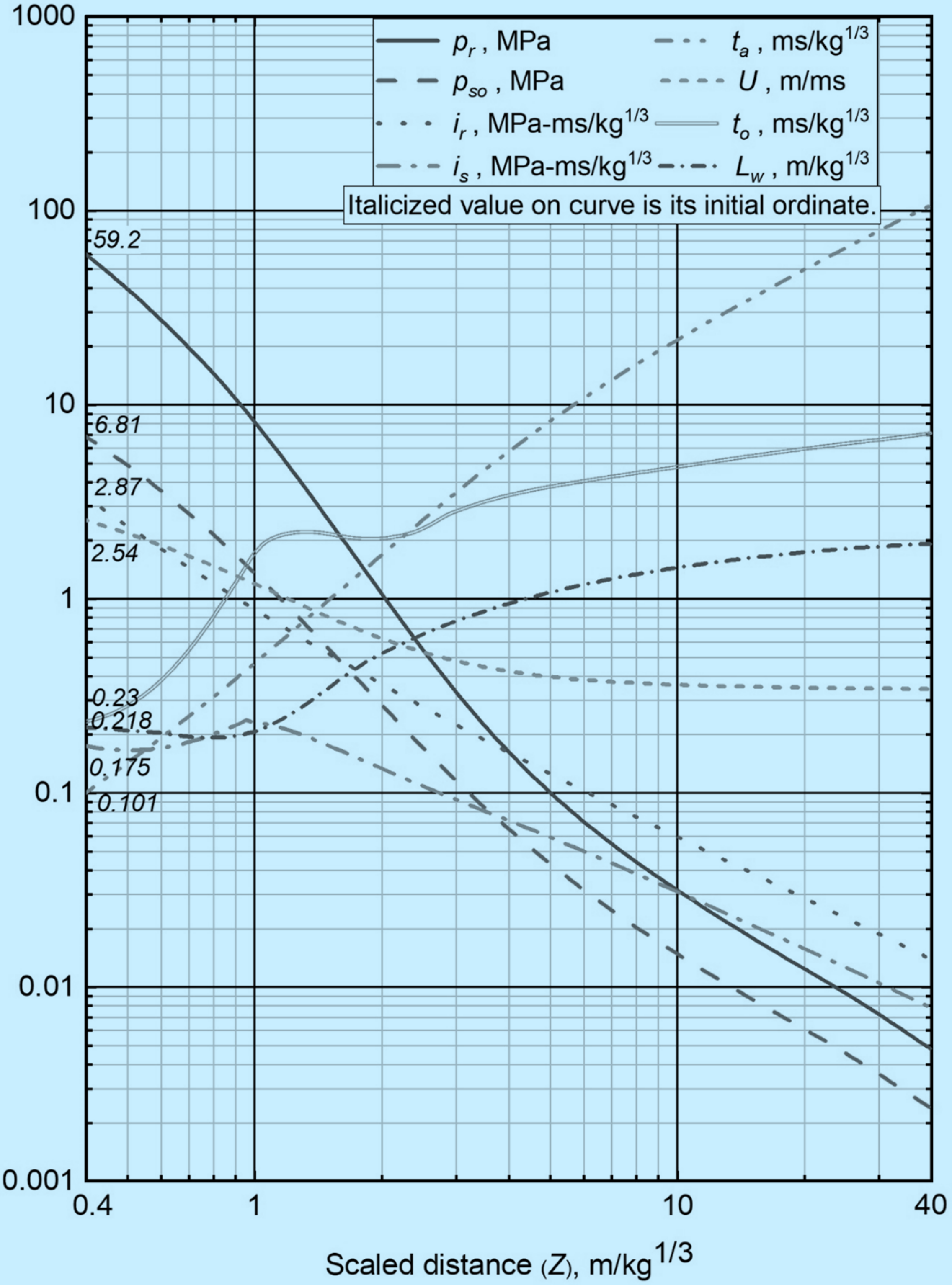


FIG. 31 POSITIVE PHASE SHOCK WAVE PARAMETERS FOR A HEMISPHERICAL TNT EXPLOSION ON SURFACE

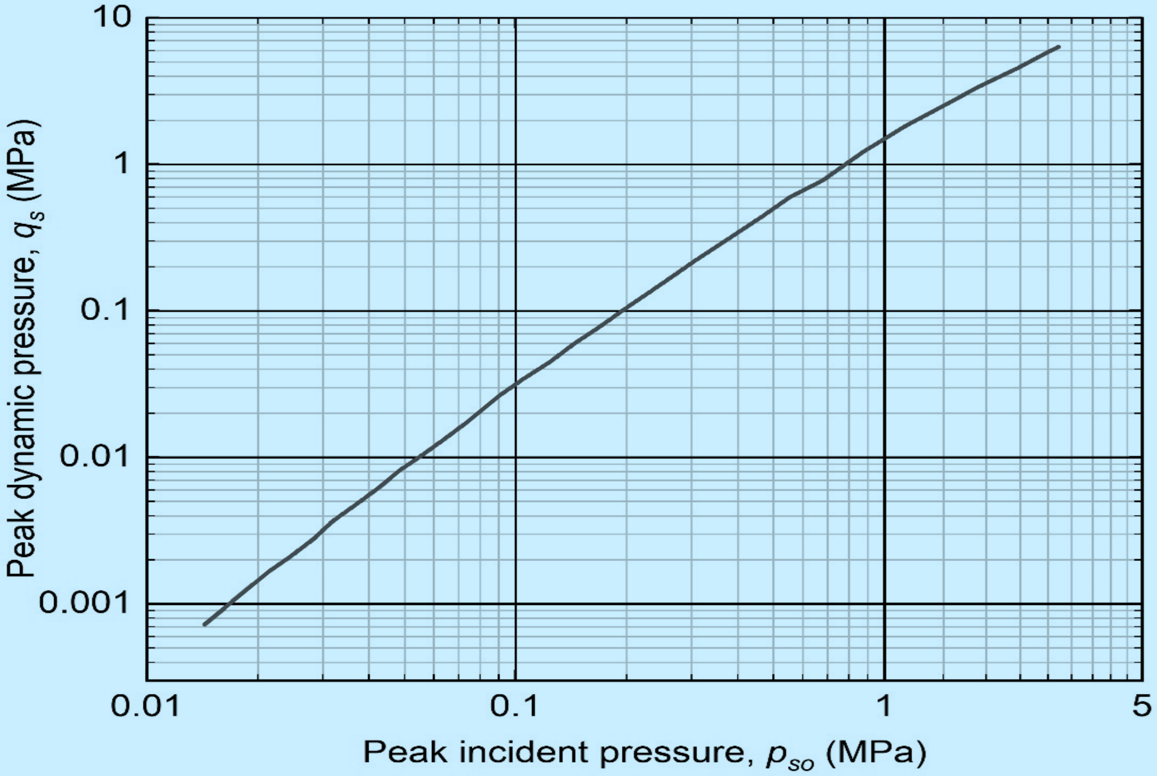


FIG. 32 PEAK DYNAMIC PRESSURE AND PEAK PARTICLE VELOCITY BEHIND A SHOCK FRONT

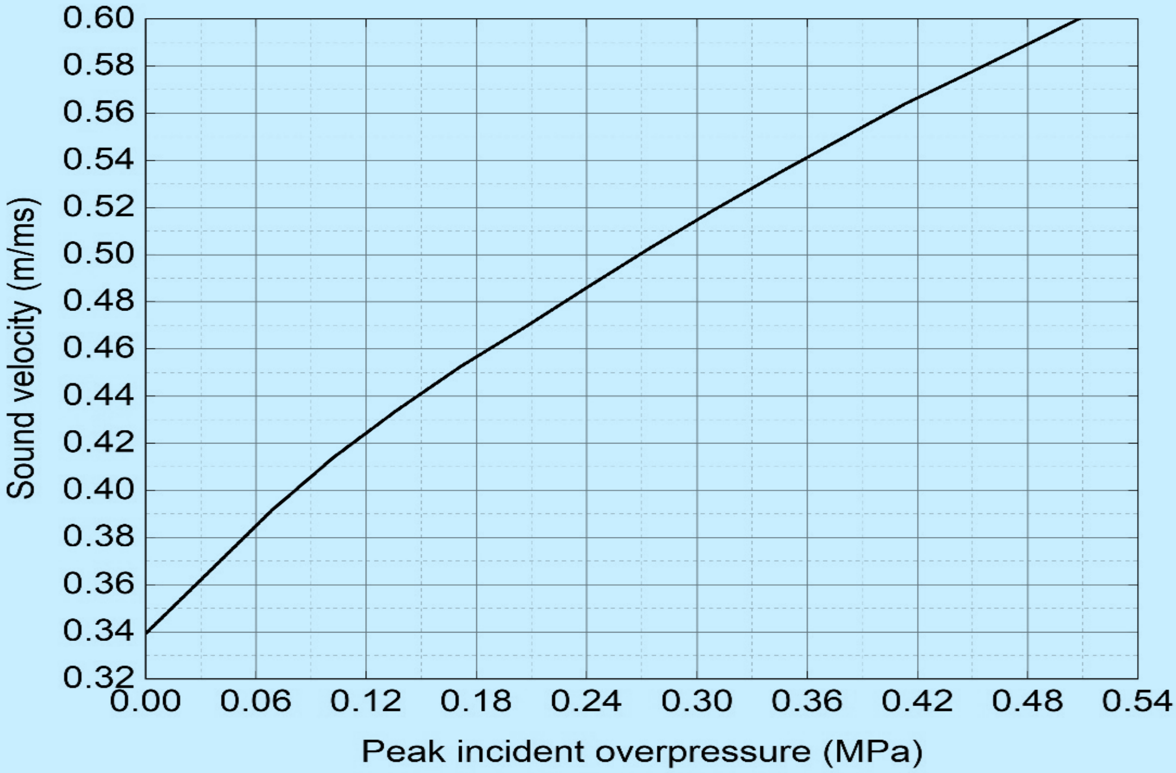


FIG. 33 SOUND VELOCITY IN THE REFLECTED OVERPRESSURE REGION

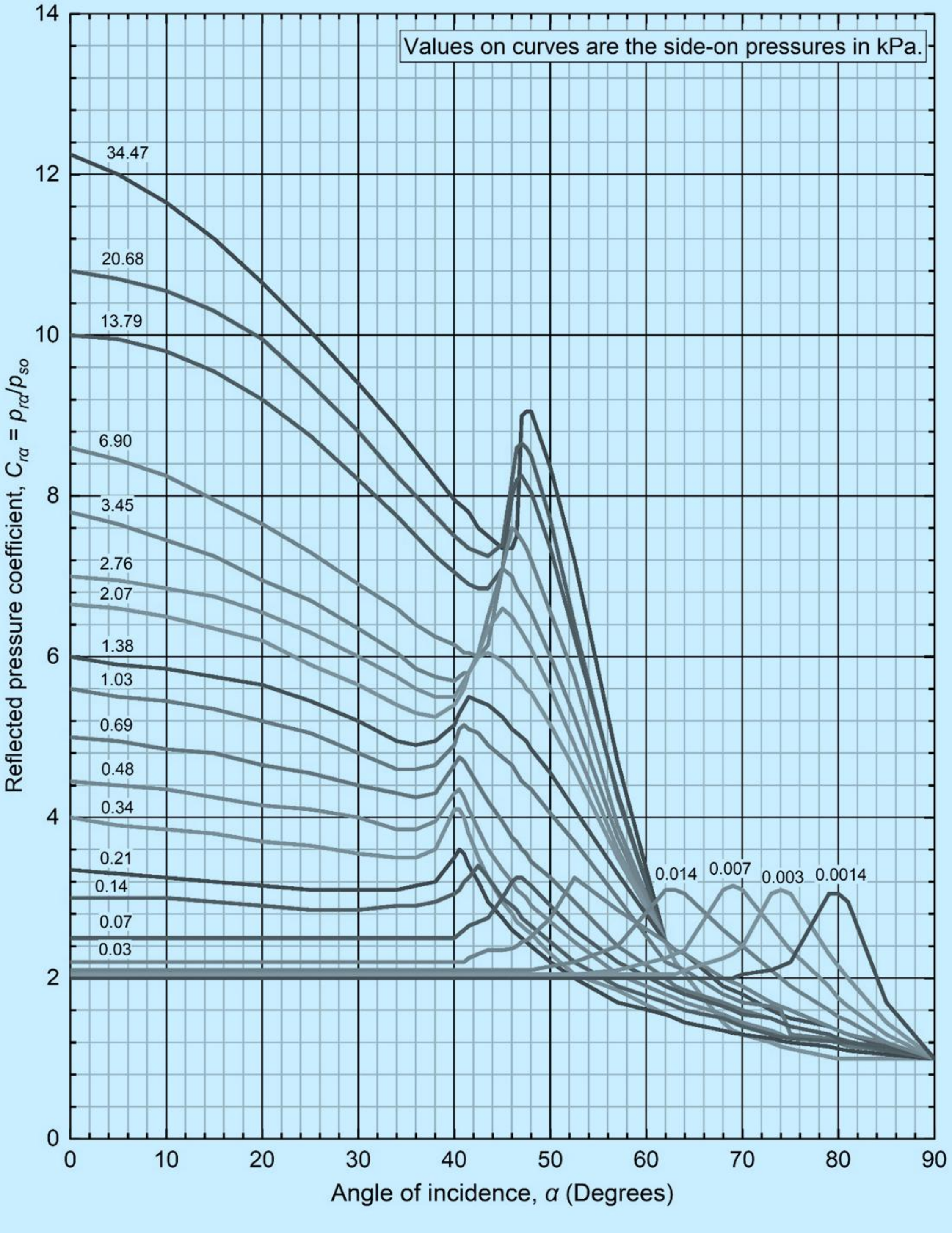


FIG. 34 INFLUENCE OF ANGLE OF INCIDENCE ON THE REFLECTED PRESSURE COEFFICIENT

L-6.5 Simplified Blast Pressure History

For the purpose of simplified analysis and design, the exponential pressure time relation in the positive phase may be idealised to a triangular pulse e as shown in Fig. 35.

The triangular pulse shall be constructed to have the same peak pressure as in the original exponential blast pressure curve and the positive phase duration (t_d) so adjusted that the area under the curve remains unchanged.

The usage of triangular representation of pressure history shall be governed by relevant provisions in this annex.

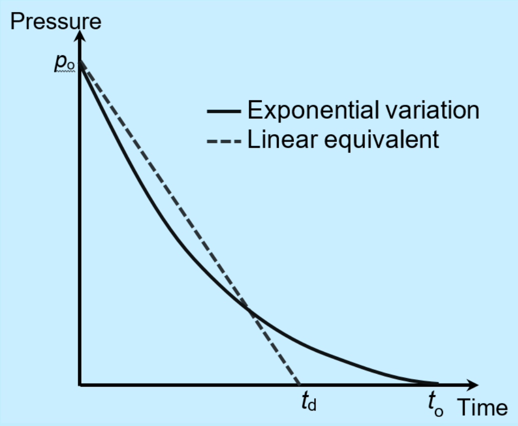


FIG. 35 SIMPLIFIED TRIANGULAR REPRESENTATION OF THE EXPONENTIAL OVERPRESSURE HISTORY

L-6.6 Ground Shocks

L-6.6.1 *Ground Shaking Intensity*

The scaled peak particle displacement, peak particle velocity and soil pressure generated by surface explosion shall be estimated using following equations:

Scaled peak particle displacement:

$$\frac{x}{M^{1/3}} = 60\frac{f}{c}\left(\frac{2.5R}{M^{1/3}}\right)^{1-n}$$

$$\text{Soil pressure, } p = 160 f \rho c \left(\frac{R}{M^{1/3}}\right)^{-n}$$

where

f = coupling factor;

n = attenuation coefficient;

M = explosive weight;

ρ = soil density;

c = soil seismic velocity; and

R = standoff distance.

Table 47 shall be used for taking the values of c, ρc and n.

The coupling factor f shall be taken as 0.14 for explosions above ground.

Table 47 Soil Properties to Calculate Ground Shock Parameters

(*Clause* L-6.6.1)

Sl No. (1)	**Material Description** (2)	**Seismic Velocity,** c (m/s) (3)	**Acoustic Impedance,** ρc (MPa/m/s) (4)	**Attenuation Coefficient,** n (5)
i)	Loose, dry sands and gravels with low relative density	182.9	0.27	3 to 3.25
ii)	Sandy loam, loess, dry sands and backfill	304.8	0.50	2.75
iii)	Dense sand with high relative density	487.7	1.00	2.5
iv)	Wet sandy clay with air voids (greater than 4 percent)	548.6	1.09	2.5
v)	Saturated sandy clays and sands with small amount of air voids (less than 1 percent)	1524	2.94	2.25 to 2.5
vi)	Heavy saturated clays and clay shales	<1524	3.40 to 4.07	1.5

L-6.6.2 *Safe Ground Particle Velocity*

For safety of buried and semi-buried structures, the peak particle velocity, u, as calculated using equation provided in **L-6.6.1** shall not exceed the values given in Table 48.

Table 48 Safe Ground Particle Velocity

(*Clause* L-6.6.2)

Sl No. (1)	**Type of Rock** (2)	**Safe Ground Particle Velocity** (mm/s) (3)
i)	Soils, weathered or soft rock	50
ii)	Hard rock	70

For safety of unlined underground structures, the peak particle velocity, u, as calculated using equation provided in **L-6.6.1** shall not exceed the values listed in Table 49.

For safety of above ground structures, the peak particle velocity, u, measured at the foundation level, as calculated using equation provided in **L-6.6.1** shall not exceed the values listed in Table 50.

L-6.6.3 *Decay of Ground Shaking with Distance*

Decay of ground shaking with distance is to be estimated based on principle of mechanics and field measurement

Table 49 PPV Damage Criterion for Unlined Underground Structures

(*Clause* L-6.6.2)

Sl No.	**Rock Type**	**Unit Weight** kg/m^3	**Compressive Strength** MPa	**Tensile Strength** MPa	**Critical Peak Particle Velocity** (m/s)			
					No Damage	*Slight Damage*	*Intermediate Damage*	*Serious Damage*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
i)	Hard rock	2600 to 2700	75 to 110	2.1 to 3.4	0.27	0.54	0.82	1.53
		2700 to 2900	110 to 180	3.4 to 5.1	0.31	0.62	0.96	1.78
		2700 to 2900	180 to 200	5.1 to 5.7	0.36	0.72	1.11	2.09
ii)	Soft rock	2000 to 2500	40 to 100	1.1 to 3.1	0.29	0.58	0.90	1.67
		2000 to 2500	100 to 160	3.4 to 4.5	0.35	0.70	1.07	1.99

Table 50 Permissible Peak Particle Velocity at the Foundation Level of Structures, in mm/s

(*Clause* L-6.6.2)

Sl No.	**Type of Structure**	**Dominant Excitation Frequency (Hz)**		
		< 8 Hz	8 Hz to 25 Hz	> 25 Hz
(1)	(2)	(3)	(4)	(5)
i)	Buildings/structures not owned by owners:			
	a) Domestic houses/structure (*kuccha* brick and cement)	5	10	15
	b) Industrial buildings (RCC and framed structures)	10	20	25
	c) Objects of historical importance and sensitive structures	2	5	10
ii)	Buildings belonging to owner with limited span of life:			
	a) Domestic houses/structures (*kuccha* brick and cement)	10	15	25
	b) Industrial buildings (RCC and framed structures)	15	25	50

L-6.7 Confined Explosions

The provisions given here are applicable for scenarios where detonation of explosives takes place inside closed spaces.

For the purpose of evaluating blast load effects, confined explosions are categorized into:

a) fully vented; and

b) partially vented.

The examples of fully and partially vented structures are shown in Fig. 36.

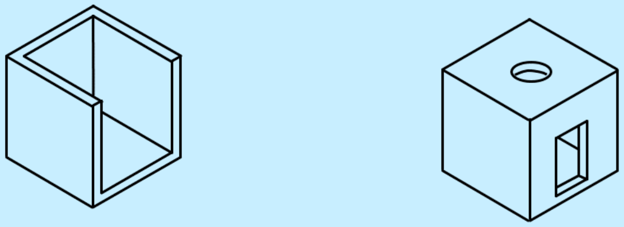


FIG. 36(A) FULLY VENTED

FIG. 36(B) PARTIALLY VENTED

FIG. 36 CONFINED EXPLOSION SCENARIO

The variation of pressure at any location inside a closed space due to detonation inside the closed space is obtained using the following assumptions:

a) surfaces internal structural members are subjected to shock waves from multiple reflections characterized by multiple peaks; and

b) shock pressure is followed by development of gas pressure of small peak overpressures but significantly longer durations.

The provisions of **L-6.7** are only applicable when following conditions are satisfied:

a) structure is of regular geometric shape; and

b) the effect of confined detonation is being evaluated at scaled distances greater than 3 m/kg$^{1/3}$.

L-6.7.1 *Fully Vented Structures*

Fully vented structures are to be primarily subjected to shock pressures and the effect of gas pressures may be neglected. The reflected overpressure history at any point inside the structure is represented in Fig. 37. The peak pressure and impulse for the first pulse may be obtained using the procedure described in **L-6.3** as a case of direct reflection of the blast wave propagating from the centre of detonation to the point of interest. The second and the third triangular pulse shall be constructed from the characteristics of the first pulse.

Further simplification of pressure variation in Fig. 37 is allowed if the ratio of total load duration ($5t_a + t_d$) to the time-period of the structure is smaller than 0.1. In such cases, the three pulses of pressure history in Fig. 37 may be combined into a single pulse of peak pressure 1.75 p_{ro} and duration equal to t_d.

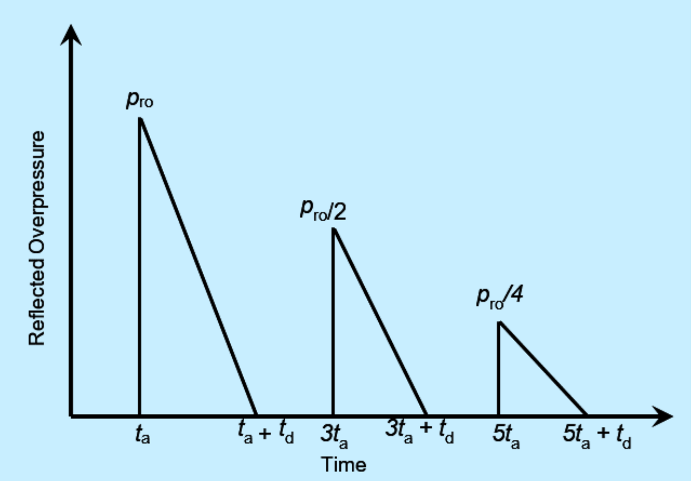


FIG. 37 REFLECTED OVERPRESSURE HISTORY FOR CONFINED DETONATION IN A FULL-VENTED SPACE

L-6.7.2 *Partially Vented Explosion*

Partially vented explosions are characterized by long duration gas pressures with minor effect of the shock pressures.

Wherever, required, the arrival time of the peak gas pressure is taken as the end time of the shock phase, that is, $5t_a + t_d$, as determined in **L-6.7.1**.

The blast load effects of confined explosion in partially vented structure is evaluated using advanced numerical technique as per the provisions of **L-8.3.3**.

The interior surface of a partially vented structure subject to confined explosion may conservatively be designed for the peak gas overpressure, p_g, which needs to be applied statically.

This peak gas overpressure is obtained from the chart in Fig. 38. The use of charts requires following condition to be satisfied:

$$0 \leq A / V_f^{2/3} \leq 0.022$$

where

A = structure's total vent area; and

V_f = free volume which shall be calculated as the total volume excluding the volume of all interior equipment and structural elements.

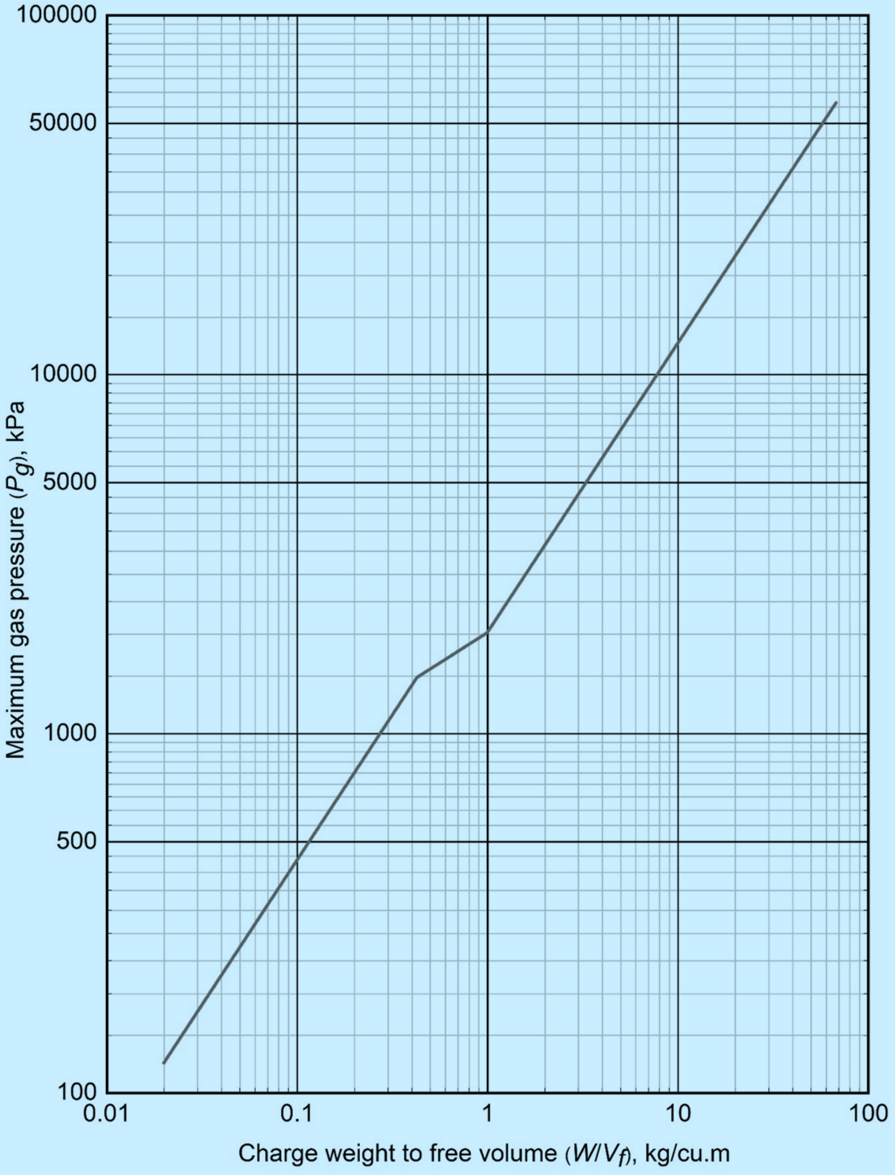


FIG. 38 PEAK GAS PRESSURE PRODUCED BY A TNT DETONATION IN A PARTIALLY VENTED STRUCTURE

L-7 EFFECTS OF BLAST ON STRUCTURES

L-7.1 Above Ground Structures

L-7.1.1 *Types of Structures*
Structures are categorized into following two types for the purpose of determining its interaction with the blast wave and calculating effective blast overpressure history:

a) *Diffraction type structures* — These are the closed structures without openings, with the total area opposing the blast. These are subjected to both the shock wave overpressure p_{so} and the dynamic pressures q caused by blast wind; and

b) *Drag type structures* — These are the open structures composed of elements like beams, columns, trusses, etc, which have small projected area opposing the shock wave. These are mainly subjected to dynamic pressures q.

L-7.1.2 *Closed Rectangular Structures*

L-7.1.2.1 *Front face*

The peak reflected overpressure at any point on the front face of a closed rectangular structure shall be obtained using the following equation.

$$p_{r\alpha} = C_{r\alpha} p_{so}$$

where

p_{so} = peak side-on pressure that shall be obtained using Fig. 30 and Fig. 31 for spherical and hemispherical detonations, respectively, using the effective scaled distance; and

$C_{r\alpha}$ = reflection co-efficient, which shall be determined from Fig. 34 using the angle of reflection and the side-on pressure.

It is permitted to neglect spatial variation of pressure on the front face by assuming an equivalent uniform reflected overpressure which is equal to the peak reflected overpressure on the front face that is closest to the point of detonation. This, under most scenario, corresponds to the peak reflected overpressure, p_{ro}, at normal incidence ($\alpha = 0$ degrees).

The reflected overpressure, p_r, on the front face drops from the peak value p_{ro} to zero in time t_{rf}, whichever, is calculated as, $t_{rf} = 2i_{ro}/p_{ro}$, where p_{ro} and i_{ro} shall be obtained from using Fig. 30 and Fig. 31 for spherical and hemispherical detonations, respectively.

The stagnation overpressure, p_s, at the edges of the front face drops from the peak value, $p_{so} + C_d q_o$, to zero in time t_{of}, whichever, is calculated as, $t_{of} = 2i_{so}/p_{so}$, where p_{so} and i_{so} shall be obtained using Fig. 30 and Fig. 31 for spherical and hemispherical detonations, respectively. The drag coefficient, C_d, shall be taken as 1.0. The peak dynamic pressure, q_o, shall be determined from Fig. 32.

The reflected overpressure acting at a point on the front face drops from the peak value p_{ro} to overpressure ($p_{so} + C_d q$) in clearance time t_c or t_{of}, whichever, is less (*see* Fig. 40).

The drag coefficient, C_d, for different faces of closed rectangular structures located above ground shall be taken as per Table 51.

The clearing time, t_{cp}, for a point on the front wall is given by

$$t_{cp} = \frac{3S}{U}$$

where

S = H or W/2 whichever, is less (*see* Fig. 39); and

U = shock front velocity to be obtained from using Fig. 30 and Fig. 31 for spherical and hemispherical detonations, respectively.

The average clearing time, t_c, required to clear the front face of reflection effects from the roof down and inwards from the sides shall be calculated using the following expression:

$$t_c = \frac{4HW}{C_r(W+2H)}$$

where

C_r = velocity of sound in the reflected overpressure region that shall be determined using Fig. 33.

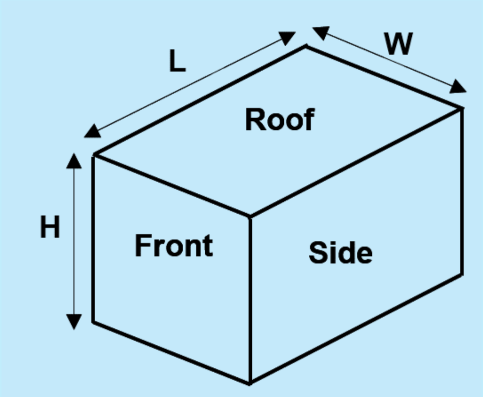


FIG. 39 ABOVE GROUND RECTANGULAR STRUCTURE

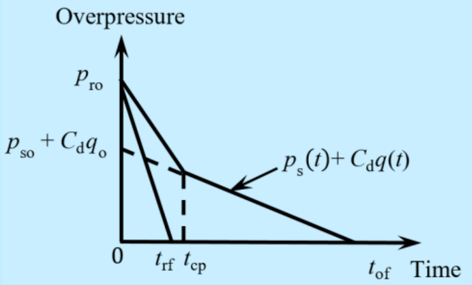


FIG. 40 REFLECTED OVERPRESSURE AT A POINT ON THE FRONT SURFACE OF FINITE REFLECTING SURFACE

The average net loading on the front face ($W \times H$) as a function of time is shown in Fig. 41 depending on whether t_c is smaller than or equal to t_{of}. The pressures p_{ro}, p_{so} and q, the impulses t_{ro} and I_{so} are for the actual explosion that are determined according to **L-6.3**.

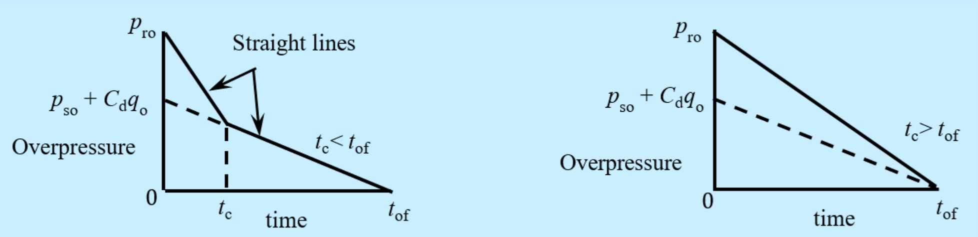


FIG. 41 REFLECTED OVERPRESSURE HISTORY ON THE FRONT FACE OF A CLOSED RECTANGULAR STRUCTURE

L-7.1.2.2 *Rear face*

Using the pressures for the actual explosion, the average loading on the rear face ($W \times H$) in Fig. 39 shall be taken as shown in Fig. 42, where the time has been taken from the instant the shock first strikes the front face. The time intervals of interest are the following:

$\frac{L}{U}$ = the travel time of shock from front to rear face; and

$\frac{4S}{U}$ =pressure rise time on the back face.

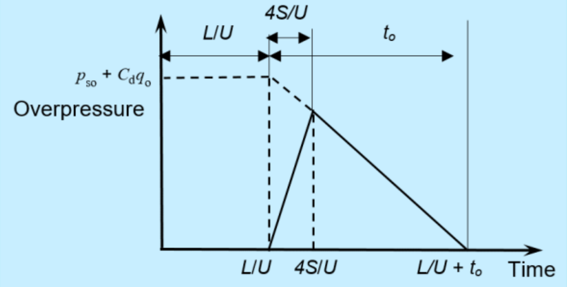


FIG. 42 OVERPRESSURE VERSUS TIME FOR REAR FACE

L-7.1.2.3 *Roof and side walls*

The average pressure versus time curve for roof and side walls is given in Fig. 43(A) when t_d is greater than the transit time $t_t = L/U$. When t_t is greater than t_d, the load on roof and side walls may be considered as a moving triangular pulse having the peak value of overpressure $p_{so}+C_d q_o$ and time t_o as shown in Fig. 43(B).

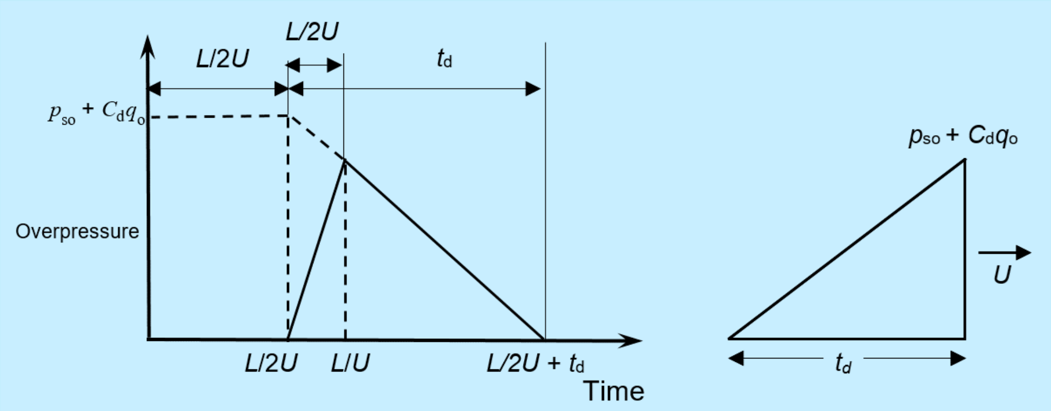


FIG. 43(A) AVERAGE PRESSURE DIAGRAM $t_d > t_t$

FIG. 43(B) MOVING PRESSURE PULSE FOR $t_t > t_d$

FIG. 43 OVERPRESSURE VERSUS TIME FOR ROOF AND SIDE WALLS

Table 51 Drag Coefficient C_d

(*Clause* L-7.1.2.1)

Sl No. (1)	**Shape of Element** (2)	**Drag Coefficient C_d** (3)	**Remarks** (4)
i)	Front vertical face	1.0	
ii)	Roof, near and side faces for:		For closed rectangular structures located above ground
	a) q_o = 0 kPa to 170 kPa	- 0.4	
	b) q_o = 170 kPa to 350 kPa	- 0.3	
	c) q_o = 350 kPa to 1 MPa	- 0.2	

L-7.1.2.4 *Overturning of structure*

The average net load as a function of time which tends to cause sliding and overturning of the building is obtained by subtracting the loading on back face from that on the front face.

L-7.1.3 *Closed Cylindrical Arch-Shape Structures*

L-7.1.3.1 *Gable ends*

The loading may be taken same as for front and rear faces of above ground rectangular structure.

L-7.1.3.2 *Curved surface*

The direction of shock wave propagation is taken transverse to the ridge of the structure and since the usual arch spans are large so that the transit time t_t is greater than the positive phase time t_d, average loading condition cannot be assumed. Therefore, the loading on curved surface may be taken as a moving triangular pulse as shown in Fig. 43(B).

L-7.1.3.3 *Closed dome structures*

The loading on a domical structure may be taken as a moving triangular pressure pulse as shown in Fig. 43(B). The variation of pressure transverse to the direction of propagation of the pulse may be considered symmetrical varying according to cosine θ where the angle θ is measured from longitudinal vertical section of the dome, as shown in Fig. 44.

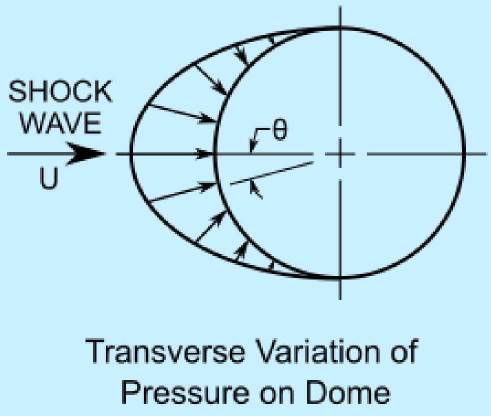


FIG. 44 TRANSVERSE VARIATION OF PRESSURE ON DOME

L-7.2 Blast Load on Below-Ground Structures

L-7.2.1 *Types of Structures*

The below-ground structures are classified into buried and semi-buried structures depending upon the earth cover and slopes of earth berms. The buried structures are subjected only to the general overpressure p_{so}, the reflected and dynamic pressures being neglected. The semi-buried structures are subjected to partial dynamic pressures besides the general overpressure. Both are acted upon by air-induced ground shock also.

For assessing the effects of above-ground blasts on below-ground structures, dynamic finite element analysis can be performed considering the flexibility of soil and interactions of blast induced ground waves with the structure.

L-8 RESPONSE OF STRUCTURAL ELEMENTS

L-8.1 Properties of Materials

The nominal properties of materials are obtained as per relevant codes and guidelines. The change in material properties due to high strain rates associated with blast response are to be incorporated using the provisions in **L-8.1.1** and **L-8.1.2**.

L-8.1.1 *Elastic Modulus and Poisson's Ratio*

The elastic modulus and Poisson's ratio of the constituent materials used in the structural elements shall be estimated based on relevant standards as applicable to that material.

No increase in elastic modulus and Poisson's ratio is to be considered for the calculation of blast response of structures.

L-8.1.2 *Dynamic Strength*

L-8.1.2.1 *Design strength of structural steel*

The average dynamic increase factors of strength for structural, carbon, mild, weldable or rivet steels and high strength alloy steels are listed in Table 52 and Table 53.

Table 52 Dynamic Increase Factors for Mild Steels

(*Clause* L-8.1.2.1)

Sl No. (1)	Material (2)	Dynamic Increase Factors (3)
i)	Yield strength in bending and shear	1.25
ii)	Yield strength in tension and compression	1.20
iii)	Ultimate strength	1.00

Table 53 Dynamic Increase Factors for High Strength Steels

(*Clause* L-8.1.2.1)

Sl No. (1)	Material (2)	Dynamic Increase Factors (3)
i)	Yield strength in bending and shear	1.10
ii)	Yield strength in tension and compression	1.05
iii)	Ultimate strength	1.00

L-8.1.2.2 *Design strength of reinforced concrete*

The average dynamic strength increase factors for concrete are listed in Table 54 and for reinforcing steel are listed in Table 55.

Table 54 Dynamic Increase Factors for Reinforced Concrete

(*Clause* L-8.1.2.2)

Sl No. (1)	Strength (2)	Dynamic Increase Factors (3)
i)	Flexure	1.15
ii)	Compression	1.10
iii)	Diagonal tension, direct shear and bond	1.00

Table 55 Dynamic Increase Factors for Reinforcing Steel

(*Clause* L-8.1.2.2)

Sl No. (1)	Strength (2)	Dynamic Increase Factors (3)
i)	Yield strength in flexure	1.2
ii)	Yield strength in compression, diagonal tension, direct shear and bond	1.1
iii)	Ultimate strength in flexure	1.1
iv)	Ultimate strength in compression, diagonal tension, direct shear and bond	1.0

L-8.1.2.3 *Design strength for masonry or plain concrete*

The average dynamic strength increase factors for masonry and plain concrete are listed in Table 56.

Table 56 Dynamic Increase Factors for Masonry and Plain Concrete

(*Clause* L-8.1.2.3)

Sl No. (1)	Strength (2)	Dynamic Increase Factors (3)
i)	Flexure	1.15
ii)	Compression	1.10
iii)	Diagonal tension and direct shear and bond	1.00

L-8.1.3 *Design Strength*

For obtaining design strength, the resistance of various elements is to be estimated using the strength increased by the dynamic increase factors mentioned in Q-8.1.2.

L-8.1.4 *Deformation Limits*

Structural elements subjected to blast loading can be designed subject to certain allowable dynamic ductility ratios and support rotations.

The blast resistance of a flexural member is to be expressed in terms of maximum permissible deflection. Support rotation and ductility is to be used to characterize the blast resistance of reinforced concrete and structural steel members, respectively.

The support rotation shall be defined as per Fig. 45.

The maximum permissible deflection defines the energy absorption capacity of the element which is equal to the area under the resistance versus deflection curve. For a given blast scenario, greater the permissible deflection, lesser will be the maximum resistance required in the member.

The allowable deformation parameters are included in Table 57.

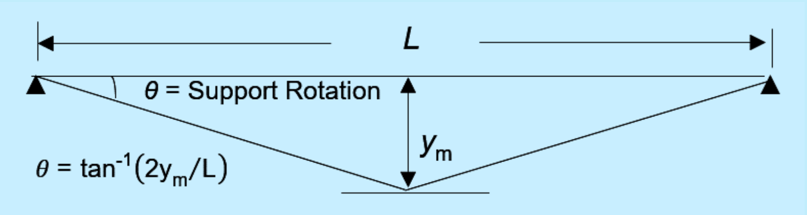


FIG. 45 SUPPORT ROTATION IN A FLEXURAL MEMBER

Table 57 Allowable Deformation Parameters

(*Clause* L-8.1.4)

Sl No. (1)	Material (2)	Low Damage (3)	Medium Damage (4)	High Damage (5)
i)	Ductility ratio in structural steel members subjected to bending and direct stresses	3	10	20
ii)	Support rotation in reinforced concrete members subjected to bending and direct stresses (in degrees)	1	2	4

L-8.2 Modelling of Structural Members

L-8.2.1 *Geometry, Material and Boundary Conditions*

The methods of modelling are applicable to structural members of regular prismatic sections.

L-8.2.2 *Equivalent Single Degree of Freedom* (*SDOF*) *Model*

The structural element or system may be replaced by an equivalent single spring-mass system having effective stiffness k_{E} and effective mass equal to $K_{\mathrm{LM}}M_{\mathrm{t}}$, where M_{t} is the actual mass of the member under consideration and K_{LM} is a load-mass factor depending upon the stiffness and mass distribution in the member and its boundary conditions. The equivalent system is defined so that the deflection of the equivalent single mass is the same as that of some significant point in the given structure. The effective stiffness k_{E} is defined with respect to the deflection of this point.

The load-mass factor K_{LM} is equal to the ratio of mass factor K_{M} to the load factor K_{L}. The factors are evaluated on the basis of an assumed deflected shape of the structure as given below:

$$K_{\mathrm{M}} = \frac{1}{M_{\mathrm{t}}}\left\{\sum_{r=1}^{n} M_{\mathrm{r}}\emptyset_{\mathrm{r}}^{2} + \int m\emptyset^{2}(x)\,dx\right\}$$

$$K_{\mathrm{L}} = \frac{1}{P_{\mathrm{t}}}\left\{\sum_{r=1}^{j} p_{\mathrm{r}}\emptyset_{\mathrm{r}} + \int p(x)\emptyset(x)dx\right\}$$

where

n = number of concentrated masses;

M_r = concentrated mass at point r ;

M_t = total actual mass;

$\phi_r\phi_r$ = deflection at point r of an assumed deflected shape for concentrated loads;

m = distributed mass intensity per unit length;

$\phi_{(X)}$ = deflection at point x of an assumed deflected shape for distributed loads;

P_t = total dynamic load (at any instant of time);

j = number of concentrated load points;

P_r = concentrated dynamic force at point r; and

$p_{(X)}$ = intensity of distributed dynamic load per unit length.

L-8.2.2.1 *Effective single SDOF parameters*

Values of the factors k_E and K_{LM} for few structural members are given in Table 58 to Table 60. The effective SDOF parameters for other type of structural members shall be calculated by assuming an appropriate deflected shape as per **L-8.2.2.2**.

L-8.2.2.2 *Deflected shape*

The deflected shape is suitably chosen to resemble as far as possible the true deflected shape taking into consideration whether the structure or member remains elastic or goes into the plastic range. It may be taken the same as due to static application of the dynamic load on the structure. The deflected shape is normalized such that $\varphi(x)=1$ at the point with respect to which the effective stiffness k_E is defined.

L-8.2.2.3 *Effective time-period*

The effective time period T of the structural member may be calculated from the equation:

$$T = 2\pi\sqrt{\frac{K_{LM}\,M_t}{k_E}}$$

L-8.2.3 *Resistance Function*

The resistance versus deflection diagram of a structural element shall be idealized as elasto-plastic (*see* Fig. 46) by keeping the area under the actual and idealized curves about the same up to the maximum permissible deflection defined as per **L-8.1.4**.

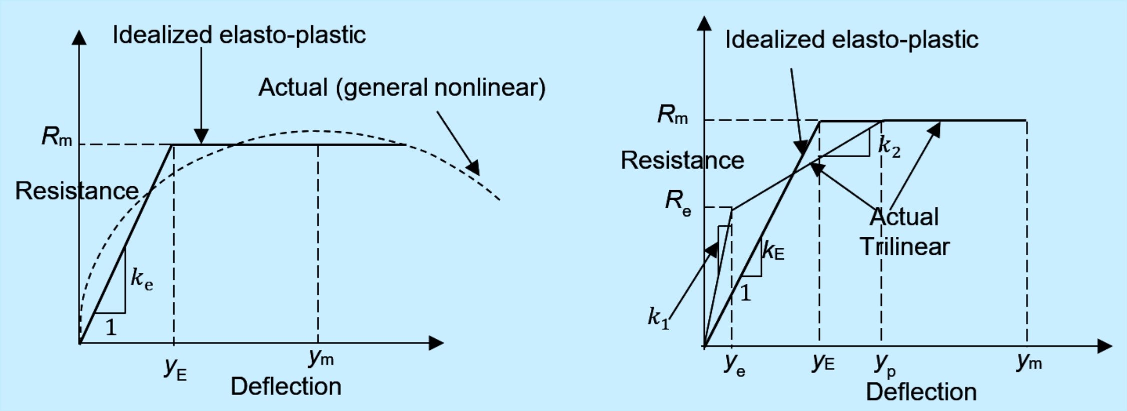

Idealized elasto-plastic
Actual (general nonlinear)
R_m
Resistance
k_e
1
y_E
y_m
Deflection
Idealized elasto-plastic
R_m
Resistance
R_e
k_2
Actual
Trilinear
k_E
1
k_1
y_e
y_E
y_p
y_m
Deflection

FIG. 46(A) GENERAL NONLINEAR

FIG. 46(B) TRILINEAR

FIG. 46 IDEALIZATION OF RESISTANCE DEFLECTION DIAGRAM

A trilinear resistance versus deflection diagram may be simplified to its elasto-plastic (bilinear) equivalent of same peak resistance (R_m) and the elastic parameters calculated using following equations:

$$y_E = y_e + y_p \left(1 - \frac{R_m}{R_e}\right)$$

$$k_E = \frac{R_m}{y_E}$$

L-8.3 Methods of Analysis

These provisions apply to structures, components and systems subject to near-field and far-field detonations but not for contact or near-contact detonations.

L-8.3.1 *Analysis of Members*

Blast loaded structural components of a structure may be analysed independently provided it can be demonstrated that such independent member analysis would yield conservative performance of the member and the structure.

L-8.3.1.1 *Equivalent SDOF analysis*

The equivalent SDOF analysis may be used to determine response of structural members subject to blast loads when the following criteria are satisfied:

a) The equivalent mass, stiffness and damping parameters in the model must capture the dynamic response and failure mode of the structural member being analysed; and

b) A single flexural deformation mode controls the dynamic response of the structural system.

The equivalent SDOF analysis shall make use of following parameters:

a) Blast-pressure history obtained using L-6.3;

b) The effective time-period calculated using L-8.2.2.3;

c) Resistance function of the structural element established using provisions of L-8.2.3; and

d) Maximum permissible deflection provided in L-8.1.4.

L-8.3.1.2 *Blast overpressure history*

The exponential blast pressure history of Fig. 28 shall be idealized to a triangular pulse [Fig. 47(A) as per provisions of **L-6.5** for the purpose of obtaining equivalent SDOF blast loads. Such idealization may neglect the effect of negative phase, unless otherwise it is expected to influence the flexure response of the structural member.

The positive phase duration of the triangular loading shall be calculated as:

$$t_\mathrm{d} = \frac{2i_{ro}}{p_{ro}}$$

If the influence of clearing on the blast pressure history applied to the front face of the structural element is found to be significant, then the equivalent SDOF blast loads shall be idealized to Fig. 47(B) using **L-7.1.2**.

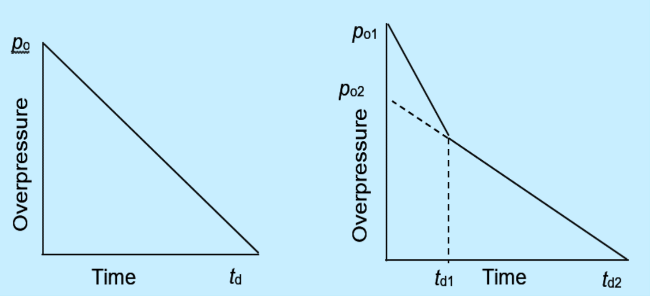


FIG. 47(A) LINEAR

FIG. 47(B) BILINEAR

FIG. 47 IDEALIZED BLAST PRESSURE HISTORIES

When the ratio of time duration t_{d1}, or t_{d2}, to the natural period of the element is less than 0.1, the problem may be considered as an impulse problem taking the area under the pressure versus time curve as impulse per unit area. In such a case, the shape of pressure-time curve is not important.

L-8.3.1.3 *Uniform blast pressure distribution*

A uniform distribution of blast pressure over the length of the structural member may be considered provided one of the following conditions are satisfied:

a) The minimum scaled distance to the structural component is greater than 1.2 m/kg$^{1/3}$; and

b) The variation of peak reflected pressures over the middle two-third of the component span length is less than 25 percent.

   For uniform distribution of blast pressure, the pressure value calculated at the closest point on the structure from the centre of detonation may be considered over the whole reflecting surface.

L-8.3.1.4 *Non-uniform blast pressure distribution*

For members subjected to spatially non-uniform blast loads, the effect of non-uniformity on the response shall be considered.

These provisions shall be applicable for non-uniform blast pressure distribution, provided the conditions outlined in **L-8.3.1.3** are not satisfied and the minimum scaled distance to the structural component is between 0.4 m/kg$^{1/3}$ and 1.2 m/kg$^{1/3}$.

An equivalent impulse weighted using deflected shape function shall be considered for the structural component as per following expression:

$$i_e = \frac{\int_0^L \int_0^H i(x,y)\phi(x,y)dxdy}{\int_0^L \int_0^H \phi(x,y)dxdy}$$

where

i_e = equivalent impulse of uniformly distributed load;

L = length of loaded area;

H = width of loaded area;

$\emptyset(x,y)$ = deflected shape function of blast-loaded component; and

$i(x,y)$ = non-uniform impulse applied to loaded area.

The simplified triangular representation of the pressure time history shall be constructed as per provisions of **L-6.5** by calculating the positive loading phase duration using the equivalent uniform impulse (i_e) and the peak overpressure at the midspan or geometric centre of the reflecting surface.

A safety factor of 1.25 shall be used if a non-uniform blast load is represented as an equivalent uniform impulse in a blast analysis.

L-8.3.1.5 *Elastic SDOF response*

For elastic analysis (ductility ratio $\mu \leq 1.0$) of structures, the effective stiffness k_E and load mass factor K_{LM} shall be used as given in Table 58 to Table 60.

For elastic response of an SDOF system, the peak response (y_m) and the time to peak response (t_m) may be obtained using following expressions:

$$\frac{y_m}{y_0} = 2 - \frac{t_m}{t_d}; \qquad \text{when } t < t_d$$

$$t_m = \frac{2}{\omega}\tan^{-1}(\omega t_d) \qquad \text{when } t < t_d$$

$$\frac{y_m}{y_0} = \frac{1}{\omega t_d}\sqrt{2(1-\cos\omega t_d - \omega t_d \sin\omega t_d) + (\omega t_d)^2}; \qquad \text{when } t > t_d$$

$$t_m = \frac{1}{\omega}\tan^{-1}\left(\frac{1-\cos\omega t_d}{\sin\omega t_d - \omega t_d}\right) \quad \text{when } t > t_d$$

where

y_m = peak elastic displacement;

y_o = peak static displacement; and

t_m = time to the peak displacement.

L-8.3.1.6 *Inelastic SDOF response*

For elasto-plastic analysis, k_E shall be used as given in Table 58 to Table 60 but value of K_{LM} may be chosen in between the elastic and plastic cases depending upon the ductility factor.

Based on the elasto-plastic resistance-deflection curve shown in Fig. 46 and triangular pressure-time curve shown in Fig. 47(A), the ratio of resistance R_m, required to the peak dynamic load (F_1) is given in Fig. 48 for various values of t_d/T and µ.

The time to peak deflection (t_m)shall be obtained from Fig. 49 for various values of td/T and µ.

When the time ratio, t_d/T, is less than 0.1, the ratio k may be computed from the following equation:

$$k = \frac{\pi}{\sqrt{2\mu - 1}} \cdot \frac{t_d}{T}$$

When the pressure-time diagram is given by Fig. 47B, the following equation shall be satisfied:

$$\frac{P_{01}}{R_m}k_1+\frac{P_{02}}{R_m}k_2=1$$

where

R_m = the required resistance; and

k_1, k_2 = the values of ratios k for ductility ratio μ and time ratios t_{d1}/T and t_{d2}/T respectively.

For elasto-plastic design of fixed slabs, the modified value of k_E is to be worked out in accordance with Fig. 46(B) using the stiffness values of slab in elastic and elasto-plastic cases as given in Table 60 and K_{LM} is to be suitably chosen depending upon the ductility factor.

The value of modular ratio shall be taken the same as in static design for calculating EI.

For calculating moment of inertia I of reinforced concrete sections, the concept of effective transformed area shall be used.

For analysis of reinforced concrete sections when the simplified elasto-plastic resistance function is used, the elastic stiffness shall be based on effective moment of inertia that shall be calculated as the average of the gross moment of inertia of the transformed section and the cracked moment of inertia.

The gross and cracked moment of inertias shall be obtained from Fig. 50.

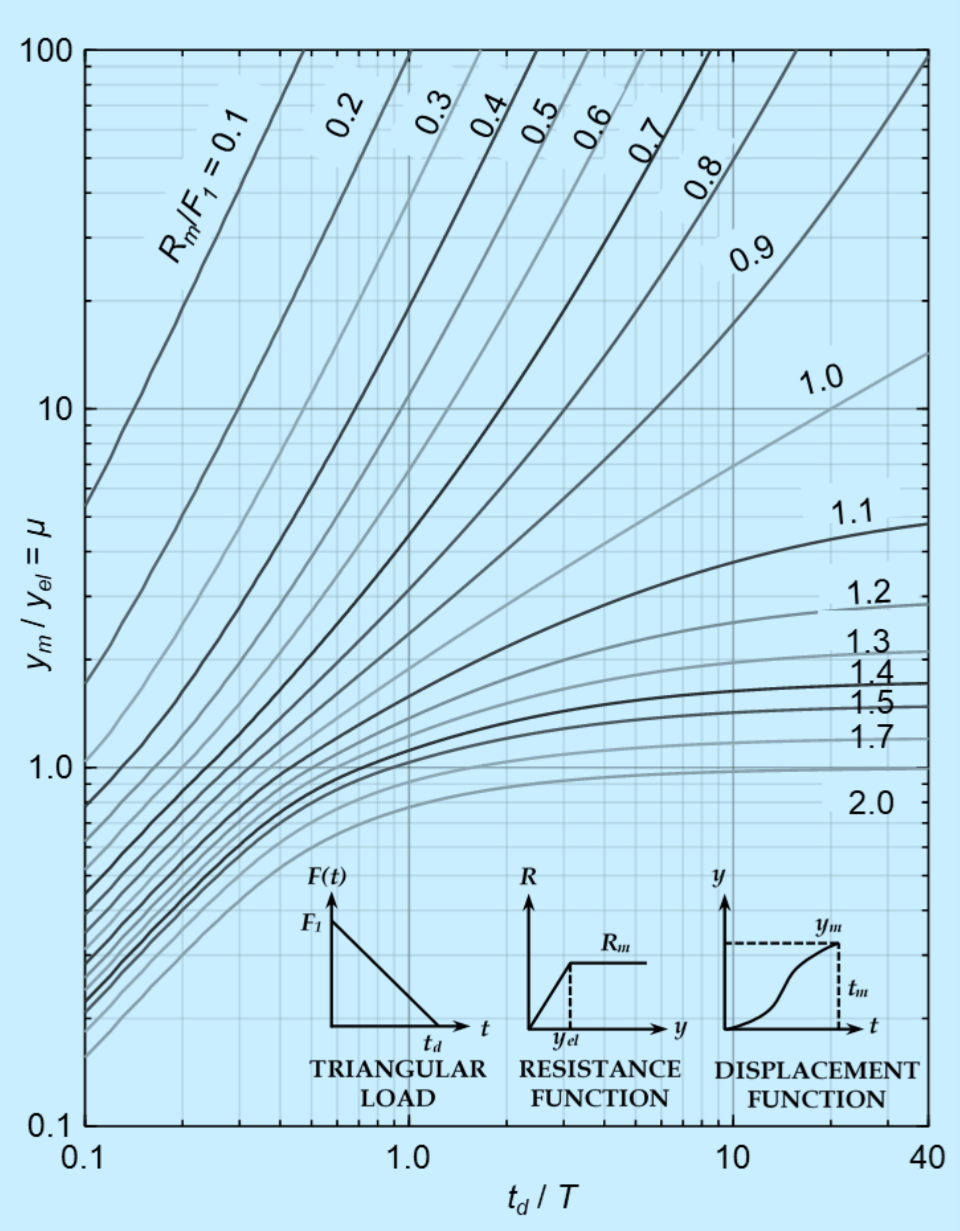


FIG. 48 PEAK DUCTILITY DEMAND OF SDOF SYSTEM SUBJECT TO TRIANGULAR PULSE LOADING

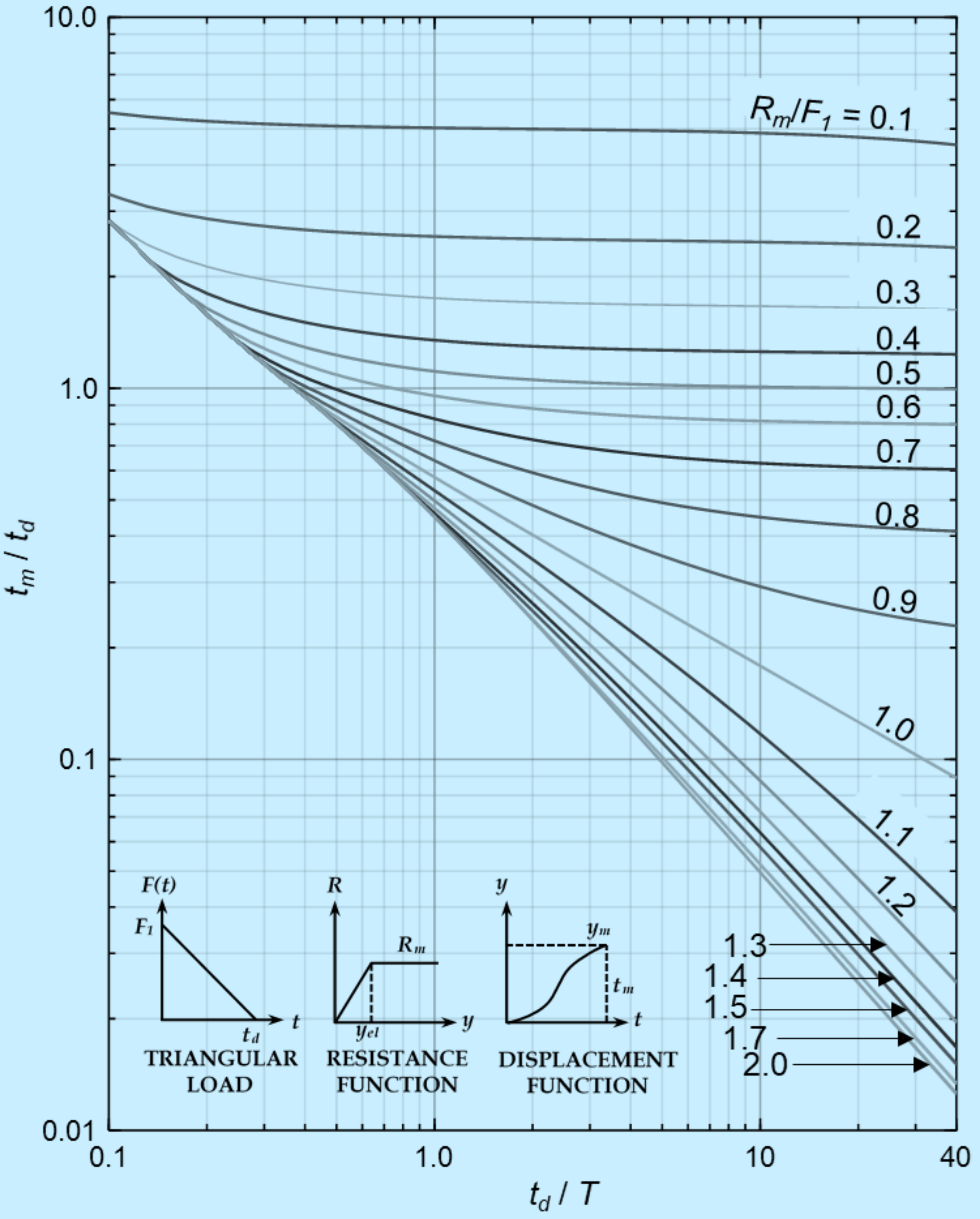


FIG. 49 TIME TO PEAK DUCTILITY DEMAND OF SDOF SYSTEM SUBJECT TO TRIANGULAR PULSE

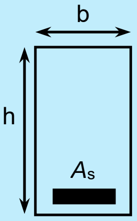
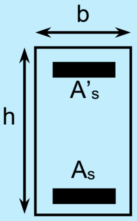
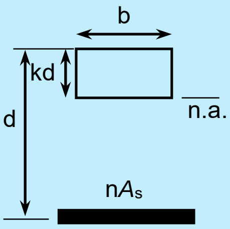
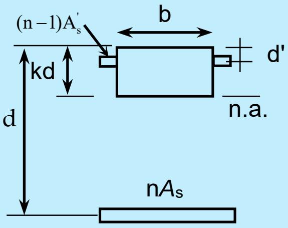
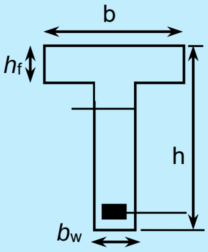
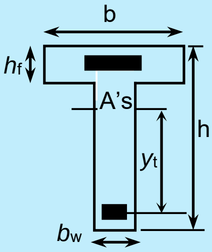
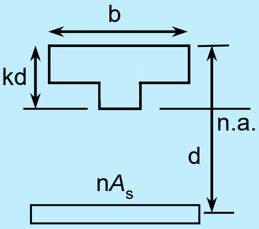
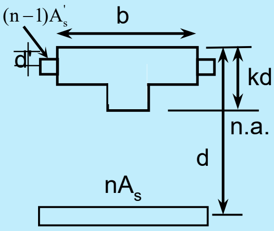
Gross Section	*Cracked Transformed Section*	Gross and Cracked Moment of Inertia
 	 Without compression steel  With compression steel	$n = \frac{E_s}{E_c}$ $B = \frac{b}{(nA_s)}$ $I_g = \frac{bh^3}{12}$ Without compression steel: $kd = (\sqrt{2dB + 1} - 1)/B$ $I_{cr} = bk^3d^3/3 + nA_s(d - kd)^2$ With compression steel: $r = (n - 1)A'_s/(nA_s)$ $kd = \left[\sqrt{2dB(1 + rd'/d) + (1 + r)^2} - (1 + r)\right]/B$ $I_{cr} = bk^3d^3/3 + nA_s(d - kd)^2 + (n - 1)A'_s(kd - d')^2$
 	 Without compression steel  With compression steel	$n = \frac{E_s}{E_c}$ $C = b_w/(nA_s),\ f = h_f(b - b_w)/(nA_s)$ $y_t = h\text{-}1/2\left[(b - b_w)h_f^2 + b_w h^2\right]/[(b - b_w)h_f + b_w h],$ $I_g = (b - b_w)h_f^3/12 + b_w h^3/12 + (b - b_w)h_f\,(h - h_f/2 - y_t)^2 + b_w h(y_t - h/2)^2$ Without compression steel: $kd = \left[\sqrt{C(2d + h_f f) + (1 + f)^2} - (1 + f)\right]/C$ $I_{cr} = (b - b_w)h_f^3/12 + b_w k^3d^3/3 + (b - b_w)h_f\,(kd - h_f/2)^2 + nA_s(d - kd)^2 + (n - 1)A_s(kd - d')2$ With compression steel: $kd = \left[\sqrt{C(2d + h_f f + 2rd') + (f + r + 1)^2} - (f + r + 1)\right]/C$ $I_{cr} = (b - b_w)h_f^3/12 + b_w k^3d^3/3 + (b - b_w)h_f\,(kd - h_f/2)^2 + nA_s(d - kd)^2 + (n - 1)A'_s(kd - d')2$

FIG. 50 CRACKED MOMENT OF INERTIA OF PRISMATIC SECTIONS

L-8.3.2 *MDOF Analysis*

The multi degree of freedom (MDOF) analysis is permitted for structural systems which cannot be analysed using the simplified SDOF analysis, provided the expected failure mechanism under blast load can adequately be represented using the MDOF model representation.

L-8.3.2.1 The numerical model of MDOF system may comprise of distributed elements or combined lumped mass and stiffness elements.

L-8.3.2.2 The spring in the lumped-mass stiffness should adequately represent the member resistance-deflection behaviour by incorporating appropriate constitutive relationship.

L-8.3.2.3 The lumped-mass stiffness system should be able to properly account for the dynamic behaviour and failure modes at the structure and the element level.

L-8.3.2.4 The use of structural damping is permitted for MDOF system when the expected response is within elastic range. These structural damping values for elastic response shall conform to the typical values used for different type of structures.

L-8.3.2.5 The energy dissipation during inelastic response should be accounted by using appropriate nonlinear member resistance-deflection curves. Supplemental damping in form of structural damping is not permitted for nonlinear range of response.

L-8.3.2.6 The time-step for MDOF analysis shall be determined based on accuracy and convergence requirement. The time-step should be sufficiently small such that it captures the rise and decay of the applied blast load time history.

L-8.3.3 *Finite Element Analysis*

Advanced numerical analysis techniques, such as explicit dynamic finite element analysis (FEA), may be used to analyse structures subject to blast loading, if the methods described in **L-8.3.1** and **L-8.3.2** cannot be reliably used to obtain the response. Such methods shall be required if one or more of the following conditions are encountered:

a) detonation involves scaled distances smaller than 0.4 m/kg$^{1/3}$;
b) detonation of non-spherical charge masses at scaled distances smaller than 3 m/kg$^{1/3}$;
c) the blast wave propagation involves interaction with surrounding environment before it reaches the location of interest;
d) the variation in geometric and material properties of structural elements or the structure cannot appropriately be represented using the simplified methods; and
e) the interaction between the blast wave and structure is of significance and the assumption of rigid reflecting surface is not valid.

The FEA shall consider the modelling of non-ductile failure modes and failure surfaces that cannot be considered in the simplified SDOF and the MDOF methods of analysis.

The time-step of analysis need to be decided based on size of the smallest element of interest with appropriate consideration to the accuracy and convergence of the response.

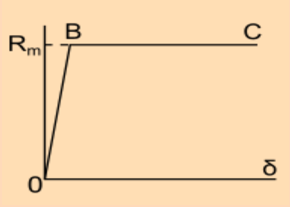
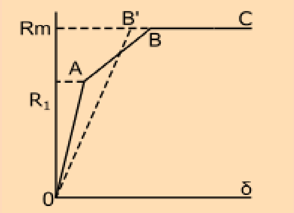
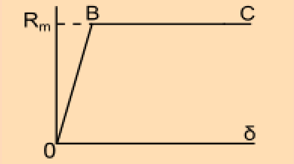
The interaction of blast load with the surrounding shall be considered using computational fluid dynamics (CFD) methods.

Where the shape and size of the charge mass is expected to play a major role in the detonation process and the resulting blast load, the detonation process itself may be modelled.

The FEA methods shall not be subjected to the response limits typically used for structural members in the simplified SDOF and the MDOF analysis.

Table 58 Transformation Factors for Beams and One-way Slabs

(*Clauses* L-8.2.2.1, L-8.3.1.5 *and* L-8.3.1.6)

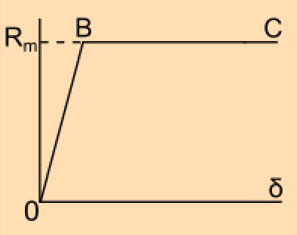
Sl No.	**Resistance Curve, End-Conditions of Beams or One-way Slabs**	**Dynamic Loading**	**Strain Range**	**Load-Mass Factor** K_{LM}		**Maximum Resistance** R_m	**Effective Spring Constant** k_E	**Dynamic Reaction**
				Concentrated Mass	Uniform Mass			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
i)		Uniform $P_t = pL$	Elastic	–	0.78	$8M_p/L$	$384EI/5L^3$	$0.39 R_m + 0.11 P_t$
			Plastic	–	0.66	$8M_p/L$	–	$0.38 R_m + 0.12 P_t$
		Concentrated at mid-span $P_t = P$	Elastic	1.0	0.49	$4M_p/L$	$48EI/L^3$	$0.78 R_m - 0.28 P_t$
			Plastic	1.0	0.33	$4M_p/L$	–	$0.75 R_m - 0.25 P_t$
		Concentrated at third points P/2 each $P_t = P$	Elastic	0.87	0.60	$6M_p/L$	$56.4EI/L^3$	$0.62 R_m - 0.12 P_t$
			Plastic	1.0	0.56	$6M_p/L$	–	$0.52 R_m - 0.02 P_t$
ii)	 Fixed at both ends	Uniform $P_t = pL$	Elastic (OA)	–	0.77	$12M_{ps}/L$	$384EI/L^3$	$0.36 R_1 + 0.14 P_t$
			Elastic (OB')	–	0.78	$(8/L)(M_{ps} + M_{pm})$	$307EI/L^3$	$0.39 R_m + 0.11 P_t$
			Plastic	–	0.66	$(8/L)(M_{ps} + M_{pm})$	–	$0.38 R_m + 0.12 P_t$
		Concentrated at mid-span $P_t = P$	Elastic (OB)	1.0	0.37	$(4/L)(M_{ps} + M_{pm})$	$192EI/L^3$	$0.71 R_m - 0.21 P_t$
			Plastic	1.0	0.33	$(4/L)(M_{ps} + M_{pm})$	–	$0.75 R_m - 0.25 P_t$
iii)	Fixed at one end and simply supported at the other	Uniform $P_t = pL$	Elastic (OA)	–	0.78	$(8/L)(M_{ps})$	$185EI/L^3$	$V_1 = 0.26R_1 + 0.12P_t$ $V_2 = 0.43R_1 + 0.19P_t$

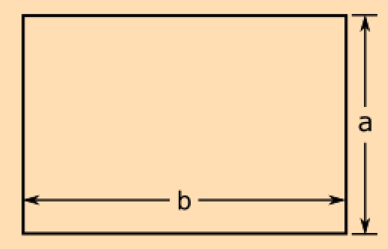
				Elastic (OB')	–	0.78	$(4/L)(M_{ps} + 2M_{pm})$	$160EI/L^3$	$0.39\ R_m + 0.11$
				Plastic	–	0.66	$(4/L)(M_{ps} + 2M_{pm})$	–	$0.38\ R_m + 0.12$
			Concentrated at mid-span $P_t = P$	Elastic (OA)	1.0	0.43	$(16/3L)M_{ps}$	$107EI/L^3$	$V_1 = 0.54R_1 + 0.14P_t$ $V_2 = 0.25R_1 + 0.07P_t$
				Elastic (OB')	1.0	0.49	$(2/L)(M_{ps} + 2M_{pm})$	$106EI/L^3$	$0.78\ R_m - 0.28\ P_t \pm M_{ps}/L$
				Plastic	1.0	0.33	$(2/L)(M_{ps} + 2M_{pm})$	–	$0.75\ R_m - 0.25\ P_t \pm M_{ps}/L$

L = span;
p = dynamic pressure;
P_t = dynamic load;
M_p = plastic moment of section;
M_{pm} = M_p at mid-span
M_{ps} = M_p at support;
R_m = maximum resistance; and
k_E = effective spring constant.

Table 59 Transformation Factors for Two-way Slabs — Four Sides, Simply Supported, Uniformly Loaded

(*Clauses* L-8.2.2.1, L-8.3.1.5 *and* L-8.3.1.6)





Sl No.	Strain Range	a/b	Load Mass Factor K_{LM}	Max Resistance R_m	Spring Constant k_E	Dynamic Reactions	
						V_A	V_B
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	Elastic (OB)	1.0	0.68	$12(M_{pfa} + M_{pfb})/a$	$252EI/a^2$	$0.07P_r + 0.18R_m$	$0.07P_r + 0.18R_m$
		0.9	0.70	$(12M_{pfa} + 11M_{pfb})/a$	$230EI/a^2$	$0.06P_r + 0.16R_m$	$0.08P_r + 0.20R_m$
		0.8	0.71	$(12M_{pfa} + 10.3M_{pfb})/a$	$212EI/a^2$	$0.06P_r + 0.14R_m$	$0.08P_r + 0.22R_m$
		0.7	0.73	$(12M_{pfa}+9.8M_{pfb})/a$	$201EI/a^2$	$0.05P_r + 0.13R_m$	$0.08P_r + 0.24R_m$
		0.6	0.74	$(12M_{pfa} + 9.3M_{pfb})/a$	$197EI/a^2$	$0.04P_r + 0.11R_m$	$0.09P_r+ 0.26R_m$
		0.5	0.75	$(12M_{pfa} + 9.0M_{pfb})/a$	$201EI/a^2$	$0.04P_r + 0.09R_m$	$0.09P_r + 0.28R_m$
ii)	Plastic (BC)	1.0	0.51	$12(M_{pfa} + M_{pfb})/a$	-	$0.09P_r + 0.16R_m$	$0.09P_r + 0.16R_m$
		0.9	0.51	$(12M_{pfa} + 11M_{pfb})/a$	-	$0.08P_r + 0.15R_m$	$0.09P_r + 0.18R_m$
		0.8	0.54	$(12M_{pfa} + 10.3M_{pfb})/a$	-	$0.07P_r + 0.13R_m$	$0.10P_r + 0.20R_m$
		0.7	0.58	$(12M_{pfa} + 9.8M_{pfb})/a$	-	$0.06P_r + 0.12R_m$	$0.10P_r + 0.22R_m$
		0.6	0.58	$(12M_{pfa} + 9.3M_{pfb})/a$	-	$0.05P_r + 0.10R_m$	$0.10P_r + 0.25R_m$
		0.5	0.59	$(12M_{pfa} + 9.0M_{pfb})/a$	-	$0.04P_r + 0. 08R_m$	$0.11P_r + 0.27R_m$

M_{pfa} = total positive ultimate moment capacity along mid-span section parallel to short edge;

M_{pfb} = total positive ultimate moment capacity along mid-span section parallel to long edge;

I = moment of inertia per unit width of slab;

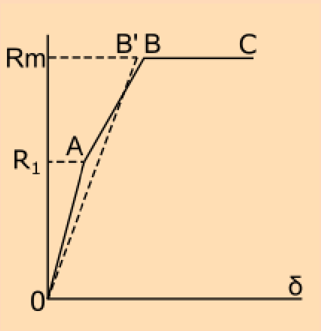
P_t = dynamic load;

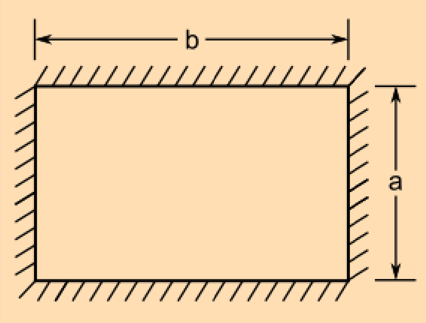
V_A = total dynamic reaction along a short edge; and

V_B = total dynamic reaction along a long edge.

Table 60 Transformation Factors for Two-way Slabs — Fixed four sides, Uniform loaded

(*Clauses* L-8.2.2.1, L-8.3.1.5 *and* L-8.3.1.6)





Sl No.	Strain Range	a/b	Load Mass Factor K_{LM}	Max Resistance R_m	Strain Range	Spring Constant k_E	Dynamic Reactions	
							V_A	V_B
(1)	(2)	(3)	(4)	(5)	(6)	(7)	*(8)*	*(9)*
i)	Elastic (OA)	1.0	0.63	29.2 M^o_{psb}	810 EI/a^2	$0.10P_t + 0.15R_1$	$0.10P_t + 0.15R_1$	1.0
		0.9	0.68	27.4 M^o_{psb}	742 EI/a^2	$0.09P_t + 0.14R_1$	$0.10P_t + 0.17R_1$	0.9
		0.8	0.69	26.4 M^o_{psb}	705 EI/a^2	$0.08P_t + 0.12R_1$	$0.11P_t + 0.19R_1$	0.8
		0.7	0.71	26.2 M^o_{psb}	692EI/a^2	$0.07P_t + 0.11R_1$	$0.11P_t + 0.21R_1$	0.7
		0.6	0.71	27.3 M^o_{psb}	724 EI/a^2	$0.06P_t + 0.09R_1$	$0.12P_t + 0.23R_1$	0.6
		0.5	0.72	30.2 M^o_{psb}	806 EI/a^2	$0.05P_t + 0.08R_1$	$0.12P_t + 0.25R_1$	0.5
ii)	Elasto-plastic (OB')	1.0	0.67	$(1/a)[12(M_{pfa}+M_{psa})+12(M_{pfb}+M_{psb})]$	252 EI/a^2	$0.07P_t + 0.18R_m$	$0.07P_t + 0.18R_m$	1.0
		0.9	0.70	$(1/a)[12(M_{pfa}+M_{psa})+11(M_{pfb}+M_{psb})]$	230 EI/a^2	$0.06P_t + 0.16R_m$	$0.08P_t + 0.20R_m$	0.9
		0.8	0.71	$(1/a)[12(M_{pfa}+M_{psa})+10.3(M_{pfb}+M_{psb})]$	212 EI/a^2	$0.06P_t + 0.14R_m$	$0.08P_t + 0.22R_m$	0.8
		0.7	0.73	$(1/a)[12(M_{pfa}+M_{psa})+9.8(M_{pfb}+M_{psb})]$	201 EI/a^2	$0.05P_t + 0.13R_m$	$0.08P_t + 0.24R_m$	0.7
		0.6	0.74	$(1/a)[12(M_{pfa}+M_{psa})+9.3(M_{pfb}+M_{psb})]$	197 EI/a^2	$0.04P_t + 0.11R_m$	$0.09P_t + 0.26R_m$	0.6
		0.5	0.75	$(1/a)[12(M_{pfa}+M_{psa})+9.0(M_{pfb}+M_{psb})]$	201 EI/a^2	$0.04P_t + 0.09R_m$	$0.09P_t + 0.28R_m$	0.5

iii)	Fully plastic (BC)	1.0	0.51	$(1/a)[12(M_{pfa}+M_{psa})+12(M_{pfb}+M_{psb})]$	–	$0.09P_t+0.16R_m$	$0.09P_t+0.16R_m$	1.0
		0.9	0.51	$(1/a)[12(M_{pfa}+M_{psa})+11(M_{pfb}+M_{psb})]$	–	$0.08P_t+0.15R_m$	$0.09P_t+0.18R_m$	0.9
		0.8	0.54	$(1/a)[12(M_{pfa}+M_{psa})+10.3(M_{pfb}+M_{psb})]$	–	$0.07P_t+0.13R_m$	$0.10P_t+0.20R_m$	0.8
		0.7	0.58	$(1/a)[12(M_{pfa}+M_{psa})+9.8(M_{pfb}+M_{psb})]$	–	$0.06P_t+0.12R_m$	$0.10P_t+0.22R_m$	0.7
		0.6	0.58	$(1/a)[12(M_{pfa}+M_{psa})+9.3(M_{pfb}+M_{psb})]$	–	$0.05P_t+0.10R_m$	$0.10P_t+0.25R_m$	0.6
		0.5	0.59	$(1/a)[12(M_{pfa}+M_{psa})+9.0(M_{pfb}+M_{psb})]$	–	$0.04P_t+0.08R_m$	$0.11P_t+0.27R_m$	0.5

Range (OA) = moment at centre of long edge just becomes plastic;
Range (OB') = moment at supports and mid-span sections just becomes plastic;
M^o_{psb} = negative ultimate moment capacity per unit width at centre of long edge;
M_{psa} = total negative ultimate moment capacity along a short edge support;
M_{psb} = total negative ultimate moment capacity along a long edge support;
M_{pfa}, M_{pfb}, I, P_t = (*see* Table 46);
V_A = total dynamic reaction along a short edge; and
V_B = total dynamic reaction along a long edge.

L-9 LOAD COMBINATIONS FOR DESIGN

L-9.1 Partial Safety Factor

A partial safety factor of unity shall be assumed for blast loads.

L-9.2 Imposed loads

Imposed load on floors shall be considered as per **3**. No Imposed load shall be considered on roof at the time of blast.

L-9.3 Load Combination

Wind or earthquake forces shall not be assumed to occur simultaneously with blast effects. Effects of temperature and shrinkage shall be neglected.

Following load combinations for limit state design shall be considered:

$$1.0DL + 0.5IL + 1.0B$$
$$0.9DL + 1.0B$$

where

DL = design dead load;

IL = design imposed load; and

B = design blast load.

L-10 For design of structures for blast effects of explosions above ground, *see also* good practice [C-1(16)].

For safety of structures during underground blasting, *see also* good practice [C-1(17)].

ANNEX M

(*Clause* 10.2.2 *and* *Table* 61)

SUMMARY OF DISTRICTS HAVING SUBSTANTIAL MULTI-HAZARD RISK AREAS

State	*Name of Districts Having Substantial Multi-Hazard Prone Area*			
	E.Q. and Flood	Cyclone and Flood	E.Q., Cyclone and Flood	E.Q. and Cyclone
(1)	(2)	(3)	(4)	(5)
Andhra Pradesh	Adilabad, Karim Nagar, Khammam	Krishna, Nellore, Srikakulam, Visakhapatnam, Vizianagram	East Godavari, Guntur, Prakasam, West Godavari	—
Assam	All 22 districts listed in Table 61 could have M.S.K IX or more with flooding	No cyclone, but speed can be 50 m/s in districts of Table 61 causing local damage except Dhubri	—	—
Bihar	All 25 districts listed in Table 61	—	—	—
Goa	—	—	—	North and South Goa
Gujarat	Banaskantha, Danthe GS, Gandhinagar, Kheda, Mahesana, Panchmahals, Vadodara	—	Ahmedabad, Bharuch, Surat, Valsad	Amreli, Bhavnagar, Jamnagar, Rajkot, Junagad, Kachcha
Haryana	All 8 districts listed in Table 61	—	—	—
Kerala	Idduki, Kottayam, Palakkad, Pathanamthitta	—	Alappuzha, Ernakulum, Kannur, Kasargod, Kollam, Kozhikode, Malappuram, Thiruvanathapura, Thrissur	—
Maharashtra	—	—	—	Mumbai, Rayagad, Ratnagiri, Sindhudurg, Thane
Orissa	—	Ganjam	Baleshwar, Cuttack, Puri	Dhenkanal
Punjab	All 12 districts listed in Table 61	—	—	—
Uttar Pradesh and Uttarakhand	All 50 districts listed in Table 61	—	—	—
West Bengal	Birbhum, Darjeeling, Jalpaiguri, Cooch Behar, Malda, Murshidabad, West Dinajpur	—	Bardhaman, Kolkata, Hugli, Howrah, Midnapore, Nadia, North and South 24 Parganas	Bankura
Union Territories	Delhi	—	Yanam (Py)	Diu
India	**139 Districts**	**6 Districts**	**29 Districts**	**16 Districts**

Table 61 Multi-Hazard Prone Districts

(*Annex* M)

Assam

Barpeta, Bongaigaon, Cachar[1], Darrang, Dhemaji, Dhuburi, Dibrugarh, Goalpara, Golaghat, Hailaknadi[1], Jorhat, Kamrup, Karbianglong, Karimganj[1], Kokrajhar, Lakhimpur, Morigaon, Nagaon, Nalbari, Sibsagar, Sonitpur, Tinsukia

Bihar[2]

Araria, Begusarai, Bhagalpur, Bhojpur, Darbhanga, Gopalganj, Katihar, Khagaria, Kishanganj, Madhepura, Madhubani, Munger, Muzaffarpur, Nalanda, Nawada, Paschim Champaran, Patna, Purbachamparan, Purnia, Samastipur, Saran, Saharsa, Sitamarhi, Siwan, Vaishali

Haryana[3]

Ambala, Bhiwani, Faridabad, Gurgaon, Hisar, Jind, Kurukshetra, Rohtak

Punjab[4]

Amritsar, Bathinda, Faridkot, Firozpur, Gurdaspur, Hoshiarpur, Jalandhar, Kapurthala, Ludhiana, Patiala, Rupnagar, Sangrur

Uttar Pradesh and Uttarakhand[5]

Agra, Aligarh, Allahabad, Azamgarh, Bahraich, Ballia, Barabanki, Bareilly, Basti, Bijnor, Budaun, Bulandshahr, Deoria, Etah, Etawah, Faizabad, Farrukhabad, Fatehpur, Firozabad, Ghaziabad, Ghazipur, Gonda, Gorakhpur, Hardoi, Haridwar, Jaunpur, Kanpur (Dehat), Kanpur (Nagar), Kheri, Lucknow, Maharajganj, Mainpuri, Mathura, Mau, Meerut, Mirzapur, Mordabad, Muzaffarnagar, Nainital, Pilibhit, Partapgarh, Raebareli, Rampur, Saharanpur, Shahjahanpur, Siddarth Nagar, Sitapur, Sultanpur, Unnao, Varanasi

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[1] Districts liable to cyclonic storm but no storm surge

[2] No cyclonic storm in Bihar

[3] No cyclonic storm in Haryana

[4] No cyclonic storm in Punjab

[5] No cyclonic storm in Uttar Pradesh and Uttarakhand

ANNEX N

[*Clause* 11.2]

STRUCTURAL DESIGN BASIS REPORT

N-1 This report shall accompany the application for Building Permit.

N-2 In case information on items (iii), (x), (xviii), (xix) and (xx) of Part 1 of SDBR not can be given at this time, it should be submitted at least one week before commencement of construction.

N-3 In case of reinforced concrete framed buildings, a certificate to the effect that the Part 3 of the SDBR will be completed and submitted at least one month before commencement of construction, shall be submitted with the application for building permit. In addition to the completed report, the following additional information shall be submitted, at the latest, one month before the commencement of construction:

a) Foundations:

  1) In case raft foundation has been adopted, indicate stiffness (K) value used for analysis of the raft;
  2) In case pile foundations have been used, give full particulars of the piles, type, diameter, length, capacity; and
  3) In case of high water table, indicate system of countering water pressure and indicate the existing water table and that assumed to design foundations.

  NOTE — The report/certificate of sub-surface investigation shall be duly considered and used in the preparation of foundation design and details.

b) Idealization for earthquake analysis:

  1) In case of a composite system of shear walls and rigid frames, give distribution of base shear in the two systems on the basis of analysis and that used for design of each system; and
  2) Indicate the idealization of frames and shear walls adopted in the analysis with the help of sketches.

c) Submit framing plans of each floor and in case of basements, indicate the system used to contain earth pressures.

N-4 The latest version of the Indian Standards with their amendments as indicated in the SDBR template given below, shall be referred for the preparation of the report.

N-5 The format of Part 1 of SDBR shall be as below:

PART 1 GENERAL DATA			
Sl No.	*Description*	*Information*	*Notes*
i)	Address of the building: a) Name of the building; b) Plot number; c) Subplot number, if any; d) Town Planning Scheme (if applicable): 1) Name; and 2) Number. e) Locality/Township; and f) District		
ii)	Name of owner		
iii)	Name of Building Constructor on record		

Sl No.	*Description*	*Information*	*Notes*
iv)	Name of Architect/Engineer on record		
v)	Name of Structural engineer on record		
vi)	Use of the building		
vii)	Number of storeys above ground level (including storeys to be added later, if any)		
viii)	Number of basements below ground level		
ix)	Type of structure: a) Load bearing walls; b) R.C.C frame; c) R.C.C frame and shear walls; and d) Steel frame.		
x)	Soil data: a) Type of soil; and b) Design safe bearing capacity.		IS 1892 IS 1904
xi)	Dead loads (Unit weight adopted): a) Earth; b) Water; c) Brick masonry; d) Plain cement concrete; e) Reinforced cement concrete; f) Floor finish; g) Other fill materials; and h) Piazza floor fill and landscape.		IS 875 (Part 1)
xii)	Imposed (Live) loads: a) Piazza floor accessible to fire tender; b) Piazza floor not accessible to fire tender; c) Floor loads[1]; and d) Roof loads[2].		IS 875 (Part 2)
xiii)	Cyclone/Wind: a) Speed; and b) Design pressure intensity.		IS 875 (Part 3)
xiv)	Other loads, if any		Relevant parts of IS 875
xv)	Seismic zone		IS 1893 (Part 1)
xvi)	Importance factor (*I*)		IS 1893 (Part 1)
xvii)	Earthquake zone factor (Z)		IS 1893 (Part 1)
xviii)	Elastic force reduction factor (*R*)		IS 1893 (Part 1)
xix)	Fundamental natural period (approximate)		IS 1893 (Part 1)

Sl No.	*Description*	*Information*	*Notes*
xx)	Horizontal site-specific acceleration PSA (A_{SS})		IS 1893 (Part 1)
xxi)	Expansion/Separation Joints[3]		

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[1] Enclose small scale plans of each floor on A4 sheets

[2] In case terrace garden is provided, indicate additional fill load and imposed (live) load

[3] Indicate on a small scale plan on A4 sheet

Signature

(Registered Engineer/Structural Engineer)

N-6 The format of Part 2 of SDBR shall be as below:

<table>
<tr><th colspan="5">PART 2 LOAD BEARING MASONRY BUILDINGS</th></tr>
<tr><th><i>Sl No.</i></th><th><i>Description</i></th><th><i>Information</i></th><th colspan="2"><i>Notes</i></th></tr>
<tr><td rowspan="4">i)</td><td rowspan="4">Building category</td><td rowspan="4"></td><td colspan="2">IS 4326
IS 1893 (Part 1)</td></tr>
<tr><td>Zone / Building</td><td>II III IV V</td></tr>
<tr><td>Ordinary</td><td>B C D E</td></tr>
<tr><td>Important</td><td>C D E E</td></tr>
<tr><td>ii)</td><td>Basement provided</td><td></td><td colspan="2"></td></tr>
<tr><td>iii)</td><td>Number of floors including ground floor (all floors including stepped floors in hill slopes)</td><td></td><td colspan="2"></td></tr>
<tr><td>iv)</td><td>Type of wall masonry</td><td></td><td colspan="2"></td></tr>
<tr><td>v)</td><td>Type and mix of mortar</td><td></td><td colspan="2">IS 4326</td></tr>
<tr><td>vi)</td><td>Size and position of openings (<i>see</i> Note 1):
a) Minimum distance (b5);
b) Ratio (b1+b2+b3)/l1 or (b6+b7)/l2;
c) Minimum pier width between consequent opening (b4);
d) Vertical distance (h3);
e) Ratio of wall height to thickness; and</td><td></td><td colspan="2">IS 4326</td></tr>
</table>

Sl No.	*Description*	*Information*	*Notes*
	f) Ratio of wall length between cross wall to thickness;		
vii)	Horizontal seismic band:	**P** **TP** **NA**	(*see* Note 2)
	a) at plinth level;	☐ ☐ ☐	IS 4326
	b) at window sill level;	☐ ☐ ☐	IS 4326
	c) at lintel level;	☐ ☐ ☐	IS 4326
	d) at ceiling level;	☐ ☐ ☐	IS 4326
	e) at eave level of sloping roof;	☐ ☐ ☐	IS 4326
	f) at top of gable walls; and	☐ ☐ ☐	IS 4326
	g) at top of ridge walls.	☐ ☐ ☐	IS 4326
viii)	Vertical reinforcing bar:	**P** **TP** **NA**	
	a) at corners and T-junction of walls; and	☐ ☐ ☐	IS 4326
	b) at jambs of doors and window openings	☐ ☐ ☐	IS 4326
ix)	Integration of prefab roofing/ flooring elements through reinforced concrete screed	☐ ☐ ☐	IS 4326
x)	Horizontal bracings in pitched truss:		
	a) in horizontal plane at the level of ties; and	☐ ☐ ☐	
	b) in the slopes of pitched roofs	☐ ☐ ☐	

NOTES

1 Information in Sl No. (vi) of Part 2 should be given on separate A4 sheets for all walls with large number of openings.

2 P indicates "Information Provided"; TP indicates "Information to be Provided" and NA indicates "Not Applicable". Tick mark one box which is applicable.

Signature

(Registered Engineer/Structural Engineer)

N-7 The format of Part 3 of SDBR shall be as below:

PART 3 REINFORCED CONCRETE FRAMED BUILDINGS			
Sl No.	*Description*	*Information*	*Notes*
i)	Type of Building: a) Regular frames; b) Regular frames with shear walls; c) Irregular frames; d) Irregular frames with shear walls; and e) Soft storey.		IS 1893 (Part 1)
ii)	Number of basements		
iii)	Number of floors including ground floor		
iv)	Horizontal floor system: a) Beams and slabs; b) Waffles; c) Ribbed Floor; d) Flat slab with drops; and e) Flat plate without drops.		
v)	Soil data: a) Type of soil; b) Recommended type of foundation: 1) Independent footings; 2) Raft; and 3) Piles. c) Recommended bearing capacity of soil; d) Recommended, type, length, diameter and load capacity of piles; e) Depth of water table; f) Chemical analysis of ground water; and g) Chemical analysis of soil.		
vi)	Foundations: a) Depth below ground level; and b) Type of independent interconnected raft piles.		
vii)	System of interconnecting foundations: a) Plinth beams; and b) Foundation beams.		
viii)	Grades of concrete used in different parts of building		

Sl No.	*Description*	*Information*	*Notes*
ix)	Method of analysis used		
x)	Computer software used		
xi)	Torsion included		IS 1893 (Part 1)
xii)	Base shear:		IS 1893 (Part 1)
	a) Based on approximate fundamental period;		
	b) Based on dynamic analysis; and		
	c) Ratio of a/b.		
xiii)	Distribution of seismic forces along the height of the building		IS 1893 (Part 1) (provide sketch)
xiv)	The column of soft ground storey specially designed		IS 1893 (Part 1)
xv)	Clear minimum cover provided in:		IS 456
	a) Footing;		
	b) Column;		
	c) Beams;		
	d) Slabs; and		
	e) Walls.		
xvi)	Ductile detailing of RC frame:		
	a) Type of reinforcement used;		IS 456 IS 13920
	b) Minimum dimension of beams;		IS 13920
	c) Minimum dimension of columns;		IS 456
	d) Minimum percentage of reinforcement of beams at any cross-section;		IS 13920 IS 456
	e) Maximum percentage of reinforcement at any section of beam;		IS 13920
	f) Spacing of transverse reinforcement in 2-D length of beams near the ends;		IS 13920
	g) Ratio of capacity of beams in shear to capacity of beams in flexure;		IS 456
	h) Maximum percentage of reinforcement in column;		
	j) Confining stirrups near ends of columns and in beaL-column joints:		IS 13920
	1) Diameter; and		
	2) Spacing.		
	k) Ratio of shear capacity of columns to maximum seismic shear in the storey		

Signature

(Registered Engineer/Structural Engineer)

N-8 The format of Part 4 of SDBR shall be as below:

PART 4 STRUCTURAL STEEL/STEEL CONCRETE COMPOSITE BUILDINGS			
i)	Adopted method of design	a) Simple; b) Semi-rigid; and c) Rigid.	IS 800
ii)	Design based on	a) Elastic analysis; and b) Plastic analysis.	IS 800 SP 6 (6)
iii)	Floor construction	a) Composite; b) Non-composite; and c) Boarded.	
iv)	Roof construction	a) Composite; b) Non-composite; c) Metal; and d) Any other.	
v)	Horizontal force resisting system adopted	a) Frames; b) Braced frames; and c) Frames and shear walls.	NOTE — Seismic force as per IS 1893 (Part 1) would depend on the system.
vi)	Slenderness ratios maintained	Members defined in IS 800	IS 800
vii)	Member deflection limited to	a) Beams, rafters; b) Crane girders; c) Purlins; and d) Top of columns.	IS 800
viii)	Structural members	a) Encased in Concrete; and b) Not encased.	IS 800
ix)	Proposed material	a) General weldable; b) High strength; c) Cold formed; and d) Tubular.	IS 2062 (Part 1) IS 801, IS 811 IS 806
x)	Minimum metal thickness specified for corrosion	a) Hot rolled sections	IS 800

	protection	b) Cold formed sections c) Tubes	
xi)	Structural connections	a) Rivets b) CT bolts c) HSFG bolts d) Black bolts e) Welding- Field/Shop (Specify welding type proposed) f) Composite	IS 800 IS 1929, IS 2155, IS 1148 IS 6639, IS 1367 IS 3757, IS 4000, IS 1363 IS 1367, IS 816, IS 814, IS 1395 IS 15977, IS 6419, IS 6560, IS 813, IS 9595 IS 11384
xii)	Minimum fire rating proposed, with method	a) Rating ___ hours; b) Method proposed: 1) Intumescent painting; 2) Spraying; 3) Quilting; and 4) Fire retardant boarding.	IS 1641, IS 1642, IS 1643

Signature

(Registered Engineer/Structural Engineer)

LIST OF STANDARDS

The following list records those standards which are acceptable as 'good practice' and 'accepted standards' in the fulfillment of the requirements of this NBCS. The latest version of a standard shall be adopted at the time of enforcement of this NBCS. The standards listed may be used by the Authority as a guide in conformance with the requirements of the referred clauses in this NBCS.

In the following list, the number appearing in the first column within parentheses indicates the number of the reference in this Section.

	IS No.	*Title*
(1)	IS 8888 : 2020	Requirements of low income housing for urban areas — Guide (*second revision*)
(2)	IS 807 : 2006	Design, erection and testing (structural portion) of cranes and hoists — Code of practice (*second revision*)
	IS 3177 : 2020	Electric overhead travelling crane and gantry crane for all applications — Code of practice (*third revision*)
(3)	IS 17951 : 2023	Method for determination of performance relating to safety of external building envelope impacted by wind borne debris
(4)	IS 14732 : 2000/ISO 9867 : 1984	Guidelines for the evaluation of the response of occupants of fixed structures, especially buildings and off-shore structures, to low-frequency horizontal motion (0.063 to 1 Hz)
(5)	IS 18315 : 2023	Estimation of cyclonic factor (k_4) — Guidelines
(6)	IS 1893 (Part 1) : 2016	Criteria for earthquake-resistant design of structures: Part 1 General provisions and buildings (*sixth revision*)
(7)	IS 13827 : 1993	Improving earthquake resistance of earthen buildings — Guidelines
	IS 13828 : 1993	Improving earthquake resistance of Low strength masonry buildings — Guidelines
(8)	IS 13920 : 2016	Ductile design and detailing of reinforced concrete structures subjected to seismic forces — Code of practice (*first revision*)
(9)	IS 18168 : 2023	Earthquake resistant design and detailing of steel Buildings — Code of practice
(10)	IS 3414 : 1968	Code of practice for design and installation of joints in buildings
(11)	IS 875 (Part 5) : 1987	Code of practice for design loads (Other than earthquake) for building and structures: Part 5 Special loads and combinations (*second revision*)
(12)	IS 1642 : 2013	Fire safety of buildings (general) details of construction — Code of practice (*second revision*)
(13)	IS 14680 : 2024	Landslide control measures — Guidelines (*first revision*)
	IS 17162 : 2020	Preparation of landslide risk assessment maps in mountainous terrains — Guidelines
	IS 17163 : 2020	Site specific investigation and stability analysis of landslides — Guidelines
	IS 14496	Preparation of landslide hazard zonation maps in mountainous terrains — Guidelines:
	(Part 1) : 2020	Meso-zonation
	(Part 2) : 1998	Macro-zonation
	IS 18736 : 2024	Micropiles for slope stabilization for mitigation of landslides — Guidelines
	IS 14458 (Part 1) : 1998	Retaining wall for hill area — Guidelines: Part 1 Selection of type of wall
	IS 14458 (Part 2) : 1997	Retaining wall for hill area — Guidelines: Part 2 Design of

	IS No.	*Title*
		retaining/breast walls
	IS 14458 (Part 3) : 1998	Retaining wall for hill area — Guidelines: Part 3 Construction of dry stone walls
	IS 14458 (Part 4) : 2018	Retaining wall for hill area — Guidelines: Part 4 Construction of banded dry stone masonry walls
	IS 14458 (Part 5) : 2018	Retaining wall for hill area — Guidelines: Part 5 Construction of cement stone masonry walls
	IS 14458 (Part 6) : 2020	Retaining wall for hill area — Guidelines: Part 6 Construction of gabion walls
	IS 14458 (Part 7) : 2022	Retaining wall for hill area – Guidelines Part 7 Construction of peripheral reinforced gabion walls
	IS 14458 (Part 8) :2 025	Retaining wall for hill area – Guidelines Part 8 Design of reinforced cement concrete (RCC) Retaining Walls
	IS 14804 : 2000	Siting design and selection of materials for residential buildings in hilly areas — Guidelines
	IS 14961 : 2024	Surface water management in hilly areas (including rainwater harvesting) – Guidelines (*first revision*)
(14)	IS 15498 : 2023	Improving the cyclonic resistance of low rise houses and other buildings — Guidelines (*first revision*)
	IS 15499:2004	Guidelines for survey of housing and building typology in cyclone prone areas for assessment of vulnerability of regions and post cyclone damage estimation
	IS 17164 : 2020	Design and construction of cyclone shelters — Guidelines
	IS 17951 : 2023	Method for Determination of performance relating to safety of external building envelope impacted by wind borne debris
	IS 18153 : 2023	Improving the cyclonic resistance capacity of *Kutcha* houses — Guidelines
(15)	IS 212 : 2021	Crude coal tar for general use (*third revision*)
	IS 216 : 2006	Coal tar pitch — Specification (*second revision*)
	IS 269 : 2015	Ordinary portland cement– —Specification (*sixth revision*)
	IS 277 : 2018	Galvanized steel strips and sheets (Plain and Corrugated) - Specification (*seventh revision*)
	IS 303 : 2024	Plywood for general purposes — Specification (*fourth revision*)
	IS 383 : 2025	Coarse and fine aggregate for concrete — Specification (*fourth revision*) under revision Doc No: CED 2(27866)
	IS 399 : 1963	Classification of commercial timbers and their zonal distribution (*revised*)
	IS 404 (Part1) : 1993	Lead pipes — Specification: Part 1 for other than chemical purposes (*third revision*)
	IS 412 : 1975	Specification for expanded metal steel sheets for general purposes (*second revision*)
	IS 457 : 1957	Code of practice for general construction of plain and reinforced concrete for dams and other massive structures
	IS 458 : 2021	Precast concrete pipes (with and without reinforcement) (*fifth r*evision)
	IS 459 : 1992	Corrugated and semi — Corrugated asbestos cement sheets - Specification (*third revision*)
	IS 651 : 2007	Glazed stoneware pipes and fittings — Specification (*sixth revision*)
	IS 653 : 1992	Linoleum sheets and tiles — Specification (*third revision*)

IS No.	*Title*
IS 654 : 2025	Clay roofing tiles mangalore pattern — Specification (*fifth revision*) Under Revision Doc No: CED 30 (27732)
IS 808 : 2021	Hot rolled steel beam, column, channel and angle sections — Dimensions and properties (*fourth revision*)
IS 809 : 1992	Rubber flooring materials for general purposes — Specification (*first revision*)
IS 811 : 1987	Specification for cold formed light gauge structural steel sections (*second revision*)
IS 1077 : 2025	Common burnt clay building bricks — Specification (*sixth revision*)
IS 1173 : 1978	Specification for hot rolled and slit steel tee bars (*second revision*)
IS 1322: 1993	Bitumen felts for water proofing and damp-proofing - Specification (*fourth revision*)
IS 1343 : 2012	Prestressed concrete — Code of practice (*second revision*)
IS 1478 : 2023	Clay flooring tiles specification (*third revision*)
IS 1536 : 2023	Centrifugally cast (Spun) iron pressure pipes for water, gas and sewage - Specification (*fifth revision*)
IS 1537 : 1976	Specification for vertically cast iron pressure pipes for water, gas and sewage (*first revision*)
IS 1592 : 2003	Asbestos cement pressure pipes and joints - Specification (*fourth revision*)
IS 1626	Asbestos cement building pipes and pipe fittings, gutters and gutter fittings and roofing fitting
(Part 1) : 1994	Pipe and pipe fittings (*second revision*)
(part 2) : 1994	Gutter and gutter fittings (*second revision*)
IS 1658 : 2006	Fibre hardboards — Specification (*third revision*)
IS 1725 : 2023	Stabilized soil blocks used in general building construction — Specification (*Third Revision*)
IS 1726 : 1991	Cast iron manhole covers and frames — Specification (*third revision*)
IS 1729 :2023	Sand cast iron spigot and socket pipes, fittings and accessories —Specification (*third revision*)
IS 2095	Gypsum plaster boards - Specification:
(Part 1) : 2011	Plain gypsum plaster boards (*fourth revision*)
(Part 2) : 2022	Coated laminated gypsum plaster boards (*third revision*)
(Part 3) : 2022	Reinforced gypsum plaster boards and ceiling tiles (*fourth revision*)
IS 2180 : 2025	Specification for heavy duty burnt clay building bricks (*fourth revision*) *Under Revision* CED 30(26671)
IS 2185	Concrete masonry units — Specification
(Part 1) : 2005	Hollow and solid concrete blocks (*third revision*)
(Part 3) : 1984	Autoclaved Cellular Aerated Concrete Blocks
IS 2222 : 2025	Specification for burnt clay perforated building bricks (*fourth revision*) *Under Revision* CED 30 (28174)
IS 2314	Steel sheet piling section — Specification
(Part 1) : 2023	Hot rolled sheet pile (*second revision*)
(Part 2) : 2023	Cold formed sheet pile (*second revision*)
IS 2394: 1984	Code of practice for application of lime plaster finish (*first revision*)

IS No.	*Title*
IS 2508 : 2024	Polyethylene films and sheets — Specification (*fourth revision*)
IS 2526 : 1963	Code of practice for acoustical design of auditoriums and conference halls
IS 2541 : 1991	Preparation and use of lime concrete — Code of practice (*second revision*)
IS 2547	Specification for gypsum building plaster
(Part 1) : 1976	Excluding premixed lightweight plasters (*first revision*)
(Part 2) : 1976	Premixed lightweight plasters (*first revision*)
IS 2553 (Part 1) : 2018	Safety glass — Specification: Part 1 Architectural, building and general uses (*fourth revision*)
IS 2835 : 1987	Specification for flat transparent sheet glass (*third revision*)
IS 3087 : 2005	Particle boards of wood and other lingnocellulosic materials (medium density) for general purposes — Specification (*second revision*)
IS 3115 : 1992	Lime based blocks — Specification (*second revision*)
IS 3129 : 1985	Specification for low density particle boards
IS 3348 : 1965	Specification for fibre insulation boards
IS 3478 : 1966	Specification for high density wood particle boards
IS 4139 : 1989	Calcium silicate bricks — Specification (Second Revision)
IS 4253	Cork composition sheets — Specification
(Part 1) : 2008	Plain cork sheets (*second revision*)
(Part 2) : 2008	Cork and rubber (*second revision*)
IS 4671 : 2018	Expanded polystyrene for thermal insulation purposes (*second revision*)
IS 4860 : 1968	Specification for acid — Resistant bricks
IS 4923 : 2017	Hollow steel sections for structural use — Specification (*third revision*)
IS 6072 : 2023	Autoclaved reinforced cellular concrete wall slabs — Specifications (*first revision*)
IS 6598 : 2018	Cellular concrete for thermal insulation — Specification (*first revision*)
IS 8041 : 1990	Rapid hardening portland cement — Specification (*second revision*)
IS 9012 : 1978	Recommended practice for shotcreting
IS 12679 : 2023	By-product gypsum for construction — Specification (*second revision*)
IS 12823 : 2015	Prelaminated particle boards from wood and other Lignocellulosic material — Specification (*first revision*)
IS 12894 : 2002	Pulverized fuel ash — Lime bricks — Specification (*first revision*)
IS 14443 : 1997	Polycarbonate sheets — Specification
IS 14587 : 2023	Prelaminated medium density fibre board — Specification
IS 14635	Fluoropolymer dispersions and moulding and extrusion materials
(Part 2) : 2020	Preparation of test specimens and determination of properties (*first revision*)
IS 14753 : 1999	Polymethyl methacrylate (pmma) (acrylic) sheets
IS 14862 : 2000	Fibre cement flat sheets — Specification

	IS No.	*Title*
	IS 15622 : 2017	Pressed ceramic tiles — Specification (*first revision*)
	IS 15658 : 2001	Concrete paving blocks — Specification (*first revision*)
	IS 16720 : 2018	Pulverized fuel ash-cement bricks — Specification
	IS 17452 : 2020	Use of alkali activated concrete for precast products — Guidelines
(16)	IS 4991 : 1968	Criteria for blast resistant design of structures for explosions above ground
(17)	IS 6992 : 1973	Criteria for safety and design of structures subject to underground blasts

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART C STRUCTURAL DESIGN

SECTION 2 SOILS AND FOUNDATIONS

BUREAU OF INDIAN STANDARDS

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National Building Code Sectional Committee, CED 46

FOREWORD

This NBCS (Part C/Sec 2) deals with the structural design aspects of foundations and mainly covers the design principles involved in different types of foundations.

This Section was published in 1970 and subsequently revised in 1983, 2005 and 2016 as a chapter of the National Building Code of India. In the first revision of 1983, design considerations in respect of shallow foundation were modified, provisions regarding pier foundation were added and provisions regarding raft foundation and pile foundation were revised and elaborated. In the second revision of 2005, design considerations in respect of shallow foundations were again modified, method for determining depth of fixity, lateral deflection and maximum moment of laterally loaded piles were modified and reference was made to ground improvement techniques.

In the third revision in 2016, the significant changes incorporated were: including the extension of the scope to cover the design of foundations on rock, modifications to definitions in line with prevailing engineering practices; addition of new terms related to pile foundations and ground improvement; inclusion of the clause on site investigation and number of modifications, such as, new methods of soil investigation; addition of depth of exploration for pile foundations; addition of new sub-clauses on vertical interval for field tests and site investigation report; inclusion of method for assessment of liquefaction potential of a site; modification of permissible differential settlements and tilt (angular distortion) for shallow foundations in soils; modification of procedures for calculation of bearing capacity, structural capacity, factor of safety, lateral load capacity, overloading, etc, in case of pile foundations; revision of design parameters with respect to adhesion factor, earth pressure coefficient, modulus of subgrade reaction, etc, for design of pile foundations to make them consistence with the outcome of modern research and construction practices; inclusion of provision for use of any established dynamic pile driving formulae, instead of recommending any specific formula, to control the pile driving at site, giving due consideration to limitations of various formulae; inclusion of a reference to spun piles, which are used in deep marshy soils where conventional pile installation beyond 50 m is difficult; elaboration of the clause on ground improvement techniques; and addition of a table on summary of soil improvement methods.

In the current revision, this publication has been renamed as National Building Construction Standards (NBCS).

As a result of technical developments in this subject, the experience gained since implementation of 2016 version of the NBCS and feedback received as well as the revision of related Indian Standards on the subject, a need was felt to revise this Section. The significant modifications made in this revision of the subsection include amongst others, the following:

a) Provisions on location and depth of investigation have been modified;

b) Provisions on various boring techniques have been updated and continuous soil samplers have been included;

c) Series of in-situ tests have been added, such as electric cone penetration test using piezocone with pore pressure measurement (CPTu), field California bearing ratio (CBR) test, cross hole seismic test (CHST), ground penetrating radar survey (GPR), spectral analysis of surface wave (SASW) and multi-channel analysis of surface wave (MASW), dilatometer test (DMT) and in-situ permeability test, etc;

d) Provisions on optical and acoustic tele-viewer methods have been added;

e) Provisions on pressuremeter test (PMT) have been detailed;

f) Detailed explanation for deep foundation has been added;

g) The provisions for the design and construction of Combined Piled Raft Foundations (CPRF) have been added. These provisions cover a composite foundation system that utilizes both raft and pile components to effectively transfer structural loads to the ground; and

h) Provision relating to geotechnical instrumentation has been introduced.

For detailed information regarding structural analysis and soil mechanics aspects of individual foundations, reference should be made to standard textbooks and available literature.

The requirements for geotechnical engineering services, including roles and responsibilities, qualifications and experience of professionals and deliverables expected from various stakeholders, are covered in IS 19235 : 2025 ‘Geotechnical engineering services — Requirements’. While the standard primarily addresses pre-construction services, it also outlines interlinked construction stage services, thereby providing comprehensive guidance for geotechnical aspects throughout the project lifecycle.

The information contained in this section is mainly based on the following Indian Standards:

IS 1080 : 1985	Code of practice for design and construction of shallow foundations in soils (other than raft, ring and shell) (*second revision*)
IS 1892 : 2021	Subsurface investigation for foundations — Code of practice (*second revision*)
IS 1904 : 2021	General requirements for design and construction of foundation in soils — Code of practice (*fourth revision*)
IS 2911	Code of practice for design and construction of pile foundations
(Part 1/Sec 1) : 2010	Concrete piles, Section 1 Driven cast *in-situ* concrete piles (*second revision*)
(Part 1/Sec 2) : 2010	Concrete piles, Section 2 Bored cast *in-situ* piles (*second revision*)
(Part 1/Sec 3) 2010	Concrete piles, Section 3 Driven precast concrete piles (*second revision*)
(Part 1/Sec 4) : 2010	Concrete piles, Section 4 Precast concrete piles in prebored holes (*first revision*)
(Part 2) : 2021	Timber piles (*second revision*)
(Part 3) : 2021	Under-reamed piles (*second revision*)
IS 2950 (Part 1) : 1981	Code of practice for design and construction of raft foundations: Part 1 Design (*second revision*)
IS 19117 : 2025	Design and construction of combined piled raft foundations — Code of practice
IS 2131 : 2025	Standard penetration test of soil — Method of test

All standards, whether given herein above or cross-referred to in the main text of this Section, are subject to the revision. The parties to agreement based on this Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

As the regulation of land development and buildings is a state subject and is dealt by the states and local bodies such as urban local bodies within their jurisdiction through building regulatory documents like building regulations, building byelaws and fire regulations, this document is voluntary in nature and is non-binding. The implementation depends on adoption by concerned parties or stipulations in a contract or by appropriate adoption by the concerned authorities.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 ‘Rules for rounding off numerical values (*second revision*)’. The number of significant places retained in the rounded off value should be the same as that of the specified value in this Section.

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Important Explanatory Note for Users of the NBCS

In any Part/Section of this NBCS, where reference is made to **'good practice'** in relation to design, constructional procedures or other related information and where reference is made to **'accepted standard'** in relation to material specification, testing, or other related information, the Indian Standards listed at the end of the Part/Section shall be used as a guide to the interpretation.

At the time of publication, the editions indicated in the standards were valid. All standards are subject to revision and parties to agreements based on any Part/Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

In the list of standards given at the end of a Part/Section, the number appearing within parentheses in the first column indicates the number of the reference of the standard in the Part/Section. For example:

a) Good practices [C-2(1)] refers to the Indian Standard(s) given at serial number (1) of the list of standards given at the end of this Part/Section, that is, IS 1892 : 2021 'Code of practice for subsurface investigation for foundation (*second revision*)', IS 2131 : 2025 'Method of standard penetration test for soils (*second revision*)', IS 2132 : 1986 'Code of practice for thin walled tube sampling of soils (*second revision*)', IS 4434 : 1978 'Code of practice for in-situ vane shear test for soils (*first revision*)', IS 4968 (Part 1) : 1976 'Method for subsurface sounding for soils: Dynamic method using 50 mm cone without bentonite slurry (*first revision*)', IS 4968 (Part 2) : 1976 'Method for subsurface sounding for soils: Dynamic method using cone and bentonite slurry (*first revision*)', IS 4968 (Part 3) : 1976 'Method for subsurface sounding for soils: Static cone penetration test (*first revision*)', IS 8763 : 1978 'Guide for undisturbed sampling of sands and sandy soils' and IS 9214 : 1979 'Method for determination of modulus of subgrade reaction (k-value) of soils in the field'.

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART C STRUCTURAL DESIGN

SECTION 2 SOILS AND FOUNDATIONS

1 SCOPE

1.1 This NBCS (Part C/Section 2) covers geotechnical design (principles) of building foundations, such as shallow foundations, like, continuous strip footings, combined footings, raft foundations, deep foundations like pile foundations and other foundation systems to ensure safety and serviceability without exceeding the permissible stresses of the materials of foundations and the bearing capacity of the supporting soil/rock.

1.2 This Section also covers provisions relating to preliminary work required for construction of foundations and protection of excavation.

2 TERMINOLOGY

For the purpose of this Section, the following definitions shall apply.

2.1 General

2.1.1 *Clay* — An aggregate of microscopic and sub-microscopic particles derived from the chemical decomposition and disintegration of rock constituents. It is plastic within a moderate to wide range of water content. The particles are less than 0.002 mm in size.

2.1.2 *Clay*, *Firm* — A clay which at its natural water content can be moulded by substantial pressure with the fingers and can be excavated with a spade.

2.1.3 *Clay*, *Soft* — A clay which at its natural water content can be easily moulded with the fingers and readily excavated.

2.1.4 *Clay*, *Stiff* — A clay which at its natural water content cannot be moulded with the fingers and requires a pick or pneumatic spade for its removal.

2.1.5 *Foundation* — That part of the structure which is in direct contact with and transmits loads to the ground.

2.1.6 *Gravel* — Angular, rounded or semi-rounded particles of rock or soil of particle size between 4.75 mm and 75 mm.

2.1.7 *Peat* — A fibrous mass of organic matter in various stages of decomposition generally dark brown to black in colour and of spongy consistency.

2.1.8 *Sand* — Cohesion less aggregates of angular, sub-angular, sub-rounded, rounded, flaky or flat fragments of more or less unaltered rocks, or mineral of size between 4.75 mm and 0.075 mm IS Sieve.

2.1.9 *Sand*, *Coarse* — Sand of particle size between 2.0 mm and 4.75 mm IS Sieve.

2.1.10 *Sand*, *Fine* — Sand of particle size between 0.075 mm and 0.425 mm IS Sieve.

2.1.11 *Sand*, *Medium* — Sand of particle size between 0.425 mm and 2.0 mm IS Sieve.

2.1.12 *Silt* — Fine-grained soil or fine-grained portion of soil which exhibits a little or no plasticity and has a little or no strength when air dried. The size of particles ranges from 0.075 mm to 0.002 mm.

2.1.13 *Soft Rock* — A rocky cemented material which offers a high resistance to picking up with pick axes and sharp tools but which does not normally require blasting or chiselling for excavation.

2.1.14 *Soil*, *Black Cotton* — Inorganic clays of medium to high compressibility. They form a major soil group in India. They are predominately montmorillonitic in structure and yellowish black or blackish grey in colour. They are characterized by high shrinkage and swelling properties.

2.1.15 *Soil*, *Coarse Grained* — Soils which include the coarse and largely siliceous and unaltered products of rock weathering. They possess no plasticity and tend to lack cohesion when in dry state. In these soils, more than half the total material by weight is larger than 75-micron IS Sieve size.

2.1.16 *Soil*, *Fine Grained* — Soils consisting of the fine and altered products of rock weathering, possessing cohesion and plasticity in their natural state, the former even when dry and both even when submerged. In these soils, more than half of the material by weight is smaller than 75-micron IS Sieve size.

2.1.17 *Soil*, *Highly Organic and Other Miscellaneous Soil Materials* — Soils consisting of large percentages of fibrous organic matter, such as peat and particles of decomposed vegetation. In addition, certain soils containing shells, concretions, cinders and other non-soil materials in sufficient quantities are also grouped in this division.

2.1.18 *Total Settlement* — The total downward movement of the foundation unit under load.

2.2 Ground Improvement

2.2.1 *Ground Improvement* — Enhancement of the in-place properties of the ground by controlled application of techniques suited to subsoil conditions.

NOTE — These techniques are used to improve the load bearing capacity and settlement potential of the loose or soft soil lying close to the surface or at depths.

2.2.2 *Injection* — Introduction of a chemical/cementitious material into a soil mass by application of pressure.

2.2.3 *Liquefaction* — It is a state primarily in saturated cohesionless soils wherein the effective shear strength is reduced to negligible value for all engineering purposes, when the pore pressure approaches the total confining pressure during earthquake shaking. In this condition, the soil tends to behave like a fluid mass.

2.2.4 *Preloading* — Application of loads to achieve improvement of soil properties prior to imposition of structural loads.

2.2.5 *Soil Densification* — A technique to densify cohesionless soils by imparting shocks or vibrations.

2.2.6 *Soil Reinforcement* — Rods, strips or geosynthetics (metallic or fabric) incorporated within soil mass to impart resistance to tensile, shear and compressive forces.

2.3 Shallow Foundation

2.3.1 *Back Fill* — Materials used or reused to fill an excavation.

2.3.2 *Bearing Capacity*, *Safe* — The maximum intensity of loading that the soil will safely carry with a factor of safety against shear failure of soil irrespective of any settlement that may occur.

2.3.3 *Bearing Capacity*, *Ultimate* — The intensity of loading at the base of a foundation which would cause shear failure of the supporting soil.

2.3.4 *Bearing Pressure*, *Allowable* (*Gross or Net*) — The intensity of loading which the foundation will carry without undergoing settlement in excess of the permissible value for the structure under consideration but not exceeding safe bearing capacity.

The net allowable bearing pressure is the gross allowable bearing pressure minus the surcharge intensity.

NOTE — The concept of ‘gross’ and ‘net’ used in defining the allowable bearing pressure could also be extended to safe bearing capacity, safe bearing pressure and ultimate bearing capacity.

2.3.5 *Factor of Safety* (*with Respect to Bearing Capacity*) — A factor by which the ultimate bearing capacity (net) shall be reduced to arrive at the value of safe bearing capacity (net).

2.3.6 *Footing* — A structure constructed in brick work, masonry or concrete under the base of a wall or column for the purpose of distributing the load over a larger area.

2.3.7 *Foundation*, *Raft* — A substructure supporting an arrangement of columns or walls in a row or rows transmitting the loads to the soil by means of a continuous slab, with or without depressions or openings.

2.3.8 *Made-up Ground* — Refuse, excavated soil or rock deposited for the purpose of filling a depression or raising a site above the natural surface level of the ground.

2.3.9 *Offset* — The projection of the lower step from the vertical face of the upper step.

2.3.10 *Permanent Load* — Loads which remain on the structure for a period, or a number of periods, long enough to cause time dependent deformation/settlement of the soil.

2.3.11 *Shallow Foundation* — A foundation whose width is generally equal to or greater than its depth. The shearing resistance of the soil in the sides of the foundation is generally neglected.

2.3.12 *Spread* (*or Isolated or Pad*) *Foundation/Footing* — A foundation which transmits the load to the ground through one or more footings. A spread footing (or isolated or pad) is provided to support an individual column. A spread footing is circular, square or rectangular slab of uniform thickness. Sometimes, it is stepped or haunched to spread the load over a large area.

2.3.13 *Strip Foundation/Footing* — A type of shallow foundation which provides continuous and longitudinal bearing for loads carried by vertical elements, such as continuous wall foundation beams or the like. A strip footing is also provided for a row of columns which are so closely spaced that their spread footings overlap or nearly touch each other. A strip footing is also known as continuous footing.

2.4 Pile Foundation

2.4.1 *Allowable Load* — The load which may be applied to a pile after taking into account its ultimate load capacity, group effect, the allowable settlement, negative skin friction and other relevant loading conditions including reversal of loads, if any.

2.4.2 *Anchor Pile* — An anchor pile means a pile meant for resisting pull or uplift forces.

2.4.3 *Batter Pile* (*Raker Pile*) — The pile which is installed at an angle to the vertical using temporary casing or permanent liner.

2.4.4 *Bored Cast In-Situ Pile* — Piles formed by boring a hole in the ground by percussive or rotary method with the use of temporary/permanent casing or drilling mud and subsequently filling the hole with reinforced concrete.

2.4.5 *Bored Compaction Pile* — A bored cast *in-situ* pile with or without bulb(s) in which the reinforcement cage is driven by suitable method in the freshly filled concrete in the bore. If the pile is with bulb(s), it is known as under-reamed bored compaction pile.

2.4.6 *Bored Pile* — A pile formed with or without casing by excavating or boring a hole in the ground and subsequently filling it with plain or reinforced concrete.

2.4.7 *Cut-off Level* — It is the level where a pile is cut-off to support the pile caps or beams or any other structural components at that level.

2.4.8 *Driven Cast in-situ Pile* **—** The pile formed within the ground by driving a casing of uniform diameter, or a device to provide enlarged base and subsequently filling the hole with reinforced concrete. For displacing the subsoil the casing is driven with a plug or a shoe at the bottom. When the casing is left permanently in the ground, it is termed as cased pile and when the casing is taken out, it is termed as uncased pile. The steel casing tube is tamped during its extraction to ensure proper compaction of concrete.

2.4.9 *Efficiency of a Pile Group* — It is the ratio of the actual supporting value of a group of piles to the supporting value arrived at by multiplying the pile resistance of an isolated pile by their number in the group.

2.4.10 *Initial Load Test* — A test pile is tested to determine the load carrying capacity of the pile by loading either to its ultimate load or to twice the estimated safe load.

2.4.11 *Negative Skin Friction* — Negative skin friction is the force developed through the friction between the pile and the soil in such a direction as to increase the loading on the pile, generally due to drag of a consolidating soft layer around the pile resting on a stiffer bearing stratum such that the surrounding soil settles more than the pile.

2.4.12 *Pile Spacing* **—** The spacing of piles means the centre to centre distance between adjacent piles.

2.4.13 *Precast Concrete Piles in Prebored Holes —* A pile constructed in reinforced concrete in a casting yard and subsequently lowered into prebored holes and the annular space around the pile grouted.

2.4.14 *Precast Driven Pile* — The pile constructed in concrete in a casting yard and subsequently driven into the ground when it has attained sufficient strength.

2.4.15 *Routine Test* — Test carried out on a working pile with a view to check whether pile is capable of taking the working load assigned to it without exceeding permissible settlement.

2.4.16 *Safe Load* **—** It is the load derived by applying a factor of safety on the ultimate load capacity of the pile/pile group or as determined from load test.

2.4.17 *Ultimate Load Capacity* — The maximum load which a pile can carry before failure, that is, when the founding strata fails by shear as evidenced from the load settlement curve or the pile fails as a structural member.

2.4.18 *Under-Reamed Pile* — A bored cast *in-situ* or bored compaction concrete pile with enlarged bulb(s) made by either cutting or scooping out the soil or by any other suitable process.

An under-reamed pile having more than one bulb is termed as multi under-reamed piles. The piles having two bulbs may be called double under-reamed piles.

2.4.19 *Working Load* — The load assigned to a pile as per design.

2.4.20 *Working Pile* — A pile forming part of the foundation system of a given structure.

2.5 Combined Piled-Raft Foundations

2.5.1 *Allowable Load* **—** The load which can be applied on the combined pile-raft foundation system by taking into account the load capacities of piles and raft, soil-pile-raft interaction effects and allowable displacement from serviceability criteria, negative skin friction on pile and other relevant loading types including reversal of loads, if any. In other words, it is the load at which the allowable settlement reduction ratio considering serviceability is achieved.

2.5.2 *Angular Distortion* ($\boldsymbol{\theta}$) **—** Vertical distance after deformation due to applied load between the points of maximum and minimum settlement divided by the horizontal distance between the two points (*see* Fig. 1).

2.5.3 *Combined Piled Raft Foundation* **—** A pile group in which the raft connecting all the pile heads positively contributes to the overall foundation behaviour. The presence of raft is recognized and its contribution in sharing the load with the pile group is taken into account. This composite foundation which combines load carrying capabilities of raft and pile foundations together, considers four interactions, namely, pile-pile interaction, pile-soil interaction, pile-raft interaction and raft-soil interaction [*see* Fig. 2(A)].

2.5.3.1 *Large CPRF* **—** CPRF in which the ratio of raft width (Br) to pile length (Lp) is greater than 1, that is, $\frac{B_r}{L_p} > 1$.

2.5.3.2 *Small CPRF* **—** CPRF in which the ratio of raft width (Br) to pile length (Lp) is less than or equal to 1, that is, $\frac{B_r}{L_p} \leq 1$.

2.5.4 *Cut-off Level* **—** The level where a pile is cut-off in order to make structural connection to the pile caps or beams or raft or any other structural component at that level.

2.5.5 *Design Load* — The loads (compression, tension, lateral, moment or any combination thereof) considered to act on the CPRF during the life of the structure satisfying provisions mentioned in other relevant Indian Standards.

2.5.6 *Design Stress* — The stress (compressive, tensile or combination) imposed on the CPRF by the design load and calculated in accordance with engineering practice.

2.5.7 *Differential Settlement of CPRF* (*Spr*, *Diff*) — The difference between the maximum and the minimum settlement, across any section of the CPRF (*see* Fig. 1).

2.5.8 *Limiting Capacity* — The vertical load at which for a CPRF, bearing capacity failure occurs due to exceedance of the combined capacity of raft resistance and that of piles in terms of shaft resistance and end bearing resistance. The assessed value of the total resistance Rtot,k(s) of the CPRF depends on the settlements of the foundation and consists of the sum of the assessed pile resistances $\Sigma Rpile{,}k{,}j$ (s) and the assessed raft resistance, Rraft,k (s) [*see* Fig. 2(A)]. The assessed raft resistance results from the integration of the settlement dependent contact pressure, $\sigma(s,\, x,\, y)$ in the ground plan area of the raft and can be expressed as, $Rraft{,}k(s) = \iint \sigma(s,\, x,\, y)dxdy$. Similarly, due considerations for horizontal load capacity and moment capacity should be considered for the CPRF system.

2.5.9 *Load Eccentricity* (*eL or eB*) — Distance between the point of application of applied resultant load and the centre of gravity of the pile-raft system along length and width, respectively (*see* Fig. 1).

2.5.10 *Maximum CPRF Settlement* (*Spr*, *Max*) — The maximum value of settlement occurred at a particular point of the CPRF system (*see* Fig. 1).

2.5.11 *Pile-Pile Interaction* — The result of pile group effect, defined as the changes in the load-displacement response of a pile group and single piles due to superimposition of stress and displacement field of a single pile in a group [*see* Fig. 2(A)].

2.5.12 *Pile-Raft Interaction* — The changes in the load-displacement response of pile group when the raft is being rested to the soil surface [*see* Fig. 2(A)].

2.5.13 *Pile-Raft Coefficient or Load Sharing Ratio* (α_{CPRF}) — The ratio between the sum of the pile resistances and the value of the total resistance.

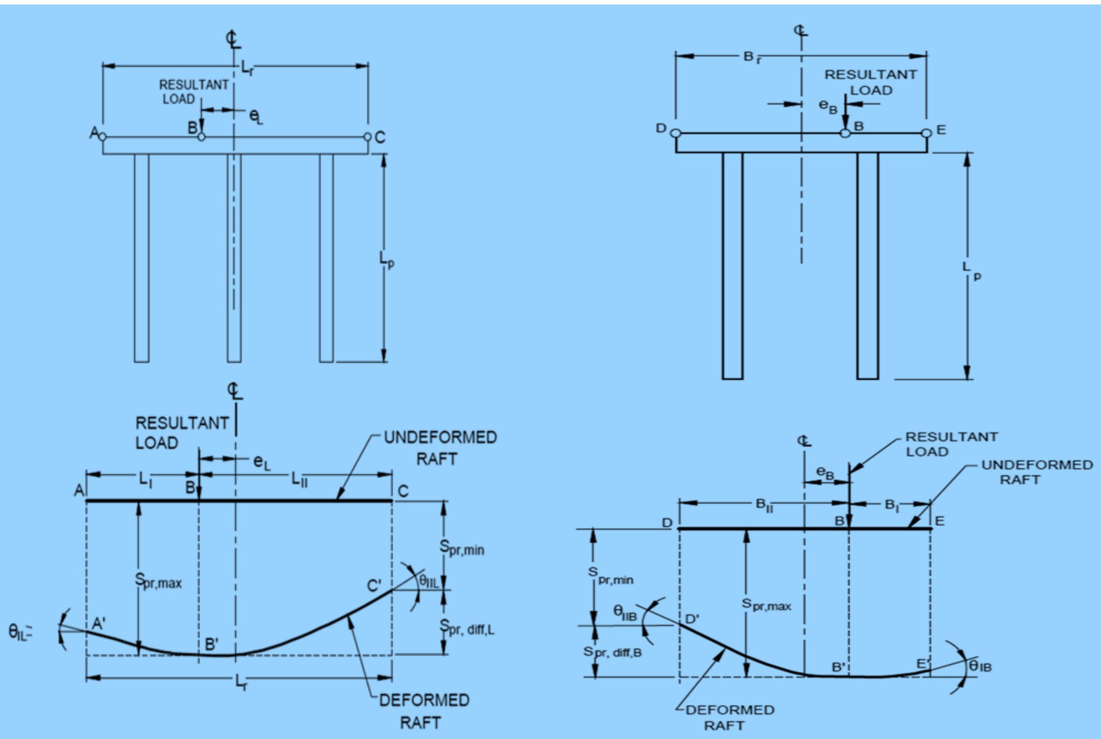
NOTE — $\alpha_{\mathrm{CPRF}} = \frac{R_{\mathrm{piles}}}{R_{\mathrm{total}}}$, in which R_{piles} is the resistance provided by piles and R_{total} is the total resistance provided by the CPRF system under vertical load as shown in Fig. 2(B). Whenever, α_{CPRF} is equal to 1, all the vertical loads are taken up by the pile component which essentially makes the system to behave as a pile group foundation. Whereas, α_{CPRF} equals to zero indicates that the vertical loads are borne by raft component, hence, the foundation behaviour will be like spread raft foundation. To utilize both the foundation components effectively, the value of α_{CPRF} should be chosen carefully and the standard is not valid for $\alpha_{\mathrm{CPRF}} \geq 0.9$.

2.5.14 *Pile-Enhanced Raft* — CPRF in which the piles are designed to mobilize their total ultimate capacity and the raft carries majority of the design load [*see* Fig. 3(A)].

2.5.15 *Raft-Pile Interaction* — The modification in the load carrying mechanism of the raft when piles are introduced beneath [*see* Fig. 2(A)]

2.5.16 *Raft-Enhanced Pile* — CPRFs in which both the piles and raft work within a pseudo-elastic range of behaviour. The pile group capacity is not fully mobilized at working load and the pile group carries majority of the design load [*see* Fig. 3(B)].

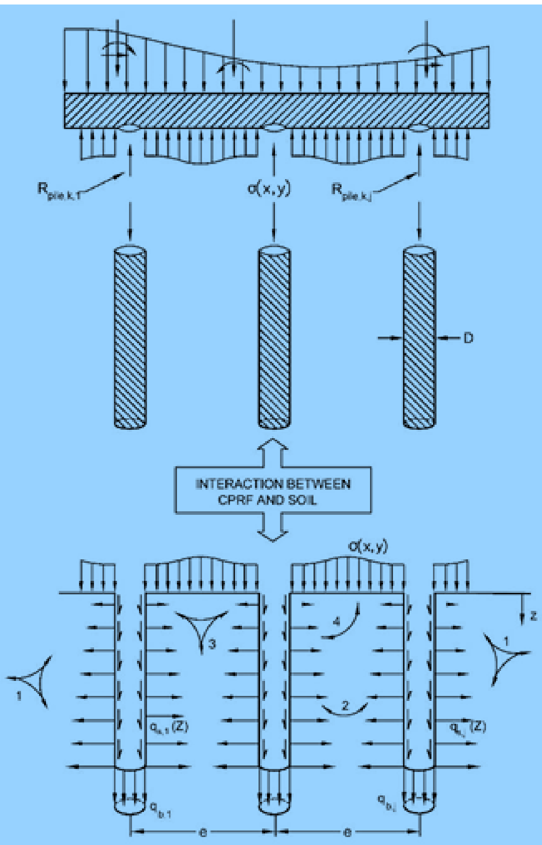
2.5.17 *Settlement Reduction Ratio* (*SRR*) — The ratio of the difference of settlement of the unpiled raft under the given loading, Sr and the settlement of the piled raft under the same loading considered in the case of the unpiled raft, S_{pr} to the settlement of the unpiled raft, that is, under any given loading conditions, SRR $= \frac{(S_{\mathrm{r}} - S_{\mathrm{pr}})}{S_{\mathrm{r}}}$.



℄
L_r
RESULTANT LOAD
e_L
A
B
C
L_p
RESULTANT LOAD
e_L
UNDEFORMED RAFT
A
L_I
B
L_{II}
C
$S_{pr,min}$
$S_{pr,max}$
C'
θ_{IIL}
θ_{IL}
A'
B'
$S_{pr,diff,L}$
L_r
DEFORMED RAFT
B_r
RESULTANT LOAD
e_B
D
B
E
L_p
RESULTANT LOAD
UNDEFORMED RAFT
e_B
B_{II}
B_I
D
B
E
$S_{pr,min}$
$S_{pr,max}$
θ_{IIB}
D'
$S_{pr,diff,B}$
B'
E'
θ_{IB}
DEFORMED RAFT

FIG. 1(A) ALONG RAFT LENGTH FIG.1(B) ALONG RAFT WIDTH

FIG.1 SCHEMATIC REPRESENTATION OF CPRF SYSTEM AND VARIOUS PARAMETERS FOR DESIGN CONSIDERATION BASED ON SERVICEABILITY LIMIT STATE


$R_{pile,k,1}$
σ(x,y)
$R_{pile,k,j}$
D
INTERACTION BETWEEN CPRF AND SOIL
σ(x,y)
z
1
3
4
1
2
$q_{s,1}(Z)$
$q_{s,j}(Z)$
$q_{b,1}$
$q_{b,j}$
e
e

Key

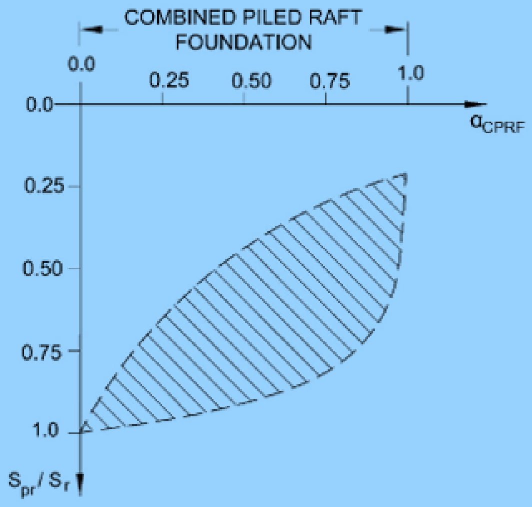
1 Pile-soil interaction

2 Pile-pile interaction

3 Raft-soil interaction

4 Pile-raft interaction

FIG. 2A SOIL-STRUCTURE INTERACTION



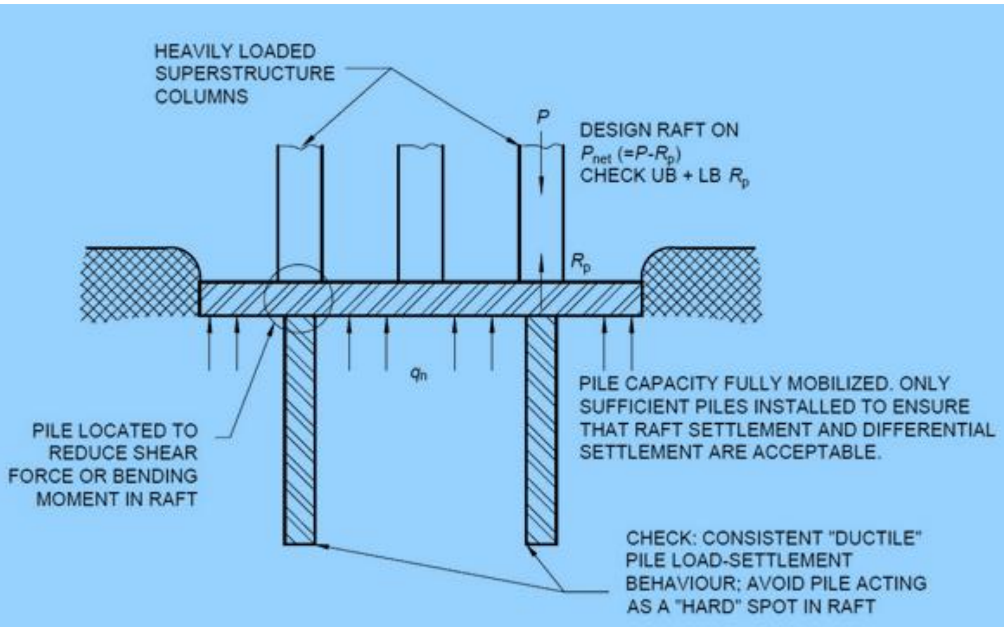
Key

S_{pr} Settlement of combined piled raft foundation

S_r Settlement of raft foundation

FIG. 2B TYPICAL VARIATION OF α_{CPRF} WITH SETTLEMENT RATIO

FIG. 2 SOIL-STRUCTURE INTERACTION AND VARIATION OF α_{CPRF} FOR ACPRF


HEAVILY LOADED SUPERSTRUCTURE COLUMNS
P
DESIGN RAFT ON P_{net} (=P-R_p) CHECK UB + LB R_p
R_p
q_n
PILE CAPACITY FULLY MOBILIZED. ONLY SUFFICIENT PILES INSTALLED TO ENSURE THAT RAFT SETTLEMENT AND DIFFERENTIAL SETTLEMENT ARE ACCEPTABLE.
PILE LOCATED TO REDUCE SHEAR FORCE OR BENDING MOMENT IN RAFT
CHECK: CONSISTENT "DUCTILE" PILE LOAD-SETTLEMENT BEHAVIOUR; AVOID PILE ACTING AS A "HARD" SPOT IN RAFT

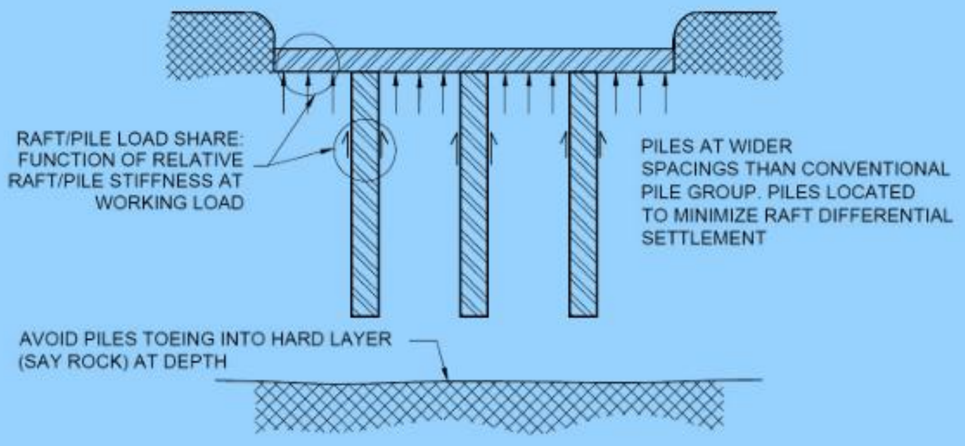
Key

q_n	Net contact stress on underside of raft
P	Column load
R_P	Pile capacity
UB	Upper bound
LB	Lower bound

Favourable ground conditions — Deep deposits of homogenous clays; typically stiff clays at raft level.

Typical design scenario — A raft which does not quite work, a small number of piles are added to resolve local non-compliances (for example, differential settlement, shear or bending moment).

FIG. 3A PILE-ENHANCED RAFT


RAFT/PILE LOAD SHARE: FUNCTION OF RELATIVE RAFT/PILE STIFFNESS AT WORKING LOAD
PILES AT WIDER SPACINGS THAN CONVENTIONAL PILE GROUP. PILES LOCATED TO MINIMIZE RAFT DIFFERENTIAL SETTLEMENT
AVOID PILES TOEING INTO HARD LAYER (SAY ROCK) AT DEPTH

Favourable ground conditions — Competent soils at raft level (stiff clays, dense sands) and depth; interbedded sands/clays.

Typical design scenario — A value-engineered pile group, often the raft was provided as a pile cap, but is then used to provide significant capacity.

FIG. 3B RAFT-ENHANCED PILE

FIG. 3 PILE-ENHANCED RAFT AND RAFT-ENHANCED PILE

3 SITE INVESTIGATION

3.1 General

3.1.1 Site investigation is essential in determining the physical, chemical and engineering properties of subsoil to arrive at the required foundation system. However, in areas which have already been developed, information may be obtained regarding the existing local knowledge, records of trial pits, boreholes, etc, in the vicinity and the behaviour of the existing structures, particularly those of a similar nature to those proposed. This information may be made use of for design of foundation of lightly loaded structures of not more than two storeys and also for deciding the scope of further investigation for other structures.

3.1.2 If the existing information is not sufficient or is inconclusive, the proposed site should be explored in detail as per good practice [C-2(1)], so as to obtain a knowledge of the type, uniformity, consistency, thickness, sequence and dip of the strata, hydrology of the area and also the engineering properties. In the case of lightly loaded structures of not more than two storeys the tests required to obtain the above information are optional, mainly depending on site conditions.

3.1.3 *Geotechnical Engineering Services*

Geotechnical engineering services encompass the entire process of understanding ground conditions and providing reliable inputs for civil engineering works. They include site reconnaissance, planning and execution of field and laboratory investigations and interpretation of soil and rock behaviour for safe and economical design. The services also define the roles of the Appointing Authority (AA), Geotechnical Consultant (GC) and Geotechnical Investigation Agency (GIA), along with structured models of appointment — Model 1, where GC and GIA are appointed separately and Model 2, where GC is appointed and may additionally act as GIA. These provisions cover both pre-construction and interlinked construction stage activities, ensuring that the design and execution of works are based on sound geotechnical data and professional judgement.

A clear distinction is laid down between geotechnical factual reports (GFR), which document the results of investigations and geotechnical interpretive reports (GIR), which provide engineering analysis and design recommendations. The framework specifies minimum qualifications and experience requirements for team leaders to promote competence and accountability, while also incorporating provisions on safety, quality assurance, quality control and declarations against conflict of interest. Together, these measures strengthen transparency, consistency and technical integrity in geotechnical practice. Reference may be made to the good practice [C-2(2)] for more detail.

3.2 Stages of Subsurface Investigation

3.2.1 The stages of subsurface investigation are:

a) site reconnaissance;

b) preliminary investigation;

c) detailed investigation;

d) construction stage investigation; and

e) post-construction stage investigation.

3.2.2 *Site Reconnaissance*

3.2.2.1 Site reconnaissance would help in deciding future programme of field investigations, that is, to assess the need for preliminary and/or detailed investigations.

This would also help in determining scope of work, methods of exploration to be adopted, *in-situ* tests to be carried out and administrative arrangements required for the investigation. Where detailed information on the geotechnical conditions is not available, an inspection of site and study of topographical features are helpful in getting information about soil, rock and ground-water conditions. Site reconnaissance includes a study of local topography, excavations, ravines, quarries, escarpments; evidence of erosion or landslides, behaviour of existing structures at or near the site; water level in streams, water courses and wells; flood marks; nature of vegetation; drainage pattern, location of seeps, springs and swamps, evidence of expansive soils. Information on some of these may be obtained from topographical maps, geological maps, pedological and soil survey maps, vicinity maps, metrological data and digitized images.

3.2.2.2 Data regarding removal of overburden by excavation, erosion or landslides should be obtained. This gives an idea of the amount of pre-consolidation the soil strata have undergone. Similarly, data regarding recent fills is also important to study the consolidation characteristics of the fill as well as the original strata.

3.2.2.3 The type of flora affords at times some indication of the nature of the soil. The extent of swamp and superficial deposits and peats will usually be obvious. In general, such indications, while worth noting, require to be confirmed by actual exploration.

3.2.2.4 *Ground-water conditions*

The ground-water level fluctuates and will depend upon the permeability of the strata and the head causing the water to flow. The water level in streams and water courses, if any, in the neighbourhood, should be noted, but it may be misleading to take this as an indication of the depth of the water table in the ground. Wells at the site or in the vicinity give useful indications of the ground-water conditions. Flood marks of rivers may indicate former highest water levels. Tidal fluctuations may be of importance. There is also a possibility of there being several water tables at different levels, separated by impermeable strata and some of this water may be subject to artesian head. It is also important to collect water samples to check its suitability for construction purpose and any treatment of foundation required for corrosion protection.

3.2.2.5 *Enquiries regarding earlier use of the site*

In certain cases, the earlier uses of the site may have a very important bearing on proposed new works. This is particularly so in areas, where there have been underground workings, such as worked-out ballast pits, quarries, old brick fields, coal mines and mineral workings. Enquiries should be made regarding the location of shafts and workings, particularly shallow ones, where there may be danger of collapse, if heavy new structures are superimposed.

The possibility of damage to sewers, conduits and drainage systems by subsidence should also be investigated.

3.2.3 *Preliminary Investigation*

The purpose of preliminary investigation is to assess the feasibility of a project. The preliminary investigation includes determination of approximate depth, thickness, extent and composition of sub-strata, ground water table and also to obtain approximate information regarding strength and compressibility of the various strata. The preliminary investigation comprises boreholes with standard penetration test (SPT), collection of disturbed samples (DS), undisturbed samples (UDS), dynamic cone penetration test (DCPT), trial pits and laboratory testing. Geophysical investigation may also be carried out during the preliminary investigation to establish the sequence of layers, their approximate properties, depth of bedrock, etc.

3.2.4 *Detailed Investigation*

Planning of detailed investigation is generally based on the information obtained in the preliminary investigation. The objective is to find the sequence of various layers, thickness of the layers, ground water table and detailed engineering properties of each layer. Detailed investigation involves *in-situ* (field) testing and laboratory testing. The *in-situ* tests are described in 3.4. Laboratory testing on soil/rock/water samples collected from the site is carried out to determine the index, physical, engineering and chemical properties as given in 3.5.7. The type and number of tests shall depend upon the nature of the project, geology of the area and site conditions.

3.2.5 *Construction Stage Investigation*

During construction, there may be a requirement of additional investigation to overcome the difficulties/modifying the foundation system due to change in subsoil/ground water conditions. The type of test required shall be selected from those specified under detailed investigation.

3.2.6 *Post-construction Stage Investigation*

At times, in order to study the behaviour/strengthening of substructure/foundation, investigation may be required.

3.3 Subsurface Exploration

The subsurface exploration includes the following:

- a) Geophysical investigation;
- b) Trial pits;
- c) Subsurface soundings;
- d) Boring in soil;
- e) Core drilling in rock; and
- f) Location and depth of investigation.

3.3.1 *Geophysical Investigation*

The geophysical investigation includes measurement of physical properties of the ground based on which the type of strata and depth of strata can be approximately evaluated. These tests provide a quick means of getting useful information about the stratification and underground utilities. This will enable to plan the depth/extent of the *in-situ* tests and type of test to be carried out *in-situ* and in the laboratory. The method provides only approximate parameters about the strata which need to be confirmed by conducting detailed investigation. These methods may be employed to get preliminary information on stratigraphy or complement a rationalized boring programme by correlation of stratigraphy between widely spaced boreholes. Commonly adopted geophysical tests are given in Table 1.

Table 1 Geophysical Tests

(*Clause* 3.3.1)

Sl No. (1)	Type of Test (2)	Property Measured (3)
i)	Electrical resistivity test (ERT)	Electrical resistivity
ii)	Seismic refraction test (SRT)	Primary wave velocity
iii)	Cross hole seismic test (CHST) and down hole seismic test (DHST)	Shear wave velocity
iv)	Spectral analysis of surface wave (SASW) and multi-channel analysis of surface wave (MASW)	Primary/Shear wave velocity
v)	Ground penetrating radar survey (GPR survey)	Electromagnetic intensity (resistivity)
vi)	Thermal resistivity test	Thermal conductivity

3.3.2 *Trial Pit*

This method consists of excavating a pit at the site and thereby exposing the strata. This enables visual inspection of the strata, collection of disturbed/undisturbed samples and carrying out *in-situ* tests. Generally, trial pits are excavated up to 4 m depth below the ground level.

Minimum dimension of the pit shall be such that there is an adequate working space for excavation and carrying out sampling/testing. Generally, the pits have planned dimensions varying from 1 m × 1 m up to 3 m × 3 m depending on the depth required.

After the pit is excavated, the details of the strata shall be recorded with the description of each layer with thickness and ground water table, if any. After collecting the samples/in-situ testing, the pit shall be backfilled with the same excavated material. Arrangement shall be made for dewatering below ground water table. Precautions shall be taken to prevent surface water draining into the trial pit.

3.3.3 *Subsurface Soundings*

Subsurface soundings provide quick means to get continuous resistance against penetration indicating compactness of the strata. The following sounding tests are generally carried out:

a) Dynamic cone penetration test;

b) Static cone penetration test; and

c) Static cone penetration test using piezocone with pore water pressure measurement.

The limitation of soundings is that samples cannot be collected. In addition, strata having stones, gravels, boulders, etc and stiff formations cannot be penetrated by sounding device.

3.3.4 *Boring in Soil*

Various techniques are available for boring in soil depending on the substrata and depth of investigation. Commonly used boring methods are given below and described in **3.3.4.1** to **3.3.4.4**.

a) Auger boring;

b) Shell and auger boring;

c) Rotary boring; and

d) Percussion drilling.

In general, the diameter of the borehole is about 100 mm to 150 mm. In boreholes, in-situ testing like standard penetration test along with collection of disturbed and undisturbed samples at regular depth intervals and at change of strata is carried out. Other *in-situ* tests may also be carried out in the boreholes as per requirements.

In order to prevent caving in of soil during boring, stabilizing fluid like bentonite slurry/temporary steel casing or combination of both should be used.

The bottom of the borehole shall be cleaned prior to sampling/testing at different levels.

3.3.4.1 *Auger boring*

An auger is either power or hand operated with periodic removal of cuttings. The bore profile is prepared based on physical observation of the cut material removed from auger.

The process is slow in case of manual operation. Hand operated auger is generally used for boring up to a depth of 6 m. Casing is not used in this method. The method is convenient considering ease of mobilization. The auger is used in soil where borehole stands unsupported. Auger is penetrated into the ground for a depth of about 300 mm to 600 mm and the auger is withdrawn for removing the cuttings. The auger is then reintroduced to extend the borehole.

3.3.4.2 *Shell and auger boring*

Shell and auger boring is adopted for deep boreholes. The equipment consists of auger and a shell (bailer) for boring, connected with steel wire ropes/drilling rods which are lowered/raised with the help of tripod and mechanical winch. The casing is lowered in the borehole by rotating/pushing to the required depth.

The auger is generally used up to the ground water table level followed by shell.

The shell is raised/lowered repeatedly to cut the soil at the bottom and the cut material collected in the shell is removed. In stiff cohesive soil, it may be necessary to soak the borehole while boring above the ground water table. Where ground water is encountered, the water level in the borehole shall always be maintained at or above the water table.

The method is efficient to drill in hard strata but may disturb the soil at the bottom of the borehole. The method should be adopted with caution to minimize disturbances in the soil, prior to sampling/testing.

3.3.4.3 *Percussion drilling*

This method should only be used for drilling boreholes in bouldery and gravelly strata where other boring methods become ineffective.

In this method, the formation is pulverized/broken by repeated blows using a bit or a chisel. Water should be added at the time of boring and the cuttings are bailed out at intervals. The bit/chisel is suspended by a cable or rods from a hoist.

As this method involves repeated dropping of a heavy chisel and can disturb the strata considerably, it is preferable that at least 0.5 m above the level of sampling/testing, the use of percussion method shall be discontinued and the borehole advanced/cleaned with shell or any other suitable method till the sampling depth has reached.

3.3.4.4 *Rotary boring*

In this method, boring is advanced by the cutting action of a rotating bit which should be kept in firm contact with the bottom of the hole. The bit is connected at the end of hollow, jointed drill rods which are rotated by a suitable chuck. Water/stabilizing fluid like bentonite slurry is pumped continuously down the hollow drill rods and the fluid returns to the surface through the annular space between the rods and the side of the hole and the casing may not be generally required. This method can be used in all type of strata.

3.3.5 *Core Drilling in Rock*

Core drilling in rock shall be carried out with rotary hydraulic rig using diamond-tipped bit (*see* Note) as per good practice [C-2(3)]. The core drilling equipment shall conform to accepted standard [C-2(4)]. Drilling shall be carried out with NX/HX size diamond-tipped drill bits or impregnated diamond bit depending on the type of rock formation. Double tube core barrel with core lifter shall be used. The diamond bit is attached to double tube core barrel with reaming shell. The bit cuts an annular groove into the formation and the inner core formed by the groove enters into the inner barrel as a core sample. The circulating fluid is injected through the annular gap between the outer barrel and inner barrel and hence the fluid does not come in contact with the core received in the barrel. This prevents damage to the core by washing out of the loose particles in the joints (if any) and improves both core recovery and rock quality designation (RQD). After advancing the core barrel, the barrel is withdrawn, the rock cores are removed by detaching the core cutter, reassembled and introduced back in the borehole for further coring. Indexing and storage of drill cores shall be in accordance with good practice [C-2(5)].

NOTE — Tungsten carbide bit may be used for rocks like, shale, siltstone and claystone.

The drilling rig shall have necessary facilities to regulate the spindle speed, bit pressure and water pressure during core drilling to get good core recovery.

The rotational speed of the bit (spindle speed), the amount of downward pressure applied on the bit (bit pressure) and water pressure shall be suitably adjusted and properly monitored so that the core is collected with least disturbance and avoid shearing of the core from its base.

Drilling run should be 0.75 m in length. This can be increased up to 1.5 m run in case core recovery is more than 50 percent in two successive 0.75 m drill runs. If the core recovery is nil, then SPT shall be performed before commencing the next drill run.

If at any time a blocking of the bit or grinding of the core is indicated, the core barrel shall be immediately withdrawn from the borehole regardless of the length of drill run completed.

3.3.6 *Location and Depth of Investigation*

3.3.6.1 The location and depth of investigation points shall depend upon the type of structure/building considering variation in substrata based on the preliminary subsurface investigation or available geotechnical data in an already developed site. The investigation points should be arranged in such a pattern that the stratification can be assessed across the site. The guidelines as specified in **3.3.6.2** and **3.3.6.3** may be adopted for deciding the location and depth of boreholes/trial pits and other *in-situ* tests.

3.3.6.2 *Disposition of Boreholes/Trial Pits*

The guidelines for disposition of boreholes/trial pits are given in Table 2. In case significant variation in stratification is observed, additional boreholes/tests, as required may be carried out.

Table 2 Disposition of Borehole/Trial Pit

(*Clause* 3.3.6.2)

Sl No. (1)	**Type of Structure/Buildings** (2)	**Location of Borehole/Trial Pit** (3)
i)	For lightly loaded residential building (such as single/double storeyed building)	At least one borehole/trial pit in the centre of the building (*see* Note)
ii)	For building(s) in a site covering an area of about 0.4 hectares	At least one borehole in each corner and one in the centre
iii)	a) For structure/building having any of the plan dimensions exceeding 50 m b) For multiple buildings in a site covering an area of more than 0.4 hectares c) For multistoried buildings and structure of height less than and equal to 50 m	Boreholes in a grid pattern with points at not more than 50 m distance, subject to a minimum of two boreholes. Boreholes should cover built-up areas.
iv)	For multistoried buildings and structure of height more than 50 m	Minimum three boreholes at each building/structure
v)	Linear structures (roads, railways, embankments, pipelines, boundary walls, tunnels, retaining walls, transmission lines, etc)	Boreholes at a spacing of 50 m to 500 m. In highly erratic substrata, spacing may be suitably reduced. In uniform substrata, the spacing may be suitably increased.
vi)	Solar power plant	One borehole for every 2 to 5 hectares subject to a minimum of 5 boreholes per site

NOTE — Boreholes are preferred over trial pits.

3.3.6.3 *Depth of Investigation*

3.3.6.3.1 The depth of investigation shall be adequate enough to provide necessary data for estimating safe bearing capacity and settlement. In general, the investigation shall be carried out to a minimum depth to which the increase in stress level due to the foundation load is lesser than 10 percent of the in-situ stress level.

The depth of investigation also depends on the risk induced by the presence of weaker formations below the influence zone to be stressed due to the proposed construction.

3.3.6.3.2 The following guidelines may be followed for adopting the depth of investigation:

a) *Shallow foundation* (*other than raft foundations*) *in soil* —The depth of investigation shall be up to 2 to 3 times the estimated width of the largest foundation below the expected founding level;

b) *Raft foundation* (*minimum foundation width equal to 6 m for the purpose of investigation*) *in soil* — In case of raft foundation, the depth of investigation shall be up to 1.0 to 2.0 times the width of the raft foundation below the expected founding level;

c) *Pile foundation in soil* — The depth of investigation shall be sufficiently below the expected founding level of piles but this should not be less than 5 m or 5 times the diameter of piles, whichever is more beyond the estimated pile termination level;

d) *Embankments* — The depth of investigation shall be 1.0 to 2.0 times the height of the embankment;

e) *Well foundation in soil* — The depth of investigation in the case of well foundation shall be 1.5 to 2.0 times the width/diameter of the well from the estimated termination level of the well; and

f) *Penetration into rock* — In case rock formation is encountered prior to the termination depth of boreholes as stipulated in (a) to (e) above, the boreholes may be extended by minimum 5 m in rock strata depending upon rock characteristics and project requirements.

NOTE — The depth of investigation may be suitably arrived as per the specific requirements for any other foundation/substructure.

3.3.6.4 *Other in-situ tests*

The location and depth of investigation for other *in-situ* tests shall be as per the requirements.

3.4 *In-Situ* Testing

In-situ tests provide information about the strength and deformability characteristics of the strata. Following are the *in-situ* tests which may be conducted depending on the nature of the strata and project requirements:

a) Standard penetration test (SPT);
b) Vane shear test (VST);
c) Pressuremeter test (PMT);
d) Plate load test (PLT);
e) Cyclic plate load test (CPLT);
f) Block vibration test (BVT);
g) Dynamic cone penetration test (DCPT);
h) Static cone penetration test (SCPT);
j) Piezocone with pore pressure measurement (CPTu);
k) Flat dilatometer test (DMT);
m) Electrical resistivity test (ERT);
n) Seismic refraction test (SRT);
p) Down hole, up-hole and cross hole seismic test (CHST);
q) Spectral analysis of surface wave (SASW) and multi-channel analysis of surface wave (MASW) test;
r) Ground penetrating radar (GPR) survey;
s) Thermal resistivity test;
t) *In-situ* permeability test;
u) Modulus of subgrade reaction;
v) Field california bearing ratio test (CBR); and
w) Optical and acoustic tele-viewer methods.

3.4.1 *Standard Penetration Test*

Standard penetration test (SPT) shall be conducted in all type of soil deposits to determine the resistance of soil at any depth in a bore hole and to recover disturbed soil sample for laboratory testing/identification purpose.

The basis of the test consists of driving a split spoon sampler by dropping a hammer of 63.50 kg ± 0.50 kg mass onto an anvil or drive head from a height of 750 mm ± 10 mm. The number of blows necessary to achieve 300 mm penetration of the sampler after the seating penetration of 150 mm is the penetration resistance. The test shall be conducted in accordance to good practice [C-2(6)]. In this test, the drive weight assemblies namely:

a) safety hammer with inner guide rod assembly and concealed anvil over which the hammer strikes;

b) do-nut hammer or safety hammer equipped with auto trip mechanism; and

c) automatic hammer system with the housing are preferred for consistent transfer of energy in each strike.

Hammer drop system used for lifting and dropping during the test shall be either mechanical auto-trip system or fully automated system in order to minimize human error. Rope and cat-head mechanism shall be used only when the other systems namely. mechanical auto trip system/fully automated system are not practicable. The depth interval between the bottom of the test and next undisturbed sampling/testing shall not be less than 500 mm.

3.4.2 *Vane Shear Test*

Field vane shear test shall be performed inside the borehole to determine the shear strength of cohesive soils, especially in soft clays which are highly susceptible to sampling disturbance, in accordance with good practice [C-2(7)].

3.4.3 *Pressuremeter Test*

The test is carried out to determine the *in-situ* stress-strain characteristics of the substrata. The test involves positioning of a radially expandable probe at the desired depth in a borehole and applying increments of pressure to inflate the probe thus applying increasing radial stresses on the substrata in the walls of the borehole and measuring the volumetric deformations at different pressure increments. Applied pressure *versus* volumetric deformation is plotted and analyzed. Further details regarding the test are given in good practice [C-2(8)].

3.4.4 *Plate Load Test*

Plate load test shall be conducted to determine the load/settlement characteristics of the substrata. The specifications for the equipment and accessories required for conducting the test, the test procedure, field observations and reporting of results shall conform to accepted standard [C-2(9)].

3.4.4.1 *Test for determination of modulus of subgrade reaction*

Modulus of subgrade reaction shall be determined in accordance with accepted standard [C-2(10)].

3.4.5 *Cyclic Plate Load Test*

This test shall be carried out to determine the dynamic soil properties required for the analysis of foundation subjected to dynamic loads. This test shall be conducted on similar lines as the ordinary plate load test. In addition, unloading shall also be done before each stage of loading. Test set up, load increment, maximum load intensity, recording of field data, etc shall be as per accepted standards [C-2(11)].

After each stage of loading, the load shall be removed in a minimum of two stages. After each stage of reduction of load, dial gauge readings and settlements shall be taken for at least one hour until the readings stabilize. There after the next loading stage shall commence. Analysis of test data shall be reported in accordance with accepted standard [C-2(12)].

3.4.6 *Block Vibration Test*

This test shall be carried out in accordance with accepted standard [C-2(12)] to determine the dynamic soil properties required for the analysis of foundation subjected to dynamic loads.

A test pit of suitable size depending upon size of block should be made. The size of the pit may be 3 m × 6 m at the bottom and a depth preferably equal to proposed depth of foundation. The test should be conducted above the ground water table. In case of rock, the test may be performed on the surface of rock bed itself. The bottom of the pit should be levelled. Side slopes of the pit should be stable. Analysis of test data shall be reported as per accepted standard [C-2(12)].

3.4.7 *Dynamic Cone Penetration Test* (*DCPT*)

Dynamic cone penetration test is a method of sub surface sounding, wherein a continuous record of soil resistance is obtained from of the ground to the depth below by driving a cone. Dynamic cone penetration test shall be conducted either as per accepted standard [C-2(13)] or as per [C-2(14)], as required. The test shall be conducted up to the required depth; however, in order to avoid damage to the equipment, driving may be stopped when the number of blows exceeds 35 mm for 100 mm penetration when the cone is driven dry {*see* accepted standard [C-2(13)]} and 20 mm for 100 mm penetration when the cone is penetrated by circulating slurry {*see* accepted standard [C-2(14)]}. The specification for the equipment and accessories required for performing this test, procedure, field observations and reporting of results shall be in accordance with accepted standard [C-2(13)] or as per [C-2(14)], as applicable. For gravelly deposits (gravel size 100 mm to 120 mm), DCPT may be conducted as per good practice [C-2(15)].

3.4.8 *Static Cone Penetration Test* (*SCPT*)

Static cone penetration test is conducted to record the continuous *in-situ* penetration resistance of soils below the ground level. The specification for the equipment and accessories required for performing the test procedure, field observations and reporting of results shall be in accordance with accepted standard [C-2(16)].

3.4.9 *Static Cone Penetration Test using Piezocone with Pore Water Pressure Measurement* (*CPTu*)

The test is used to record the continuous *in-situ* penetration resistance, frictional resistance along with pore water pressure during penetration at the level of the base of the cone. For CPTu, all measurements shall be made by sensors contained in penetrometer.

The cone shall be pushed into the soil at a constant rate of penetration.

Test performed using this test method provide a detailed record of cone penetration which is useful for evaluation of site stratigraphy, homogeneity, voids or cavities and other discontinuities. The use of friction sleeve and porewater pressure element can provide an estimate of preliminary soil classification and correlations with engineering properties of soils.

NOTE — The test procedure, field observation and reporting of result may be referred from international standards.

3.4.10 *Flat Dilatometer Test* (*DMT*)

The test is used to determine *in-situ* strength and deformation properties of soils. The test consists of inserting a blade-shaped steel probe vertically into the soil with a thin expandable circular steel membrane mounted flush on one face and determining, at selected depths or in a semi-continuous manner, the contact pressure exerted by the soil against the membrane when the membrane is flush with the blade and subsequently the pressure exerted when the central displacement of the membrane reaches 1.10 mm. Further details regarding the test are given in good practice [C-2(8)].

NOTE — The test procedure, field observation and reporting of results may be referred from international standards.

3.4.11 *Electrical Resistivity Test*

This test is carried out to assess the substrata profiles (that is, soil and rock profiles) over large areas at a relatively lower cost and can thus supplement the information obtained from detailed site investigations.

This test involves placing four electrodes in line along the ground surface and passing an alternating current through the outer two current electrodes and measuring the resulting potential drop between the two inner potential electrodes. From the resistance, calculated as the ratio of the potential drop to the current applied, the apparent resistivity of the substrata (that is, soil or rock strata) is determined by multiplying with applicable factors which are dependent on the geometry and spacings of the four electrodes. The electrode spacings are varied and the apparent resistivity of the substrata is determined for various electrode spacings.

Detailed analysis/interpretation of the plot of apparent resistivity *versus* electrode spacings is carried out to assess the number and type of substrata and their thicknesses.

The equipment and accessories required for carrying out the test, the test procedure, recording of observations, presentation and analysis of results shall be in accordance with good practice [C-2(17)].

Electrical resistivity tests are also carried out to determine the earth resistivity of the substrata for use in the design of earthing systems. The equipment and accessories required for carrying out the test for earth resistivity determination, the test procedure, recording of observations, presentation and analysis of results shall be in accordance with good practice [C-2(18)].

3.4.12 *Seismic Refraction Test*

This test is carried out to assess the substrata profiles (that is, soil and rock profiles) over large areas to supplement the information obtained from detailed site investigations.

This test involves the generation of seismic waves in the ground using a suitable seismic source and recording these seismic waves through geophones (that is, instruments which convert ground vibrations to electrical signals) located in a line along the ground surface at regular distance intervals. From the recorded waveforms, the arrival times of the seismic waves at different geophone locations are determined and a plot is then drawn of the geophone distances *versus* the corresponding arrival times. The refraction/reflection of the seismic waves at the interfaces of the various substrata leads to variations in the arrival times of the seismic waves at larger distances from the seismic source. The slopes of the lines connecting the data points on such a plot give the seismic wave velocities of the various substrata. The thicknesses of the various substrata so identified are determined by detailed analysis/interpretation of the plot which are based on the principles of refraction/reflection of the seismic waves.

The equipment and accessories required for carrying out the test, the test procedure, recording of observations, presentation and analysis of results shall be in accordance with good practice [C-2(19)].

3.4.13 *Downhole*, *Uphole and Crosshole Seismic Tests*

These tests are carried out to determine the seismic wave velocity profiles with depth and therefrom the profiles of dynamic modulus of rigidity (that is, shear modulus) and dynamic Young’s modulus (that is, elastic modulus) with depth.

In the downhole seismic test, seismic waves are generated in the ground by a suitable seismic source at the ground surface near a borehole and the seismic waves so generated are recorded using geophones located at different depths within the borehole. On the other hand, in the uphole seismic test, seismic waves are generated at different depths within a borehole by a suitable seismic source and the seismic waves so generated are recorded using a geophone located at the ground surface near the borehole.

In the crosshole seismic test, seismic waves are generated at different depths within a borehole termed the source borehole, using a suitable seismic source and the seismic waves so generated are recorded using geophones installed at the corresponding depths in one or two other boreholes termed the receiver boreholes, located in a straight line with the source borehole at predefined borehole spacings.

In these tests, from the recorded waveforms, the seismic wave velocities are determined and therefrom the dynamic shear and elastic moduli are determined.

The equipment and accessories required for carrying out the downhole or uphole seismic test, the test procedure, recording of observations, presentation and analysis of results shall be in accordance with good practice [C-2(20)].

The equipment and accessories required for carrying out the crosshole seismic test, the test procedure, recording of observations, presentation and analysis of results shall be in accordance with good practice [C-2(21)].

3.4.14 *Spectral Analysis of Surface Wave* (*SASW*) *and Multi-Channel Analysis of Surface Wave* (*MASW*) *Test*

The tests are used for evaluation of substrata properties based on the generation of wave propagation phenomena like reflection, refraction and dispersion. Compression and surface wave velocities are measured. Further details regarding the test are given in the good practice [C-2(8)].

NOTE — The test procedure, field observation and reporting of results may be referred from international standards.

P-wave and S-wave velocities as obtained from above tests can also be used to get seismic tomography.

3.4.15 *Ground Penetrating Radar Survey*

Ground penetrating radar (GPR) is a tool to assess the presence of soil/rock strata and to identify presence of buried objects such as pipeline, conduit, concrete, etc. This works on the principle of reflection of the electromagnetic waves at the interface of two different materials. The depth of penetration below the ground surface can be increased by reducing the frequency.

3.4.16 *Thermal Resistivity Test*

Thermal resistivity test is conducted to determine the thermal conductivity of soil and soft rock in field using thermal needle probe procedure. Further details regarding the test are given in good practice [C-2(8)].

NOTE — The test procedure, field observation and reporting of results may be referred from international standards.

3.4.17 *In-situ Permeability Test (in Soil)*

In-situ permeability test is conducted to determine the water percolation capacity of the sub strata. This test is performed inside a borehole/trial pit at specified depths. The type of test shall be either pump-in or pump-out test depending on the subsoil and ground water conditions. Pump-in test is suitable for sub-strata with or without ground water; wherein pump-out test is conducted for sub-strata with ground water.

3.4.17.1 *Pump-in test*

Pump-in test is conducted in a borehole/trial pit by allowing water to percolate into the soil.

a) *Constant head method* (*in borehole*) — This test is preferred for soils with high permeability. The specification for the equipment and the procedure of testing shall be in accordance with good practice [C-2(22)];

b) *Falling head method* (*in borehole*) — This method is preferred for soils with low permeability. The specification for the equipment and the procedure of testing shall be in accordance with good practice [C-2(22)]; and

c) *Percolation test* (*in trial pit*) — Percolation test in trial pit shall be conducted as per good practice [C-2(23)].

3.4.17.2 *Pump-out test*

Pump-out test is conducted in a borehole by pumping out of water from sub-soil. The specification for the equipment and procedure for testing shall be in accordance with good practice [C-2(22)].

3.4.18 *In-situ Permeability Test* (*in Rock*)

In-situ permeability test is conducted inside the drilled hole by pumping in water under pressure to determine the percolation capacity of the rock stratum. The test may be conducted by single packer method or by double packer method. The specification for the equipment and the procedure of testing shall be in accordance with accepted standard [C-2(24)].

3.4.18.1 *Single packer method*

This method shall be adopted when the bottom elevation of the test section is the same as the bottom of the drill hole and where it is considered necessary to know the permeability value during drilling itself. This test shall be useful where the full length of the hole cannot stand encased or ungrouted. The packer shall be fixed at the top level of the test section, such that only the test section lies below the packer. Water shall then be pumped through a pipe into the test section under a required pressure and maintaining it till a constant quantity of water intake is observed. The amount of water percolating through the hole shall be recorded at every 5 min intervals. The test shall be repeated by increasing the pressure at regular intervals up to a pressure limit as specified in accordance to accepted standard [C-2(24)]. The details and observations during the test shall be suitably recorded in a proforma recommended in the accepted standard [C-2(24)].

3.4.18.2 *Double packer method*

This method shall be used when the permeability of an isolated section inside a drill hole is to be determined. Packers shall be fixed both at the top and bottom of the test section such that their spacing is exactly equal to the length of the test section.

3.4.19 *Field California Bearing Ratio* (*CBR*) *Test*

This test is carried out to determine the *in-situ* CBR value of the compacted subgrade on which the road pavement will be constructed so as to confirm that the *in-situ* CBR value is equal to or greater than the design CBR value for the road pavement. The test involves applying static loading to cause penetration of a cylindrical plunger of standard diameter into the compacted subgrade material and recording the applied static load to cause the required increments of penetration till the required maximum penetration of the plunger is achieved. Based on the plot of the recorded applied load and corresponding penetrations of the plunger, the CBR value is determined as the ratio of the applied test load to the predefined standard load for different standard penetrations of the plunger. The equipment and accessories required for carrying out the test, the test procedure, recording of observations and presentation of results shall be in accordance with accepted standard [C-2(25)].

3.4.20 *Optical and Acoustic Tele-Viewer Methods*

The optical and acoustic tele-viewers provide a continuous, 360°view of the borehole wall that allows rock mass discontinuities to be identified and characterized. Both devices can be oriented within the borehole so that the absolute orientation of features like bedding planes can be measured. An optical tele-viewer (OTV) uses a camera to record high-resolution images of the borehole wall and includes lights for illumination. An OTV is best suited for dry boreholes or boreholes filled with clear water.

Any conditions that produce cloudy or murky water or coatings on the borehole wall, limit the usefulness of the OTV. If good images are obtained, it is possible to identify locations and orientations of joints, bedding planes, foliations, faults, shears and other naturally occurring rock mass discontinuities.

The acoustic tele-viewer (ATV) uses ultrasound pulses from a rotating sensor in an open, fluid-filled borehole to record the amplitude and travel time of the signals reflected at the (high-impedance) interface between fluids and the borehole wall. Because an ATV uses ultrasound rather than visible light, the borehole fluid is not required to be clear. Rock mass discontinuities in the wall of the borehole will change the amplitude of the reflected acoustic wave compared to the surrounding material. The method does not work well in soil because of the lack of a high-impedance boundary between the fluid and soil. ATV surveys are used to provide information regarding locations and orientations of joints, bedding planes, faults, shears and other naturally occurring rock mass discontinuities.

3.5 Sampling and Testing

3.5.1 In order to identify the type of soil/rock and to determine the physical, chemical and engineering properties of sub strata, samples of soil, rock and water, as applicable are collected during the investigation. The samples are of the following two types:

a) *Disturbed sample* — The sample in which natural structure of the material is disturbed; and

b) *Undisturbed sample* — The sample in which the natural structure of the material is not disturbed.

3.5.2 The type of sample, quantity of sample and number of samples to be collected depends on the purpose of investigation and the nature of the strata condition. The interval at which the samples are collected depends on the type of strata variation of the profiles within the strata. Generally, undisturbed samples (UDS) are collected at depth interval of 3.0 m or change of strata, whichever is lower. The depth between UDS and SPT are generally staggered at 1.5 m so that at every 1.5 m depth either UDS is collected or SPT is conducted. In case of variations of profiles within a stratum, the samples shall be collected at a frequency of at least every 1.5 m to 2 m depth interval in a borehole. Wherever undisturbed sampling is not possible, such as in cohensionless soil or some utility service is encountered during the investigation, the same may be replaced by standard penetration test. In cohesive soils, when N value is above 32, undisturbed samples may be replaced by standard penetration test.

3.5.3 The following are the methods that are usually employed for sampling:

Nature of stratum	*Type of sample*	*Method of sampling*
Soil	Disturbed	Shovel, pick axe, etc Auger and shell boring Split spoon sampler
	Undisturbed	Block sample Tube sampler Piston sampler Core cutter sampler Continuous soil sampler
Rock	Disturbed	Blasting Chiseling
	Undisturbed	Coring

3.5.4 In cohesive soils, it is possible to collect undisturbed samples for examination and testing. In cohesionless soils below water table, undisturbed sampling is difficult with the samplers other than piston sampler.

3.5.5 Disturbed soil sample and undisturbed soil sample are to be obtained as per **3.5.5.1** and **3.5.5.2**, respectively.

3.5.5.1 *Disturbed soil sample*

Disturbed sample of soil is obtained during the course of excavation of trial pit, boring and after conducting standard penetration test. This sample can be used for testing of physical and chemical properties. The disturbed sample of clay is also useful for determining shear strength of remoulded sample.

3.5.5.2 *Undisturbed soil sample*

Undisturbed sample is obtained from pits and boreholes in such a manner that moisture content and structure do not get altered. This may be attained by careful protection, packing and by the use of a correctly designed sampler. Various methods of undisturbed sampling are as given in good practice [C-2(8)].

3.5.6 *Protection, Handling and Labelling of Samples*

Care should be taken in protecting, handling and subsequent transport of samples and in their full labelling, so that samples can be received in a fit state for examination and testing and can be correctly recognized as coming from a specified trial pit or boring.

3.5.7 *Examination and Testing of Samples*

3.5.7.1 The following tests shall be carried out in accordance with accepted standard [C-2(26)]:

a) *Test on disturbed/undisturbed soil samples*
   1) Visual and engineering classification;
   2) Sieve analysis and hydrometer analysis;

   3) Atterberg limits (liquid limit, plastic limit and shrinkage limit);
   4) Specific gravity;
   5) Free swell index;
   6) Light/Heavy compaction test (standard/modified proctor compaction test);
   7) California bearing ratio;
   8) Relative density (for sand); and
   9) Laboratory permeability test (constant head/falling head).

b) *Test on undisturbed soil samples*
   1) Bulk density and moisture content;
   2) Unconfined compression test (on remoulded or undisturbed sample);
   3) Swelling pressure (on undisturbed and remoulded sample);
   4) Direct shear test (drained/undrained) (on remoulded or undisturbed sample);
   5) Triaxial compression tests (on undisturbed or remoulded sample):
      i) Unconsolidated undrained;
      ii) Consolidated undrained test with/without the measurement of pore water pressure; and
      iii) Consolidated drained;
   6) Consolidation test; and
   7) Vane shear test.

c) *Test on rock samples*
   1) Visual classification;
   2) Water absorption;
   3) Porosity;
   4) Density;
   5) Specific gravity;
   6) Hardness;
   7) Slake durability;
   8) Uniaxial compression test (both saturated and unsaturated);
   9) Point load strength index;
   10) Deformability test (both saturated and unsaturated);
   11) Tensile strength (Brazilian); and
   12) Triaxial compression test.

d) *Chemical analysis on subsoil and ground water* — Tests are conducted to determine the concentration of following chemicals:
   1) *p*H value;
   2) Sulphates (SO_3 and/or SO_4);
   3) Chlorides;
   4) Organic matter; and
   5) Any other chemicals harmful to the foundation material.

In case of ground water, colour, odour, turbidity and specific conductivity should also be determined.

3.6 Soil Investigation Report

3.6.1 *General*

On completion of the *in-situ* and laboratory tests, subsurface investigation report shall be prepared which should include, geological information, procedure adopted for investigation, field observations, laboratory test data, analysis, interpretation, recommendation, etc.

3.6.2 *Information to be Provided*

3.6.2.1 The report shall include but not be limited to the following:

a) Plan showing location and depth of *in-situ* tests;

b) Geological information of the area;

c) General topography of the site;

d) Past usage and historical data of the site, if available;

e) Borelog/trial pit log (*see* good practice [C-2(8)] for format of borelog);

f) *In-situ* test results;

g) Plot of standard penetration test (N values both uncorrected and corrected) with depth for identified areas;

h) Laboratory test results (*see* good practice [C-2(8)] for format for laboratory test results);

j) Summary of strata profile; and

k) In case of pressuremeter tests, the following should be furnished:

    1) Calibration record including, description of membrane and sheath on probes, dimension of thick walled cylinder, length of flexible tubing, calibration curves/chart, temperature, etc;

    2) Drilling record including, borehole number, method of making borehole, log of soil type and condition, depth of water in borehole, weather and temperature; and

    3) *Test record* — Type of test, date and time, depth of centre point of probe, volume readings at 30 s and 60 s elapsed time and corresponding pressure readings, notes on any deviation from standard test procedure.

3.6.2.2 Reporting of *in-situ* and laboratory test results should be in accordance with relevant Indian Standards.

3.6.3 *Analysis and Interpretation of Results*

The following shall be included in the report:

a) Analysis of test results;

b) Discussion and interpretation of results analyzed including basis of adopting design parameters for the substrata;

c) For shallow foundations:

    1) Net allowable bearing pressure considering shear as well as settlement criteria for isolated footing, continuous strip footing and raft foundation; and

    2) Modulus of subgrade reaction and modulus of elasticity of substrata.

d) For pile foundations: Safe load carrying capacity;

e) Dynamic soil properties such as shear wave velocity, dynamic shear modulus, Poisson's ratio, damping ratio, as applicable;

f) Suitability of the soil for backfilling around foundations;

g) Susceptibility of sub-soil strata to liquefaction, if any, in the event of dynamic loading; and

h) Remedial measures against the presence of harmful chemicals in the sub-soil/ground water.

4 CLASSIFICATION AND IDENTIFICATION OF SOILS

The classification and identification of soils for engineering purposes shall be in accordance with accepted standard [C-2(27)].

5 MATERIALS

5.1 Cement, coarse aggregate, fine aggregate, lime, *Surkhi*, steel, timber and other materials go into the construction of foundations shall conform to the requirements of Part B 'Building Materials' of this NBCS.

5.2 Protection Against Deterioration of Materials

Where a foundation is to be in contact with soil, water or air, that is, in a condition conducive to the deterioration of the materials of the foundation, protective measures shall be taken to minimize the deterioration of the materials.

5.2.1 *Concrete*

The concrete used for construction shall be in accordance with Part C 'Structural Design/ Section 5 Structural Concrete' of this NBCS.

5.2.2 *Timber*

Where timber is exposed to soil, it shall be treated in accordance with good practice [C-2(28)].

6 GENERAL REQUIREMENTS FOR FOUNDATIONS/SUB-STRUCTURES FOR BUILDINGS

6.1 Types of Foundations

Types of foundations for buildings covered in this Section are:

a) *Shallow foundations* (*see* **7**)
    1) Pad or spread and strip foundations (*see* **7.3**);
    2) Raft foundations (*see* **7.4**);
    3) Ring foundations (*see* **7.5**); and
    4) Shell foundations (*see* **7.6**).

b) *Deep foundations*
    1) Pile Foundations
        i) Driven cast *in-situ* concrete piles (*see* **8.2**);
        ii) Bored cast *in-situ* concrete piles (*see* **8.2**);
        iii) Driven precast concrete piles (*see* **8.3**);
        iv) Precast concrete piles in prebored holes (*see* **8.4**);
        v) Under-reamed concrete piles (*see* **8.5**);
        vi) Timber piles (*see* **8.6**); and
        vii) Spun piles.

        NOTE — Spun piles are used in deep marshy soils as conventional pile installation beyond 50 m in such soils is very difficult.

c) *Other foundations/Sub-structures/Foundations for special structure*
    1) Pier foundations (*see* **10.1**);
    2) Combined piled-raft foundation (*see* **9**);
    3) Diaphragm walls (*see* **10.2**); and
    4) Machine foundations (*see* **10.2**).

6.2 Depth of Foundations

6.2.1 The depth to which foundations should be carried depends upon the following principal factors:

a) Getting adequate allowable bearing capacity;

b) In the case of clayey soils, penetration below the zone where shrinkage and swelling due to seasonal weather changes and due to trees and shrubs are likely to cause appreciable movements;

c) In fine sands and silts, penetration below the depth of frost penetration;

d) Maximum depth of scour, wherever relevant, should also be considered and the foundation should be located sufficiently below this depth; and

e) Other factors such as ground movements and heat transmitted from the building to the supporting ground may be important.

6.2.2 All foundations shall extend to a depth of at least 500 mm below natural ground level. On rock or such other weather resisting natural ground, removal of the top soil may be all that is required. In such cases, the surface shall be cleaned and, if necessary, stepped or otherwise prepared so as to provide a suitable bearing and thus prevent slipping or other unwanted movements.

6.2.3 Where there is excavation, ditch, pond, water course, filled-up ground or similar condition of the subsoil on which the structure is to be erected, the foundation of such structure shall either be carried down to a depth beyond the detrimental influence of such conditions, or retaining walls shall be provided for the purpose of shielding from the effects of such conditions.

6.2.4 A foundation in any type of soil shall be below the zone significantly weakened by root holes or cavities produced by burrowing animals or works. The depth shall also be enough to prevent the rainwater scouring below the footings.

6.2.5 Clayey soils, like black cotton soils, are seasonally affected by drying, shrinkage and cracking in dry and hot weather and by swelling in the following wet weather to a depth which will vary according to the nature of the clay and the climatic condition of the region. It is necessary in these soils, either to place the foundation bearing at such a depth where the effects of seasonal changes are not important or to make the foundation capable of eliminating the undesirable effects due to relative movement by providing flexible type of construction or rigid foundations. Adequate load counteracting against swelling pressures also provide satisfactory foundations.

6.3 Foundation at Different Levels

6.3.1 Where footings are adjacent to sloping ground or where the bottoms of the footings of a structure are at different levels or at levels different from those of the footings of adjoining structures, the depth of the footings shall be such that the difference in footing elevations shall be subject to the following limitations:

a) When the ground surface slopes downward adjacent to a footing, the sloping surface shall not intersect a frustum of bearing material under the footing having sides which make an angle of 30° with the horizontal for soil and horizontal distance from the lower edge of the footing to the sloping surface shall be at least 600 mm for rock and 900 mm for soil (*see* Fig. 4);

b) In the case of footings in granular soil, a line drawn between the lower adjacent edges of adjacent footings shall not have a steeper slope than one vertical to two horizontal (*see* Fig. 5); and

c) In case of footing in clayey soils a line drawn between the lower adjacent edge of the upper footing and the upper adjacent edge of lower footing shall not have a steeper slope than one vertical to two horizontal (*see* Fig. 6).

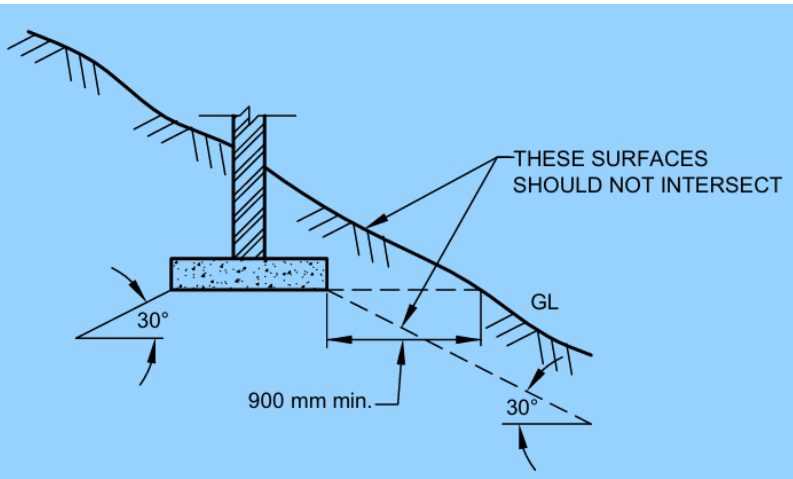

THESE SURFACES SHOULD NOT INTERSECT
GL
30°
900 mm min.
30°

FIG. 4 FOOTING IN SLOPING GROUND

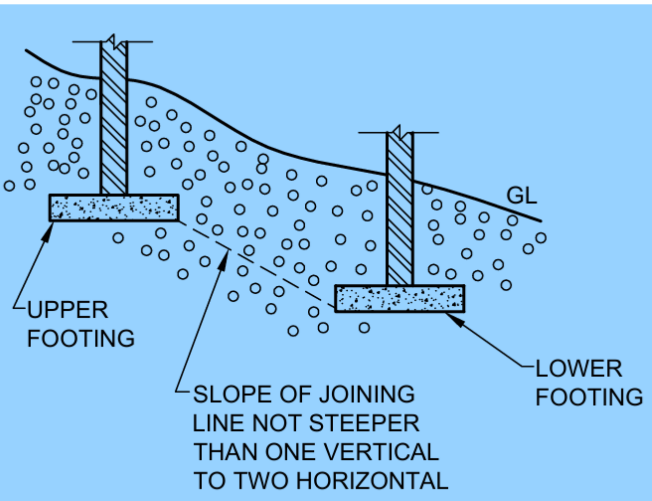

GL
UPPER FOOTING
LOWER FOOTING
SLOPE OF JOINING LINE NOT STEEPER THAN ONE VERTICAL TO TWO HORIZONTAL

FIG.5 FOOTING IN GRANULAR SOIL

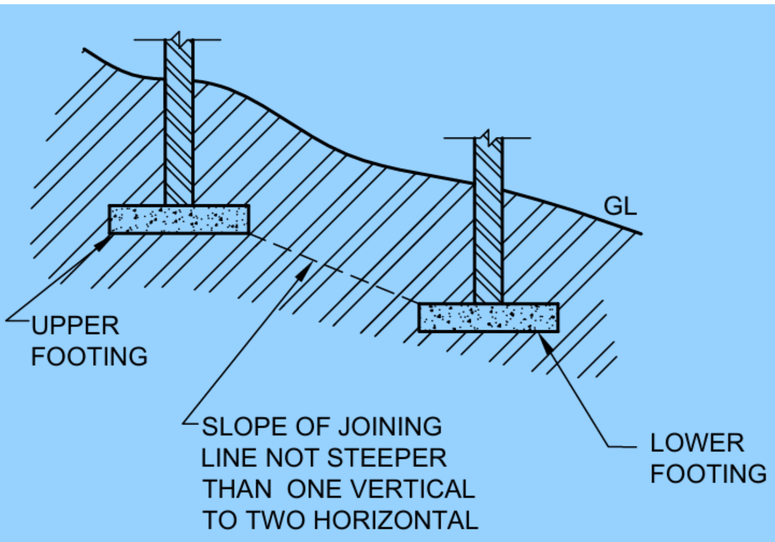

GL
UPPER FOOTING
SLOPE OF JOINING LINE NOT STEEPER THAN ONE VERTICAL TO TWO HORIZONTAL
LOWER FOOTING

FIG.6 FOOTING IN CLAYEY SOIL

6.3.2 The requirement given in 6.3.1 shall not apply in the condition where adequate provision is made for the lateral support (such as with retaining walls) of the material supporting the higher footing.

6.4 Effect of Seasonal Weather Changes

During periods of hot, dry weather a deficiency of water develops near the ground surface and in clay soils, that is associated with a decrease of volume or ground shrinkage and the development of cracks. The shrinkage of clay will be increased by drying effect produced by fast growing and water seeking trees. The range of influence depends on size and number of trees and it increase during dry periods. In general, it is desirable that there shall be a distance of at least 6 m between such trees. Boiler installations, furnaces, kilns, underground cables and refrigeration installations and other artificial sources of heat may also cause increased volume changes of clay by drying out the ground beneath them, the drying out can be to a substantial depth. Special precautions either in the form of insulation or otherwise should be taken. In periods of wet weather, clay soils swell and the cracks lend to close, the water deficiency developed in the previous dry periods may be partially replenished and a subsurface zone or zones deficient in water may persist for many years. Leakage from water mains and underground sewers may also result in large volume changes. Therefore, special care shall be taken to prevent such leakages.

6.5 Effect of Mass Movements of Ground in Unstable Areas

In certain areas mass movements of the ground are liable to occur from causes independent of the loads applied by the foundations of structures. These include mining subsidence, landslides on unstable slopes and creep on clay slopes.

6.5.1 *Mining Subsidence*

In mining areas, subsidence of the ground beneath a building or any other structure is liable to occur. The magnitude of the movement and its distribution over the area are likely to be uncertain and attention shall, therefore, be directed to make the foundations and structures sufficiently rigid and strong to withstand the probable worst loading condition and probable ground movements. Where future subsidence is likely, care should be taken to design the superstructure and foundation sufficiently strong to cater for probable ground movements. Long continuous buildings should be avoided in such areas and large building in such area should be divided into independent sections of suitable size, each with its own foundations. Expert advice from appropriate mining authority should be sought.

NOTE — For prediction of subsidence in coal mines, guidelines as given in the accepted standard [C-2(29)] may be referred.

6.5.2 *Landslide Prone Areas*

The construction of structures on slopes which are suspected of being unstable and are subject to landslip shall be avoided.

On sloping ground on clay soils, there is always a tendency for the upper layers of soil to move downhill, depending on type of soil, the angle of slope, climatic conditions, etc. In some cases, the uneven surface of the slope on a virgin ground will indicate that the area is subject to small land slips and, therefore, if used for foundation, will obviously necessitate special design consideration as specified in accepted standard [C-2(30)].

Where there may be creep of the surface layer of the soil, protection against creep may be obtained by following special design considerations.

On sloping sites, spread foundations shall be on a horizontal bearing and stepped. At all changes of levels, they shall be lapped at the steps for a distance at least equal to the thickness of the foundation or twice the height of the step, whichever is greater. The steps shall not be of greater height than the thickness of the foundation, unless special precautions are taken.

Cuttings, excavations or sloping ground near and below foundation level may increase the possibility of shear failure of the soil. The foundation shall be well beyond the zone of such shear failure.

If the probable failure surface intersects a retaining wall or other revetment, the latter shall be made strong enough to resist any unbalanced thrust. In case of doubt as to the suitability of the natural slopes or cuttings, the structure shall be kept well away from the top of the slopes, or the slopes shall be stabilized.

Cuttings and excavations adjoining foundations reduce stability and increase the likelihood of differential settlement. Their effect should be investigated not only when they exist but also when there is possibility that they are made subsequently.

Where a structure is to be placed on sloping ground, additional complications are introduced. The ground itself, particularly if of clay, may be subject to creep or other forms of instability, which may be enhanced if the strata dip in the same direction as the ground surface. If the slope of the ground is large, the overall stability of the slope and substructure may be affected. These aspects should be carefully investigated.

6.6 Precautions for Foundations on Inclined Strata

In the case of inclined strata, if they dip towards a cutting of basement, it may be necessary to carry foundation below the possible slip planes, land drainage also requires special consideration, particularly on the uphill side of a structure to divert the natural flow of water away from the foundations.

6.7 Strata of Varying Thickness

Strata of varying thickness, even at appreciable depth, may increase differential settlement. Where necessary, calculations should be made of the estimated settlement from different thickness of strata and the structure should be designed accordingly. When there is large change of thickness of soft strata, the stability of foundation may be affected. Site investigations should, therefore, ensure detection of significant variations in strata thickness.

6.8 Layers of Softer Material

Some soils and rocks have thin layers of softer material between layers of harder material, which may not be detected unless thorough investigation is carried out. The softer layers may undergo marked changes in properties if the loading on them is increased or decreased by the proposed construction or affected by related changes in ground water conditions. These should be taken into account.

6.9 Spacing Between Existing and New Foundation

The deeper the new foundation and the nearer to the existing it is located, the greater the damage is likely to be. Preferably, the minimum horizontal spacing between existing and new footings shall be equal to the width of the wider clear footing. While the adoption of such provision shall help minimizing damage to adjacent foundation, an analysis of bearing capacity and settlement shall be carried out to have an appreciation of the effect on the adjacent existing foundation. Suitable site-specific protection measures shall be adopted for the existing foundation, as required.

6.10 Preliminary Work for Construction

6.10.1 The construction of access roads, main sewers and drains should preferably be completed before commencing the work of foundations; alternatively, sufficient precautions shall be taken to protect the already constructed foundations during subsequent work.

6.10.2 *Clearance of Site*

Any obstacles, including the stump of trees, likely to interfere with the work shall be removed. Holes left by digging, such as those due to removal of old foundation, uprooted trees, burrowing by animals, etc, shall be back-filled with soil and well compacted.

6.10.3 *Drainage*

If the site of a structure is such that surface water drain towards it, land may be dressed or drains laid to divert the water away from the site.

6.10.4 *Setting Out*

Generally, the site shall be levelled before the layout of foundations are set out. In case of sloping terrain, care shall be taken to ensure that the dimensions on plans are set out correctly in one or more horizontal planes.

6.10.5 The layout of foundations shall be set out in accordance of good practice [C-2(31)]. The setting out of walls shall be facilitated by permanent row of pillars, parallel to and at a suitable distance beyond the periphery of the building. The pillars shall be located at junctions of cross walls with the peripheral line of pillars. The centre lines of the cross walls shall be extended to and permanently erected on the plastered tops of the corresponding sets of pillars. The datum lines parallel to and at the known fixed distance from the centre lines of the external walls also be permanently worked on the corresponding rows of pillars to pillars to serve as checks on the accuracy of the work as it proceeds. The tops of these pillars shall be at the same level and preferably at the plinth or floor level. The pillars shall be of sizes not less than 250 mm wide and shall be bedded sufficiently deep into ground, so that they are not disturbed.

6.11 Protection of Excavation

6.11.1 The protection of excavation during construction shall be done in accordance with good practice [C-2(32)].

6.11.2 After excavation, the bottom of the excavation shall be cleared of all loose soil and rubbish and shall be levelled, where necessary. The bed shall be wetted and compacted by heavy rammers to an even surface.

6.11.3 Excavation in clay or other soils that are liable to be effected by exposure to atmosphere shall, wherever possible, be concreted as soon as they are dug. Alternatively, the bottom of the excavation shall be protected immediately by 80 mm thick layer of cement concrete not leaner than mix 1 : 5 : 10 over which shall come the foundation concrete; or in order to obtain a dry hard bottom, the last excavation of about 100 mm shall be removed only before concreting.

6.11.4 The backfilling of the excavation shall be done with care so as not to disturb the constructed foundation and shall be compacted in layers not exceeding 150 mm thick with sprinkling of minimum quantity of water necessary for proper compaction.

6.11.5 To support excavation sides where open excavation is required beyond a certain depth and safe slopes are not feasible, shoring shall be provided. This ensures stability, allows near-vertical soil cutting and prevents soil collapse. Shoring systems can include concrete shoring pile walls (secant or tangent wall systems), soldier pile walls, diaphragm walls, or other suitable methods, depending on soil conditions, excavation depth and selected construction technology.

Temporary shoring is generally defined as a system intended for service for a limited period. If earth retention structures are required for an extended duration, they should be designed as permanent structures.
For temporary shoring, the design should consider soil pressure and ensure that the selected system, including piles and anchors (if provided), can safely support the applied loads under service conditions.

The type of earth pressure to be considered depends on the flexibility and support conditions of the shoring system. Cantilevered or flexible walls with limited support require a specific earth pressure approach, whereas more rigid walls that exhibit minimal deflection require a different consideration.

For permanent conditions, all final loads, including surcharge effects, must be resisted by the structural walls, designed with appropriate safety considerations. The structural design should ensure:

a) deflections remain within allowable limits; and

b) structural elements maintain adequate strength and stability.

6.12 Alterations During Construction

a) Where during construction the soil or rock to which foundation is to transfer loads is found not to be the type or in the condition assumed, the foundation shall be redesigned and constructed for the existing type or conditions and the Authority notified;

b) Where a foundation bears on gravel, sand or silt and where the highest level of the ground water is or likely to be higher than an elevation defined by bearing surface minus the width of the footing, the bearing pressure shall be suitably altered;

c) Where the foundation has not been placed or located as indicated earlier or is damaged or bears on a soil whose properties may be adversely changed by climatic and construction conditions, the error shall be corrected, the damaged portion repaired or the design capacity of the affected foundation recalculated to the satisfaction of the Authority; and

d) Where a foundation is placed and if the results of a load test so indicate, the design of the foundation shall be modified to ensure structural stability of the same.

7 SHALLOW FOUNDATIONS

7.1 Design Information

For the satisfactory design of foundations, the following information is necessary:

a) Type and condition of the soil or rock to which the foundation transfers the loads;

b) General layout of the columns and load-bearing walls showing the estimated loads, including moments and torques due to various loads (dead load, imposed load, wind load, seismic load) coming on the foundation units;

c) Allowable bearing pressure of the soils;

d) Changes in ground water level, drainage and flooding conditions and also the chemical conditions of the subsoil water;

e) Behaviour of the buildings, topography and environment/surroundings adjacent to the site, the type and depths of foundations and the bearing pressure; and

f) Seismic zone of the region.

7.2 Design Considerations

7.2.1 *Design Loads*

The foundation shall be proportioned for the following combination of loads:

a) Dead load + Imposed load; and

b) Dead load + Imposed load + Wind load or seismic loads, whichever is critical.

For details, reference shall be made to Part C 'Structural Design/ Section 1 Loads and Load Effects' of this NBCS.

NOTE — For shallow foundations on coarse grained soils, settlements shall be estimated corresponding to **7.2.1**(b) and for foundations on fine grained soils, the settlement shall be estimated corresponding to permanent loads only. Permanent loads shall be in accordance with good practice [C-2(33)].

7.2.2 *Allowable Bearing Pressure*

The allowable bearing pressure shall be taken as either of the following, whichever is less:

a) the safe bearing capacity on the basis of shear strength characteristics of soil; and

b) the bearing pressure that the soil can take without exceeding the permissible settlement (*see* **7.2.3**).

7.2.2.1 *Bearing capacity by calculation*

Where the engineering properties of the soil are available, that is, cohesion, angle of internal friction, density, etc, the bearing capacity shall be calculated from stability considerations of shear; factor of safety of 2.5 shall be adopted for safe bearing capacity. The effect of interference of different foundations should be taken into account. The procedure for determining the ultimate bearing capacity and bearing pressure of shallow foundations based on shear and allowable settlement criteria shall be in accordance with good practice [C-2(34)]. Depth factor correction is to be applied only when backfilling is done with proper compaction.

7.2.2.2 *Field method for determining allowable bearing pressure*

Where appropriate, plate load tests can be performed and allowable pressure determined as per accepted standard [C-2(9)]. The allowable bearing pressure for sandy soils may also be obtained by loading tests. When such tests cannot be done, the allowable bearing pressure for sands may be determined using penetration test.

7.2.2.3 Where the bearing materials directly under a foundation over-lie a stratum having smaller safe bearing capacity, these smaller values shall not be exceeded at the level of such stratum.

7.2.2.4 *Effect of wind and seismic force*

7.2.2.4.1 Where the bearing pressure due to wind is less than 25 percent of that due to dead and imposed loads, it may be neglected in design. Where this exceeds 25 percent, foundations may be so proportioned that the pressure due to combined dead, imposed and wind loads does not exceed the allowable bearing pressure by more than 25 percent.

7.2.2.4.2 When earthquake forces are considered for the computation of design loads, the permissible increase in bearing pressure of pertaining soil shall be as given in Part C 'Structural Design/Section 1 Loads and Load Effects'of this NBCS, depending upon the type of foundation of the structure and the type of soil.

7.2.2.5 *Bearing capacity of buried strata*

If the base of a foundation is close enough to a strata of lower bearing capacity, the latter may fail due to excess pressure transmitted to it from above. Care should be taken to see that the pressure transmitted to the lower strata is within the prescribed safe limits. When the footings are closely spaced, the pressure transmitted to the underlying soil will overlap. In such cases, the pressure in the overlapped zones will have to be considered. With normal foundations, it is sufficiently accurate to estimate the bearing pressure on the underlying layers by assuming the load to be spread at a slope of 2 (vertical) to 1 (horizontal).

7.2.3 *Settlement*

The permissible values of total and differential settlement for a given type of structure may be taken as given in Table 3. Total settlements of foundation due to net imposed loads shall be estimated in accordance with accepted standard [C-2(6)]. The following causes responsible for producing the settlement shall be investigated and taken into account.

a) *Causes of Settlement*:

   1) Elastic compression of the foundation and the underlying soil;
   2) Consolidation including secondary compression;
   3) *Ground water lowering* — Specially repeated lowering and raising of water level in loose granular soils tend to compact the soil and cause settlement of the footings. Prolonged lowering of the water table in fine grained soils may introduce settlement because of the extrusion of water from the voids. Pumping water or draining water by tiles or pipes from granular soils without an adequate mat of filter material as protection may, in a period of time, carry a sufficient amount of fine particles away from the soil and cause settlement;
   4) Seasonal swelling and shrinkage of expansive clays;
   5) Ground movement on earth slope, for example, surface erosion, slow creep or landslides; and
   6) Other causes, such as adjacent excavation, mining, subsidence and underground erosion.

b) *Causes of Differential Settlements*:

   1) Geological and physical non-uniformity or anomalies in type, structure, thickness and density of the soil medium (pockets of sand in clay, clay lenses in sand, wedge like soil strata, that is, lenses in soil), an admixture of organic matter, peat, mud;
   2) Non-uniform pressure distribution from foundation to the soil due to non-uniform loading and incomplete loading of the foundations;
   3) Water regime at the construction site,
   4) Overstressing of soil at adjacent site by heavy structures built next to light ones;
   5) Overlap of stress distribution in soil from adjoining structures;
   6) Unequal expansion of the soil due to excavation for footing;

7) Non-uniform development of extrusion settlements; and

8) Non-uniform structural disruptions or disturbance of soil due to freezing and thawing, swelling and softening and drying of soils.

7.2.4 *Shallow Foundations on Rocks*

Estimation of the safe bearing pressures of rocks for shallow foundations based on strength, allowable settlement and classification criteria; and also design and construction of shallow foundations on rocks shall be carried out in accordance with the good practice [C-2(35)].

7.3 Pad or Spread and Strip Foundations

7.3.1 In such type of foundations, wherever the resultant of the load deviates from the centre line by more than 1/6 of its least dimension at the base of footing, it should be suitably reinforced.

7.3.2 For continuous wall foundations (plain or reinforced) adequate reinforcement should be provided particularly at places where there is abrupt change in magnitude of load or variation in ground support.

7.3.3 On sloping sites the foundation should have a horizontal bearing and stepped and lapped at changes of levels for a distance at least equal to the thickness of foundation or twice the height of step, whichever is greater. The steps should not be of greater height than thickness of the foundations.

7.3.4 *Ground Beams*

The foundation can also have the ground beam for transmitting the load. The ground beam carrying a load bearing wall should be designed to act with the wall forming a composite beam, when both are of reinforced concrete and structurally connected by reinforcement. The ground beam of reinforced concrete structurally connected to reinforced brick work can also be used.

7.3.5 *Dimensions of Foundation*

The dimensions of the foundation in plan should be such as to support loads as given in good practice [C-2(33)]. The width of the footings shall be such that maximum stress in the concrete or masonry is within the permissible limits. The width of wall foundation (in mm) shall not be less than that given by:

$$B = W + 300$$

where

B = width at base, in mm; and

W = width of supported wall, in mm.

7.3.6 In the base of foundations for masonry foundation it is preferable to have the steps in multiples of thickness of masonry unit.

7.3.7 The plan dimensions of excavation for foundations should be wide enough to ensure safe and efficient working in accordance with good practice [C-2(32)].

7.3.8 Unreinforced foundation may be of concrete or masonry (stone or brick) provided that angular spread of load from the base of column/wall or bed plate to the outer edge of the ground bearing is not more than 1 vertical to 1/2 horizontal for masonry or 1 vertical to 1 horizontal for cement concrete and 1 vertical to 2/3 horizontal for lime concrete. The minimum thickness of the foundation of the edge should not be less than 150 mm. In case the depth to transfer the load to the ground bearing is less than the permissible angle of spread, the foundations should be reinforced.

7.3.9 If the bottom of a pier is to be belled so as to increase its load carrying capacity such bell should be at least 300 mm thick at its edge. The sides should be sloped at an angle of not less than 45° with the horizontal. The least dimension should be 600 mm (circular, square or rectangular). The design should allow for the vertical tilt of the pier by 1 percent of its height.

7.3.10 If the allowable bearing capacity is available only at a greater depth, the foundation can be rested at a higher level for economic considerations and the difference in level between the base of foundation and the depth at which the allowable bearing capacity occurs can be filled up with either: (a) concrete of allowable compressive strength not less than the allowable bearing pressure, (b) incompressible fill material, for example, sand, gravel, etc, in which case the width of the fill should be more than the width of the foundation by an extent of dispersion of load from the base of the foundation on either side at the rate of 2 vertical to 1 horizontal.

7.3.11 The cement concrete foundation (plain or reinforced) should be designed in accordance with Part C 'Structural Design/ Section 5 Structural Concrete' of this NBCS and masonry foundation in accordance with Part C 'Structural Design/ Section 4 Masonry' of this NBCS.

7.3.12 *Thickness of Footing*

The thickness of different types of footings, if not designed according to **7.2**, should be as given in Table 4.

Table 3 Permissible Differential Settlements and Tilt (Angular Distortion) for Shallow Foundations in Soils

(*Clause* 7.2.3)

Sl No.	**Type of Structure**	**Isolated Foundations**						**Raft Foundations**					
		Sand and Hard Clay			Plastic Clay			Sand and Hard Clay			Plastic Clay		
		Maximum Settlement mm	Differential Settlement mm	Angular Distortion	Maximum Settlement mm	Differential Settlement mm	Angular Distortion	Maximum Settlement mm	Differential Settlement mm	Angular Distortion	Maximum Settlement mm	Differential Settlement mm	Angular Distortion
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
i)	For steel structure	50	.003 3 *L*	1/300	50	.003 3 *L*	1/300	75	.003 3 *L*	1/300	100	.003 3 *L*	1/300
ii)	For reinforced concrete structures	50	.001 5 *L*	1/666	75	.001 5 *L*	1/666	75	.002 1 *L*	1/500	125	.002 *L*	1/500
iii)	For multistoreyed buildings												
	a) RC or steel framed buildings with panel walls	60	.002 *L*	1/500	75	.002 *L*	1/500	75	.0025 *L*	1/400	125	.003 3 L	1/300
	b) For load bearing walls												
	1) *L*/H=2[1]	60	.000 2 *L*	1/5 000	60	.000 2 *L*	1/5 000	← Not likely to be encountered →					
	2) *L*/H=7[1]	60	.000 4 *L*	½ 500	60	.000 4 *L*	1/2 500						
iv)	For water towers and silos	50	.001 5 *L*	1/666	75	.001 5 *L*	1/666	100	.0025*L*	1/400	125	.002 5 *L*	1/400

NOTES

1 The values given in the table may be taken only as a guide and the permissible total settlement/differential settlement and tilt (angular distortion) in each case should be decided as per requirements of the

2 *L* denotes the length of deflected part of wall/raft or centre-to-centre distance between columns.

3 *H* denotes the height of wall from foundation footing.

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[1] For intermediate ratios of *L*/*H*, the values can be interpolated.

Table 4 Thickness of Footings

(*Clause* 7.3.12)

Sl No. (1)	Type of Footings (2)	Thickness of Footings, *Min* (3)	Remarks (4)
i)	Masonry	a) 250 mm; and b) Twice the maximum projection from the face of the wall.	Select the greater of the two values
ii)	Plain concrete		
	a) For normal structures	a) 200 mm;	—
		b) Twice the maximum offset in a stepped footing; and	For footings resting on soil
		c) 300 mm.	For footings resting on top of the pile
	b) For lightly loaded structures	a) 150 mm; and	Resting on soil
		b) 200 mm.	Resting on pile
iii)	Reinforced concrete	a) 150 mm; and	Resting on soil
		b) 300 mm.	Resting on pile

7.3.13 *Land Slip Area*

On a sloping site, spread foundation shall be on a horizontal bearing and stepped. At all changes of levels, they shall be lapped at the steps for a distance at least equal to the thickness of the foundation or twice the height of the step, whichever is greater. The steps shall not be of greater height than the thickness of the foundation unless special precautions are taken. On sloping ground on clay soils, there is always a tendency for the upper layers of soil to move downhill, depending on type of soil, the angle of slope, climatic conditions, etc. Special precautions are necessary to avoid such a failure.

7.3.14 In the foundations, the cover to the reinforcement shall be as prescribed in Part C 'Structural Design/ Section 5 Structural Concrete' of this NBCS for the applicable environment exposure condition.

7.3.15 For detailed information regarding preparation of ground work, reference shall be made to good practice [C-2(36)].

7.4 Raft Foundations

7.4.1 *Design Considerations*

Design provisions given in 7.2 shall generally apply.

7.4.1.1 The structural design of reinforced concrete rafts shall conform to Part C 'Structural Design/Section 5 Structural Concrete' of this NBCS.

7.4.1.2 In the case of raft, whether resting on soil directly or on lean concrete, the cover to the reinforcement shall be as prescribed in Part C 'Structural Design/ Section 5 Structural Concrete' of this NBCS for the applicable environment exposure condition.

7.4.1.3 In case the structure supported by the raft consists of several parts with varying loads and heights, it is advisable to provide separation joints between these parts. Joints shall also be provided, wherever there is a change in the direction of the raft.

7.4.1.4 Foundations subject to heavy vibratory loads should preferably be isolated.

7.4.1.5 The minimum depth of foundation shall generally be not less than 1 m.

7.4.1.6 *Dimensional parameters*

The size and shape of the foundation adopted affect the magnitude of subgrade modulus and long term deformation of the supporting soil and this, in turn, influences the distribution of contact pressure. This aspect needs to be taken into consideration in the analysis.

7.4.1.7 *Eccentricity of loading*

A raft generally occupies the entire area of the building and often it is not feasible and rather uneconomical to proportion it coinciding the centroid of the raft with the line of action of the resultant force. In such cases, the effect of the eccentricity on contact pressure distribution shall be taken into consideration.

7.4.1.8 *Properties of supporting soil*

Distribution of contact pressure underneath a raft is affected by the physical characteristics of the soil supporting it. Consideration shall be given to the increased contact pressure developed along the edges of foundation on cohesive soils and the opposite effect on granular soils. Long term consolidation of deep soil layers shall be taken into account in the analysis. This may necessitate evaluation of contact pressure distribution both immediately after construction and after completion of the consolidation process. The design shall be based on the worst conditions.

7.4.1.9 *Rigidity of foundations*

Rigidity of the foundation tends to iron out uneven deformation and thereby modifies the contact pressure distribution. High order of rigidity is characterized by long moments and relatively small, uniform settlements. A rigid foundation may also generate high secondary stresses in structural members. The effect of rigidity shall be taken into account in analysis.

7.4.1.10 *Rigidity of the super structure*

Free response of the foundations to soil deformation is restricted by the rigidity of the superstructure. In the extreme case, a stiff structure may force a flexible foundation to behave as rigid. This aspect shall be considered to evaluate the validity of the contact pressure distribution.

7.4.1.11 *Modulus of elasticity and modulus of subgrade reaction*

Annex A enumerates the methods of determination of modulus of elasticity (E_s). The modulus of subgrade reaction (k) may be determined in accordance with Annex B.

7.4.2 *Necessary Information*

The following information is necessary for a satisfactory design and construction of a raft foundation:

a) Site plan showing the location of the proposed as well as the neighbouring structures;

b) Plan and cross-sections of building showing different floor levels, shafts and openings, etc, layout of load bearing walls, columns, shear walls, etc;

c) Loading conditions, preferably shown on a schematic plan indicating combination of design loads transmitted to the foundation;

d) Information relating to geological history of the area, seismicity of the area, hydrological information indicating ground water conditions and its seasonal variations, etc;

e) Geotechnical information giving subsurface profile with stratification details, engineering properties of the founding strata (namely, index properties, effective shear parameters determined under appropriate drainage conditions, compressibility characteristics, swelling properties, results of field tests like static and dynamic penetration tests, pressure meter tests, etc); and

f) A review of the performance of similar structure, if any, in the locality.

7.4.3 *Choice of Raft Type*

7.4.3.1 For fairly small and uniform column spacing and when the supporting soil is not too compressible a flat concrete slab having uniform thickness throughout (a true mat) is most suitable [*see* Fig. 7(A)].

7.4.3.2 A slab may be thickened under heavy loaded columns to provide adequate strength for shear and negative moment. Pedestals may also be provided in such cases [*see* Fig. 7(B)].

7.4.3.3 A slab and beam type of raft is likely to be more economical for large column spacing and unequal column loads particularly when the supporting soil is very compressive [*see* Fig. 7(C) and Fig. 7(D)].

7.4.3.4 For very heavy structures, provision of cellular raft or rigid frames consisting of slabs and basement walls may be considered.

7.4.4 *Methods of Analysis*

The essential task in the analysis of a raft foundation is the determination of the distribution of contact pressure underneath the raft which is a complex function of the rigidity of the superstructure, the supporting soil and the raft itself and cannot be determined with exactitude, except in very simple cases. This necessitates a number of simplifying assumptions to make the problem amenable to analysis. Once the distribution of contact pressure is determined, design bending moments and shears can be computed based on statics. The methods of analysis suggested are distinguished by the assumptions involved. Choice of a particular method should be governed by the validity of the assumptions in the particular case.

7.4.4.1 *Rigid foundation* (*conventional method*)

7.4.4.1.1 This method is based on the assumption of linear distribution of contact pressure. The basic assumptions of this method are:

a) the foundations rigid relative to the supporting soil and the compressible soil layer is relatively shallow; and

b) the contact pressure variation is assumed as planar, such that the centroid of the contact pressure coincides with the line of action of the resultant force of all loads acting on the foundation.

7.4.4.1.2 This method may be used when either of the following conditions is satisfied:

a) the structure behaves as rigid (due to the combined action of the superstructure and the foundation) with relative stiffness factor $K > 0.5$ (for evaluation of K, *see* Annex C); and

b) the column spacing is less than $1.75/\lambda$ (*see* Annex C).

7.4.4.1.3 The raft is analyzed as a whole in each of the two perpendicular directions. The contact pressure distribution is determined by the procedure outlined in Annex D. Further analysis is also based on statics.

7.4.4.1.4 In the case of uniform conditions when the variations in adjacent column loads and column spacings do not exceed 20 percent of the higher value, the raft may be divided into perpendicular strips of widths equal to the distance between mid-spans and each strip may be analyzed as an independent beam with known column loads and known contact pressures. Such beams will not normally satisfy statics due to shear transfer between adjacent strips and design may be based on suitable moment coefficients, or by moment distribution.

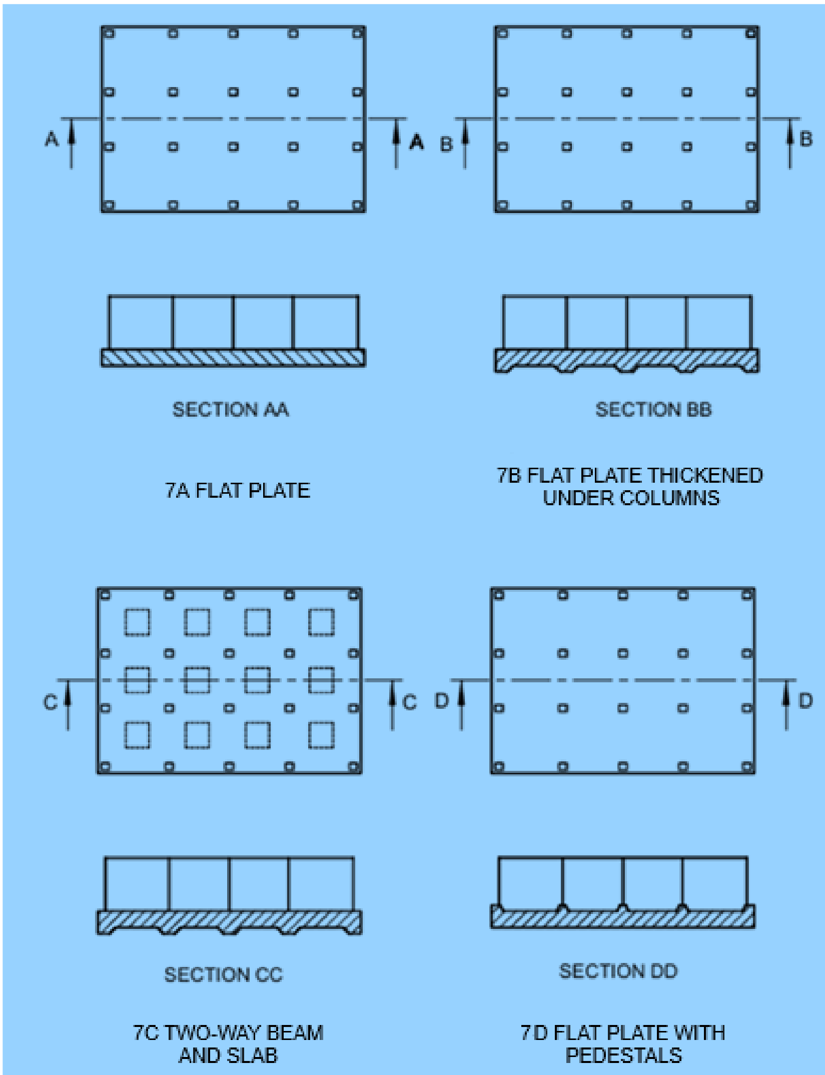
NOTE — On soft soils, for example, normally consolidated clays, peat, muck, organic silts, etc, the assumptions involved in the conventional method are commonly justified.

7.4.4.2 *Flexible foundations*

a) *Simplified method* — In this method, it is assumed that the subgrade consists of an infinite array of individual elastic springs each of which is not affected by others. The spring constant is equal to the modulus of subgrade reaction (*k*). The contact pressure at any point under the raft is, therefore, linearly proportional to the settlement at the point. Contact pressure may be determined as given in Annex E. This method may be used when all the following conditions are satisfied; and

   1) The structure (combined action of superstructure and raft) may be considered as flexible (relative stiffness factor $K < 0.5$, *see* Annex C); and

   2) Variation in adjacent column load does not exceed 20 percent of the higher value.



7A FLAT PLATE

7B FLAT PLATE THICKENED UNDER COLUMNS

7C TWO-WAY BEAM AND SLAB

7D FLAT PLATE WITH PEDESTALS

FIG.7 COMMON TYPES OF RAFT FOUNDATION

b) *General method* — For the general case of a flexible foundation not satisfying the requirements of (a) the method based on closed form solution of elastic plate theory may be used. This method is based on the theory of plates on winkler foundation which takes into account the restraint on deflection of a point provided by continuity of the foundation in orthogonal foundation. The distribution of deflection and contact pressure on the raft due to a column load is determined by the plate theory. Since the effect of a column load on an elastic foundation is damped out rapidly, it is possible to determine the total effect at a point of all column loads within the zone of influence by the method of superimposition. The computation of effect at any point may be restricted to columns of two adjoining bays in all directions. The procedure is outlined in Annex F.

7.5 Ring Foundations

For provisions regarding ring foundations, good practice [C-2(37)] shall be referred to.

7.6 Shell Foundations

For provisions regarding shell foundations, good practice [C-2(38)] shall be referred to.

8 DEEP FOUNDATIONS

8.1 Deep foundations are structural elements used to transfer loads from a building or structure through weak, compressible soil to stronger, more competent soil or rock at depth. They're essential when shallow foundations, such as footings, are not feasible due to inadequate bearing capacity or excessive settlement.

Some important types of deep foundations which are being used in building and other structures are as follows:

a) Pile foundations; and
    1) driven/bored cast *in-situ* concrete piles;
    2) driven precast concrete piles;
    3) precast concrete piles in prebored holes;
    4) under- reamed piles; and
    5) timber piles.
b) Pier foundation

8.2 Driven/Bored Cast *In-Situ* Concrete Piles

8.2.1 *General*

Piles find application in foundations to transfer loads from a structure to competent subsurface strata having adequate load-bearing capacity. The load transfer mechanism from a pile to the surrounding ground is complicated and is not yet fully understood, although application of pile foundations is in practice over many decades. Broadly, piles transfer axial loads either substantially by friction along its shaft and/or by end bearing. Piles are used where either of the above load transfer mechanism is possible depending upon the subsoil stratification at a particular site. Construction of pile foundations require a careful choice of piling system depending upon the subsoil conditions, the load characteristics of a structure and the limitations of total settlement, differential settlement and any other special requirement of a project.

8.2.2 *Materials and Stresses*

8.2.2.1 *Concrete*

Consistency of concrete to be used shall be consistent with the method of installation of piles. Concrete shall be so designed or chosen as to have a homogeneous mix having a slump/workability consistent with the method of concreting under the given conditions of pile installation.

The slump should be 150 mm to180 mm at the time of pouring.

The minimum grade of concrete to be used for bored piling shall be M 25. For sub-aqueous concrete, the requirements specified in Part C ‘Structural Design/ Section 5 Structural Concrete’ of this NBCS shall be followed. The minimum cement content shall be 400 kg/m^3. However, with proper mix design and use of proper admixture the cement content may be reduced but in no case the cement content shall be less than 350 kg/m^3 [*See also* Table 5 (and Notes thereunder) of Part C ‘Structural Design/ Section 5 Structural Concrete’ of this NBCS].

For the concrete, water and aggregates, specifications laid down in Part C ‘Structural Design/ Section 5 Structural Concrete’ of this NBCS shall be followed in general.

The average compressive stress under working load should not exceed 25 percent of the specified works cube strength at 28 days calculated on the total cross-sectional area of the pile. Where the casing of the pile is permanent, of adequate thickness and of suitable shape, the allowable compressive stress may be increased.

8.2.2.2 *Steel reinforcement*

Steel reinforcement shall conform to any one of the types of steel specified in Part C 'Structural Design/ Section 5 Structural Concrete' of this NBCS.

8.2.3 *Design Considerations*

8.2.3.1 *General*

Pile foundations shall be designed in such a way that the load from the structure can be transmitted to the subsurface with adequate factor of safety against shear failure of subsurface and without causing such settlement (differential or total), which may result in structural damage and/or functional distress under permanent/transient loading. The pile shaft should have adequate structural capacity to withstand all loads (vertical, axial or otherwise) and moments which are to be transmitted to the subsoil and shall be designed according to Part C 'Structural Design/ Section 5 Structural Concrete' of this NBCS.

8.2.3.2 *Adjacent structures*

8.2.3.2.1 When working near existing structures, care shall be taken to avoid damage to such structures. The good practice [C-2(39)] may be used as a guide for studying qualitatively the effect of vibration on persons and structures.

8.2.3.2.2 In case of deep excavations adjacent to piles, proper shoring or other suitable arrangement shall be made to guard against undesired lateral movement of soil.

8.2.3.3 *Pile capacity*

The load carrying capacity of a pile depends on the properties of the soil in which it is embedded. Axial load from a pile is normally transmitted to the soil through skin friction along the shaft and end bearing at its tip. A horizontal load on a vertical pile is transmitted to the subsoil primarily by horizontal subgrade reaction generated in the upper part of the shaft. Lateral load capacity of a single pile depends on the soil reaction developed and the structural capacity of the shaft under bending. It would be essential to investigate the lateral load capacity of the pile using appropriate values of horizontal subgrade modulus of the soil. Alternatively, piles may be installed in rake.

8.2.3.3.1 The ultimate load capacity of a pile may be estimated by means of static formula on the basis of soil test results, or by using a dynamic pile formula using data obtained during driving the pile. However, dynamic pile driving formula should be generally used as a measure to control the pile driving at site. Pile capacity should preferably be confirmed by initial load tests {*see* good practice [C-2(40)]}. For rock-socketed piles, reference shall also be made to good practice [C-2(41)] for estimating the load capacity of piles.

The settlement of pile obtained at safe load/working load from load-test results on a single pile shall not be directly used for estimating the settlement of a structure. The settlement may be determined on the basis of subsoil data and loading details of the structure as a whole using the principles of soil mechanics.

8.2.3.3.1.1 *Static formula*

The ultimate load capacity of a single pile may be obtained by using static analysis, the accuracy being dependent on the reliability of the soil properties for various strata. When computing capacity by static formula, the shear strength parameters obtained from a limited number of borehole data and laboratory tests should be supplemented, wherever possible by *in-situ* shear strength obtained from field tests. The two separate static formulae, commonly applicable for cohesive and non-cohesive soil respectively, are indicated in Annex G. Other formula based on static cone penetration test {*see* the accepted standards [C-2(42)]} and standard penetration test {*see* the accepted standard [C-2(6)]} are given in **G-3** and **G-4**.

8.2.3.3.1.2 *Dynamic formula*

For driven piles, any established dynamic formula may be used to control the pile driving at site giving due consideration to limitations of various formulae.

Whenever, double acting diesel hammers or hydraulic hammers are used for driving of piles, manufacturer's guidelines about energy and set criteria may be referred to. Dynamic formulae are not directly applicable to cohesive soil deposits such as saturated silts and clays as the resistance to impact of the tip of the casing will be exaggerated by their low permeability while the frictional resistance on the sides is reduced by lubrication.

8.2.3.3.1.3 *Load test results*

The ultimate load capacity of a single pile is determined with reasonable accuracy from test loading as per good practice [C-2(40)]. The load test on a pile shall not be carried out earlier than four weeks from the time of casting the pile.

8.2.3.3.1.4 *Uplift capacity*

The uplift capacity of a pile is given by sum of the frictional resistance and the weight of the pile (buoyant or total as relevant). The recommended factor of safety is 3.0 in the absence of any pullout test results and 2.0 with pullout test results. Uplift capacity can be obtained from static formula (*see* Annex G) by ignoring end bearing but adding weight of the pile (buoyant or total as relevant).

8.2.3.4 *Negative skin friction or dragdown force*

When a soil stratum, through which a pile shaft has penetrated into a underlying hard stratum, compresses as a result of either it being unconsolidated or it being under a newly placed fill or as a result of remoulding during driving of the pile, a dragdown force is generated along the pile shaft up to a point in depth where the surrounding soil does not move downward relative to the pile shaft. Existence of such a phenomenon shall be assessed and suitable correction shall be made to the allowable load where appropriate.

8.2.3.5 *Structural capacity*

The piles shall have necessary structural strength to transmit the loads imposed on it, ultimately to the soil. In case of uplift, the structural capacity of the pile, that is, under tension should also be considered.

8.2.3.5.1 *Axial capacity*

Where a pile is completely embedded in the soil (having an undrained shear strength not less than 0.01 N/mm^2), its axial load carrying capacity is not necessarily limited by its strength as a long column. Where piles are installed through very weak soils (having an undrained shear strength less than 0.01 N/mm^2), special considerations shall be made to determine whether the shaft would behave as a long column or not. If necessary, suitable reductions shall be made for its structural strength following the normal structural principles covering the buckling phenomenon.

When the finished pile projects above ground level and is not secured against buckling by adequate bracing, the effective length will be governed by the fixity imposed on it by the structure it supports and by the nature of the soil into which it is installed. The depth below the ground surface to the lower point of contraflexure varies with the type of the soil. In good soil the lower point of contraflexure may be taken at a depth of 1 m below ground surface subject to a minimum of 3 times the diameter of the shaft. In weak soil (undrained shear strength less than 0.01 N/mm^2) such as soft clay or soft silt, this point may be taken at about half the depth of penetration into such stratum but not more than 3 m or 10 times the diameter of the shaft, whichever is more. The degree of fixity of the position and inclination of the pile top and the restraint provided by any bracing shall be estimated following accepted structural principles.

The permissible stress shall be reduced in accordance with similar provision for reinforced concrete columns as laid down in Part C 'Structural Design/ Section 5 Structural Concrete' of this NBCS.

8.2.3.5.2 *Lateral load capacity*

A pile may be subjected to lateral force for a number of causes, such as wind, earthquake, water current, earth pressure, effect of moving vehicles or ships, plant and equipment, etc. The lateral load capacity of a single pile depends not only on the horizontal subgrade modulus of the surrounding soil but also on the structural strength of the pile shaft against bending, consequent upon application of a lateral load. While considering lateral load on piles, effect of other co-existent loads, including the axial load on the pile, should be taken into consideration for checking the structural capacity of the shaft. A recommended method for the pile analysis under lateral load is given in Annex H.

Because of limited information on horizontal subgrade modulus of soil and pending refinements in the theoretical analysis, it is suggested that the adequacy of a design should be checked by an actual field load test. In the zone of soil susceptible to liquefaction, the lateral resistance of the soil shall not be considered.

8.2.3.5.2.1 *Fixed and free head conditions*

A group of three or more piles connected by a rigid pile cap shall be considered to have fixed head condition. Caps for single piles shall be interconnected by grade beams in two directions and for twin piles by grade beams in a line transverse to the common axis of the pair so that the pile head is fixed. In all other conditions the pile shall be taken as free headed.

8.2.3.5.3 *Raker piles*

Raker piles are normally provided where vertical piles cannot resist the applied horizontal forces. Generally, the rake will be limited to 1 horizontal to 6 vertical. In the preliminary design, the load on a raker pile is generally considered to be axial. The distribution of load between raker and vertical piles in a group may be determined by graphical or analytical methods. Where necessary, due consideration should be made for secondary bending induced as a result of the pile cap movement, particularly when the cap is rigid. Free-standing raker piles are subjected to bending moments due to their own weight or external forces from other causes. Raker piles, embedded in fill or consolidating deposits, may become laterally loaded owing to the settlement of the surrounding soil. In consolidating clay, special precautions, like provision of permanent casing should be taken for raker piles.

8.2.3.6 *Spacing of piles*

The minimum centre to centre spacing of pile is considered from three aspects, namely:

a) Practical aspects of installing the piles;

b) Diameter of the pile; and

c) Nature of the load transfer to the soil and possible reduction in the load capacity of piles group.

NOTE — In the case of piles of non-circular cross-section, diameter of the circumscribing circle shall be adopted.

8.2.3.6.1 In case of piles founded on hard stratum and deriving their capacity mainly from end bearing the minimum spacing shall be 2.5 times the diameter of the circumscribing circle corresponding to the cross-section of the pile shaft. In case of piles resting on rock, the spacing of two times the said diameter may be adopted.

8.2.3.6.2 Piles deriving their load carrying capacity mainly from friction shall be spaced sufficiently apart to ensure that the zones of soils from which the piles derive their support do not overlap to such an extent that their bearing values are reduced. Generally, the spacing in such cases shall not be less than 3 times the diameter of the pile shaft.

8.2.3.7 *Pile groups*

8.2.3.7.1 In order to determine the load carrying capacity of a group of piles a number of efficiency equations are in use. However, it is difficult to establish the accuracy of these efficiency equations as the behaviour of pile group is dependent on many complex factors. It is desirable to consider each case separately on its own merits.

8.2.3.7.2 The load carrying capacity of a pile group may be equal to or less than the load carrying capacity of individual piles multiplied by the number of piles in the group. The former holds true in case of friction piles, driven into progressively stiffer materials or in end-bearing piles. For driven piles in loose sandy soils, the group capacity may even be higher due to the effect of compaction. In such cases a load test may be carried out on a pile in the group after all the piles in the group have been installed.

8.2.3.7.3 In case of piles deriving their support mainly from friction and connected by a rigid pile cap, the group may be visualized as a block with the piles embedded within the soil. The ultimate load capacity of the group may then be obtained by taking into account the frictional capacity along the perimeter of the block and end bearing at the bottom of the block using the accepted principles of soil mechanics.

8.2.3.7.3.1 When the cap of the pile group is cast directly on reasonably firm stratum which supports the piles, it may contribute to the load carrying capacity of the group. This additional capacity along with the individual capacity of the piles multiplied by the number of piles in the group shall not be more than the capacity worked out as per 8.2.3.7.3.

8.2.3.7.4 When a pile group is subjected to moment either from superstructure or as a consequence of inaccuracies of installation, the adequacy of the pile group in resisting the applied moment should be checked. In case of a single pile subjected to moment due to lateral loads or eccentric loading, beams may be provided to restrain the pile cap effectively from lateral or rotational movement.

8.2.3.7.5 In case of a structure supported on single piles/group of piles resulting in large variation in the number of piles from column to column it may result in excessive differential settlement. Such differential settlement should be either catered for in the structural design or it may be suitably reduced by judicious choice of variations in the actual pile loading. For example, a single pile cap may be loaded to a level higher than that of the pile in a group in order to achieve reduced differential settlement between two adjacent pile caps supported on different number of piles.

8.2.3.8 *Factor of safety*

8.2.3.8.1 Factor of safety should be chosen after considering:

a) the reliability of the calculated value of ultimate load capacity of a pile;

b) the types of superstructure and the type of loading; and

c) allowable total/differential settlement of the structure.

8.2.3.8.2 When the ultimate load capacity is determined from either static formula or dynamic formula, the factor of safety would depend on the reliability of the formula and the reliability of the subsoil parameters used in the computation. The minimum factor of safety on static formula shall be 2.5. The final selection of a factor of safety shall take into consideration the load settlement characteristics of the structure as a whole at a given site.

8.2.3.8.3 Higher value of factor of safety for determining the safe load on piles may be adopted, where:

a) settlement is to be limited or unequal settlement avoided;

b) large impact or vibrating loads are expected; and

c) the properties of the soil may deteriorate with time.

8.2.3.9 *Transient loading*

The maximum permissible increase over the safe load of a pile, as arising out of wind loading, is 25 percent. In case of loads and moments arising out of earthquake effects, the increase of safe load on a single pile shall be as given in 7.2.2.4.2. For transient loading arising out of superimposed loads, no increase is allowed.

8.2.3.10 *Overloading*

When a pile in a group, designed for a certain safe load is found, during or after execution, to fall just short of the load required to be carried by it, an overload up to 10 percent of the pile capacity may be allowed on each pile. The total overloading on the group should not, however, be more than 10 percent of the capacity of the group subject to the increase of the load on any pile being not more than 25 percent of the allowable load on a single pile.

8.2.3.11 *Reinforcement*

8.2.3.11.1 The design of the reinforcing cage varies depending upon the driving and installation conditions, the nature of the subsoil and the nature of load to be transmitted by the shaft - axial, or otherwise. The minimum area of longitudinal reinforcement of any type or grade within the pile shaft shall be 0.4 percent of the cross-sectional area of the pile shaft. The minimum reinforcement shall be provided throughout the length of the shaft.

8.2.3.11.2 The curtailment of reinforcement along the depth of the pile, in general, depends on the type of loading and subsoil strata. In case of piles subjected to compressive load only, the designed quantity of reinforcement may be curtailed at appropriate level according to the design requirements. For piles subjected to uplift load, lateral load and moments, separately or with compressive loads, it would be necessary to provide reinforcement for the full depth of pile. In soft clays or loose sands, or where there may be danger to green concrete due to driving of adjacent piles, the reinforcement should be provided to the full pile depth, regardless of whether or not it is required from uplift and lateral load considerations. However, in all cases, the minimum reinforcement specified in **8.2.3.11.1** shall be provided throughout the length of the shaft.

8.2.3.11.3 Piles shall always be reinforced with a minimum amount of reinforcement as dowels keeping the minimum bond length into the pile shaft below its cut-off level and with adequate projection into the pile cap, irrespective of design requirements.

8.2.3.11.4 Clear cover to all main reinforcement in pile shaft shall be not less than 50 mm. The laterals of a reinforcing cage may be in the form of links or spirals. The diameter and spacing of the same is chosen to impart adequate rigidity of the reinforcing cage during its handling and installations. The minimum diameter of the links or spirals shall be 8 mm and the spacing of the links or spirals shall be not less than 150 mm. Stiffner rings preferably of 16 mm diameter at every 1.5 m centre to centre should be provided along the length of the cage for providing rigidity to reinforcement cage. Minimum 6 numbers of vertical bars shall be used for a circular pile and minimum diameter of vertical bar shall be 12 mm. The clear horizontal spacing between the adjacent vertical bars shall be four times the maximum aggregate size in concrete. If required, the bars can be bundled to maintain such spacing.

8.2.3.12 *Design of pile cap*

8.2.3.12.1 The pile caps may be designed by assuming that the load from column is dispersed at 45º from the top of the cap to the mid-depth of the pile cap from the base of the column or pedestal. The reaction from piles may also be taken to be distributed at 45º from the edge of the pile, up to the mid-depth of the pile cap. On this basis the maximum bending moment and shear forces should be worked out at critical sections. The method of analysis and allowable stresses should be in accordance with Part C 'Structural Design/ Section 5 Structural Concrete' of this NBCS.

8.2.3.12.2 Pile cap shall be deep enough to allow for necessary anchorage of the column and pile reinforcement.

8.2.3.12.3 The pile cap should be rigid enough so that the imposed load could be distributed on the piles in a group equitably.

8.2.3.12.4 In case of a large cap, where differential settlement may occur between piles under the same cap, due consideration for the consequential moment should be given.

8.2.3.12.5 The clear overhang of the pile cap beyond the outermost pile in the group shall be a minimum of 150 mm.

8.2.3.12.6 The cap is generally cast over a 75 mm thick levelling course of concrete. The clear cover for main reinforcement in the cap slab shall not be less than 60 mm.

8.2.3.12.7 The embedment of pile into cap should be 75 mm.

8.2.3.13 *Grade beams*

8.2.3.13.1 The grade beams supporting the walls shall be designed taking due account of arching effect due to masonry above the beam. The beam with masonry due to composite action behaves as a deep beam.

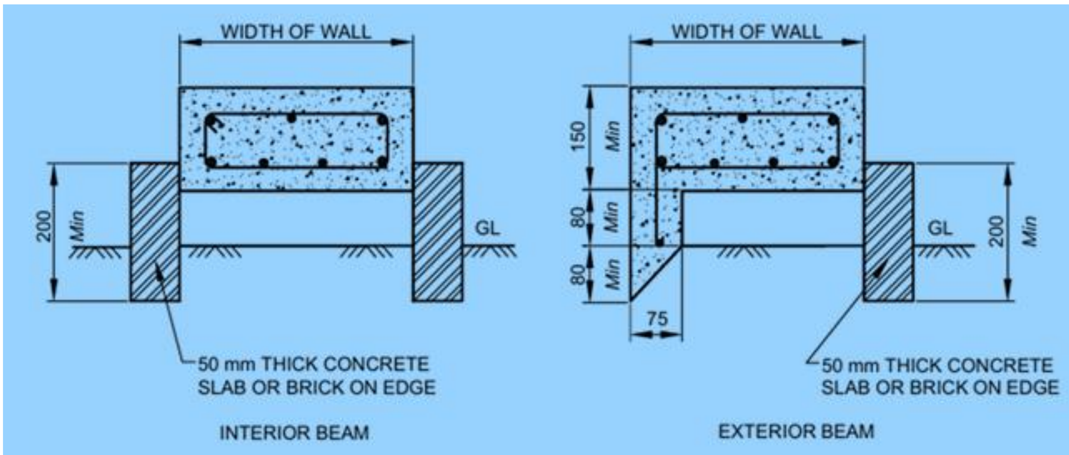
For the design of grade beams, a maximum bending moment of $\frac{wl^2}{30}$, where w is uniformly distributed load per metre run and l is the effective span in metres, shall be considered. For considering composite action, the minimum height of wall shall be 0.6 times the pile spacing. The brick strength should not be less than 3 N/mm^2. For concentrated and other loads which come directly over the beam, full bending moment should be considered.

8.2.3.13.2 The minimum overall depth of grade beams shall be 200 mm. An equal amount of reinforcement may be provided at the bottom and top of the beam. The longitudinal reinforcement both at top and bottom should not be less than three bars of 12 mm diameter with clear cover space of 50 mm. Spacing of stirrups of 8 mm diameter bars should not be more than the depth of grade beam.

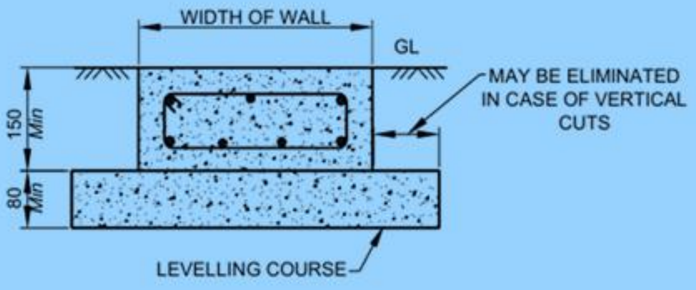
8.2.3.13.3 In expansive soils, the grade beams and 75 mm levelling concrete course shall be provided over 40 mm down gravel layer/mechanically stabilized mix (MSM) layer having a minimum compacted thickness of 300 mm and minimum width equal to five times the width of grade beams (*see* Fig. 8).

8.2.3.13.4 In the case of exterior beams over piles in expansive soils, plinth protection with proper slope shall be provided.

8.2.4 For detailed information on driven/bored cast *in-situ* concrete piles regarding control of piling, installation, defective pile and recording of data, reference shall be made to good practice [C-2(43)].


WIDTH OF WALL
WIDTH OF WALL
200
Min
GL
150
Min
80
Min
80
Min
75
GL
200
Min
50 mm THICK CONCRETE SLAB OR BRICK ON EDGE
50 mm THICK CONCRETE SLAB OR BRICK ON EDGE
INTERIOR BEAM
EXTERIOR BEAM

8A BEAM IN EXPANSIVE SOILS


WIDTH OF WALL
GL
150
Min
80
Min
MAY BE ELIMINATED IN CASE OF VERTICAL CUTS
LEVELLING COURSE

8B BEAM IN NON-EXPANSIVE SOILS

All dimensions in millimetres.

FIG.8 TYPICAL SECTIONS OF GRADE BEAMS

8.2.5 *Bored Cast In-Situ Concrete Piles on Rocks*

Design and construction of bored cast *in-situ* piles founded on rocks shall be carried out in accordance with good practice [C-2(41)].

8.2.6 *Non-Destructive Testing*

For quality assurance of concrete piles, non-destructive integrity test may be carried out prior to laying of beam/caps, in accordance with accepted standard [C-2(44)].

8.3 Driven Precast Concrete Piles

8.3.1 Provisions of **8.2** except **8.2.3.11** shall generally apply.

8.3.2 *Design of Pile Section*

8.3.2.1 Design of pile section shall be such as to ensure the strength and soundness of the pile against lifting from the casting bed, transporting, handling and driving stresses without damage.

8.3.2.2 Any shape having radial symmetry will be satisfactory for precast piles. The most commonly used cross-sections are square and octagonal.

8.3.2.3 Where exceptionally long lengths of piles are required, hollow sections can be used. If the final condition requires larger cross-sectional area, the hollow sections may be filled with concrete after driving in position.

8.3.2.4 Wherever, final pile length is so large that a single length precast pile unit is either uneconomical or impracticable for installation, the segmental precast RCC piles with a number of segments using efficient mechanical jointing could be adopted.

Excessive whipping during handling precast pile may generally be avoided by limiting the length of pile to a maximum of 50 times the least width. As an alternative, segmental precast piling technique could be used.

The design of joints shall take care of corrosion by providing additional sacrificial thickness for the joint, wherever warranted.

8.3.2.5 Stresses induced by bending in the cross-section of precast pile during lifting and handling may be estimated as for any reinforced concrete section in accordance with relevant provisions of Part C 'Structural Design/ Section 5 Structural Concrete' of this NBCS. The calculations for bending moment for different support conditions during handling are given in Table 5.

Table 5 Bending Moment for Different Support Conditions (*Clause* 8.3.2.5)

Sl No. (1)	Number of Points of Pick Up (2)	Location of Support From End in Terms of Length of Pile For Minimum Moments (3)	Bending Moment to be Allowed for Design Kn-M (4)
i)	One	0.293 L	4.3 WL
ii)	Two	0.207 L	2.2 WL
iii)	Three	0.145 L, the middle point will be at the centre	1.05 WL

NOTE — W = weight of pile, in kN;

L = length of pile, in m.

8.3.2.6 The driving stresses on a pile may be estimated by the following formula:

$$\frac{\text{Driving resistance}}{\text{Cross}-\text{sectional area of the pile}}\times[\frac{2}{\sqrt{n}}-1]$$

where

n = efficiency of the blow (*see* 8.3.2.6.1 for probable value of n).

NOTE — For the purpose of this formula, cross-sectional area of the pile shall be calculated as the overall sectional area of the pile including the equivalent area for reinforcement.

8.3.2.6.1 The formula for efficiency of the blow, representing the ratio of energy after impact to striking energy of ram, n, is:

where W is greater than $P.e$ and the pile is driven into penetrable ground,

$$\boldsymbol{n} = \frac{\boldsymbol{W} + (\boldsymbol{P}\cdot\boldsymbol{e}^2)}{\boldsymbol{W} + \boldsymbol{P}}$$

where W is less than $P.e$ and the pile is driven into penetrable ground,

$$\boldsymbol{n} = [\frac{\boldsymbol{W}+(\boldsymbol{P}\cdot\boldsymbol{e}^2)}{\boldsymbol{W}+\boldsymbol{P}}] - [\frac{\boldsymbol{W} - (\boldsymbol{P}\cdot\boldsymbol{e})}{\boldsymbol{W} + \boldsymbol{P}}]^2$$

The following are the values of n in relation to e and to the ratio of P/W:

Sl No.	*Ratio of P/W*	*e = 0.5*	*e = 0.4*	*e = 0.32*	*e = 0.25*	*e = 0*
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	½	0.75	0.72	0.70	0.69	0.67
ii)	1	0.63	0.58	0.55	0.53	0.50
iii)	1½	0.55	0.50	0.47	0.44	0.40
iv)	2	0.50	0.44	0.40	0.37	0.33
v)	2½	0.45	0.40	0.36	0.33	0.28
vi)	3	0.42	0.36	0.33	0.30	0.25
vii)	3½	0.39	0.33	0.30	0.27	0.22
viii)	4	0.36	0.31	0.28	0.25	0.20
ix)	5	0.31	0.27	0.24	0.21	0.16
x)	6	0.27	0.24	0.21	0.19	0.14
xi)	7	0.24	0.21	0.19	0.17	0.12
xii)	8	0.22	0.20	0.17	0.15	0.11

NOTES

1 W = mass of the ram, in tonne and P = weight of the pile, anvil, helmet and follower (if any), in tonne.

2 Where the pile finds refusal in rock, $0.5P$ should be substituted for P in the above expressions for n.

3 e is the coefficient of restitution of the materials under impact as tabulated below:

a) For steel ram of double-acting hammer striking on steel anvil and driving reinforced concrete pile, e = 0.5;

b) For cast-iron ram of single-acting or drop hammer striking on head of reinforced concrete pile, e = 0.4;

c) Single-acting or drop hammer striking a well-conditioned driving cap and helmet with hard wood dolly in driving reinforced concrete piles or directly on head of timber pile, e = 0.25; and

d) For a deteriorated condition of the head of pile or of dolly, e = 0.

8.3.3 *Reinforcement*

8.3.3.1 The longitudinal reinforcement of any type or grade shall be provided in precast reinforced concrete piles for the entire length. All the main longitudinal bars shall be of the same length and should fit tightly into the pile shoe, if there is one. Shorter rods to resist local bending moments may be added but the same should be carefully detailed to avoid any sudden discontinuity of the steel which may lead to cracks during heavy driving. The area of main longitudinal reinforcement shall not be less than the following percentages of the cross-sectional area of the piles:

a) For piles with a length less than 30 times the least width: 1.25 percent;

b) For piles with a length 30 to 40 times the least width: 1.5 percent; and

c) For piles with a length greater than 40 times the least width: 1.5 percent.

8.3.3.2 Piles shall always be reinforced with a minimum amount of reinforcement as dowels keeping the minimum bond length into the pile shaft below its cut-off level and with adequate projection into the pile cap, irrespective of design requirements.

8.3.3.3 Clear cover to all main reinforcement in pile shaft shall be not less than 50 mm. The laterals of a reinforcing cage may be in the form of links or spirals. The diameter and spacing of the same is chosen to impart adequate rigidity of the reinforcing cage during its handing and installations. The minimum diameter of the links or spirals shall be 8 mm and the spacing of the links or spirals shall be not less than 150 mm Stiffner rings preferably of 16 mm diameter at every 1.5 m centre to centre to be provided along the length of the cage for providing rigidity to reinforcement cage. Minimum 6 numbers of vertical bars shall be used for a circular pile and minimum diameter of vertical bar shall be 12 mm. The clear horizontal spacing between the adjacent vertical bars shall be four times the maximum aggregate size in concrete. If required, the bars may be bundled to maintain such spacing.

8.3.4 Additional provision for prestressed concrete piles shall be as per good practice [C-2(45)].

8.3.5 For detailed information regarding casting and curing, storing and handling, control of pile driving and recording of data, reference shall be made to good practice [C-2(45)].

8.3.6 *Non-Destructive Testing*

For quality assurance of concrete piles, non-destructive integrity test may be carried out prior to laying of beam/caps, in accordance with good practice [C-2(44)].

8.4 Precast Concrete Piles in Prebored Holes

8.4.1 Provisions of **8.3** except **8.3.3** shall generally apply.

8.4.2 *Handling Equipment for Lowering and Grouting Plant*

Handling equipment such as crane, scotch derricks, movable gantry may be used for handling and lowering the precast piles in the bore. The choice of equipment will depend upon length, mass and other practical requirements.

The mixing of the grout shall be carried out in any suitable high speed colloidal mixer. Normally the colloidal mixer is adequate to fill the annular space with grouts. Where this is not possible, a suitable grout pump shall be used.

8.4.3 *Reinforcement*

8.4.3.1 The design of the reinforcing cage varies depending upon the handling and installation conditions, the nature of the subsoil and the nature of load to be transmitted by the shaft - axial, or otherwise. The minimum area of longitudinal reinforcement of any type or grade within the pile shaft shall be 0.4 percent of the cross-sectional area of the pile shaft or as required to cater for handling stresses (*see* **8.3.2.5**), whichever is greater. The minimum reinforcement shall be provided throughout the length of the shaft.

8.4.3.2 Piles shall always be reinforced with a minimum amount of reinforcement as dowels keeping the minimum bond length into the pile shaft below its cut-off level and with adequate projection into the pile cap, irrespective of design requirements.

8.4.3.3 Clear cover to all main reinforcement in pile shaft shall be not less than 50 mm. The laterals of a reinforcing cage may be in the form of links or spirals. The diameter and spacing of the same is chosen to impart adequate rigidity of the reinforcing cage during its handing and installations. The minimum diameter of the links or spirals shall be 8 mm and the spacing of the links or spirals shall be not less than 150 mm. Stiffner rings preferably of 16 mm diameter at every 1.5 m centre to centre to be provided along length of the cage for providing rigidity to reinforcement cage. Minimum 6 numbers of vertical bars shall be used for a circular pile and minimum diameter of vertical bar shall be 12 mm. The clear horizontal spacing between the adjacent vertical bars shall be four times the maximum aggregate size in concrete. If required, the bars may be bundled to maintain such spacing.

8.4.3.4 A thin gauge sheathing pipe of approximately 40 mm diameter may be attached to the reinforcement cage, in case of solid piles, to form the central duct for pumping grout to the bottom of the bore. The bottom end of the pile shall have proper arrangements for flushing/cleaning for grouting. Air lift technique may be used for cleaning the borehole, however this technique should be used carefully in case of silty and sandy soil.

8.4.4 For detailed information regarding casting and curing, storing and handling, control of pile installation and recording of data, reference shall be made to good practice [C-2(46)].

8.4.5 *Non-Destructive Testing*

For quality assurance of concrete piles, non-destructive integrity test may be carried out prior to laying of beam/caps, in accordance with accepted standard [C-2(44)].

8.5 Under-Reamed Piles

8.5.1 *General*

Under-reamed piles are bored cast *in-situ* and bored compaction concrete types having one or more bulbs formed by suitably enlarging the borehole for the pileshaft. These piles are suited for expansive soils which are often subjected to considerable ground movements due to seasonal moisture variations. These also find wide application in other soil strata where economics are favorable. When the ground consists of expansive soil, for example black cotton soils, the bulb of under-reamed pile provide anchorage against uplift due to swelling pressure, apart from the increased bearing, provided topmost bulb is formed close to or just below the bottom of active zone. Negative slopes may not be stable in certain strata conditions, for example, in pure sands (clean sands with fines less than five per cent) and very soft clayey strata having N of SPT less than 2 (undrained shear strength of less than 12.5 kN/m^2). Hence formation of bulb(s) in such strata is not advisable. In subsoil strata above water table, the maximum number of bulbs in under-reamed pile should be restricted to four. In the strata such as clay, silty clay and clayey silt with high water table where sides of bore hole stand by itself without needing any stabilization by using drilling mud or otherwise, the maximum number of bulbs in under-reamed piles should be restricted to two. In strata for example clayey sand, silty sand and sandy silt with high water table where bore hole needs stabilization by using drilling mud, under-reamed piles with more than one bulb shall not be used. In loose to medium pervious strata such as clayey sand, silty sand and sandy silt strata, compaction under-reamed piles may be used as the process of compaction increases the load carrying capacity of piles. From practical considerations, under-reamed piles of more than 10 m depth shall not be used without ensuring their construction feasibility and load carrying capacity by initial load tests in advance. In view of additional anchorage available with the provision of bulbs, under-reamed piles can be used with advantage to resist uplift loads.

8.5.2 *Materials*

Provisions of 8.2.2 shall generally apply.

8.5.3 *Design Considerations*

8.5.3.1 *General*

Under-reamed pile foundation shall be designed in such a way that the load from the structure they support can be transmitted to the sub-surface with adequate factor of safety against shear failure of sub-surface and without causing such settlement (differential or total) which may result in structural damage and/or functional distress under permanent/transient loading. The pile shaft should have adequate structural capacity to withstand all loads (vertical compression, uplift, lateral) and moments which are to be transmitted to the subsoil and shall be designed according to [C-2(47)].

8.5.3.1.1 In expansive soils, the minimum length of piles shall be 3.5 m below ground level. In case of expansive soil deposits of shallow depth overlying non-expansive competent strata or rock, piles of shorter length can also be provided.

However, in case of high to very high expansive soils, due care shall be taken to establish the minimum depth of pile with the top-most (first) bulb located below the level of significant moisture variations/active zone.

8.5.3.1.2 The diameter of under-reamed bulbs may vary from 2 times to 2.5 times shaft diameter depending upon the feasibility of construction and design requirements. In bored cast *in-situ* under-reamed piles and under-reamed bored compaction piles, the bulb diameter shall be normally 2.5 times and 2 times the shaft diameter, respectively.

8.5.3.1.3 The spacing of bulbs should not be less than 1.5 times the diameter of bulb.

8.5.3.1.4 The first bulb should be at a minimum depth of 2 times the bulb diameter below ground level or cut-off level, whichever is lower.

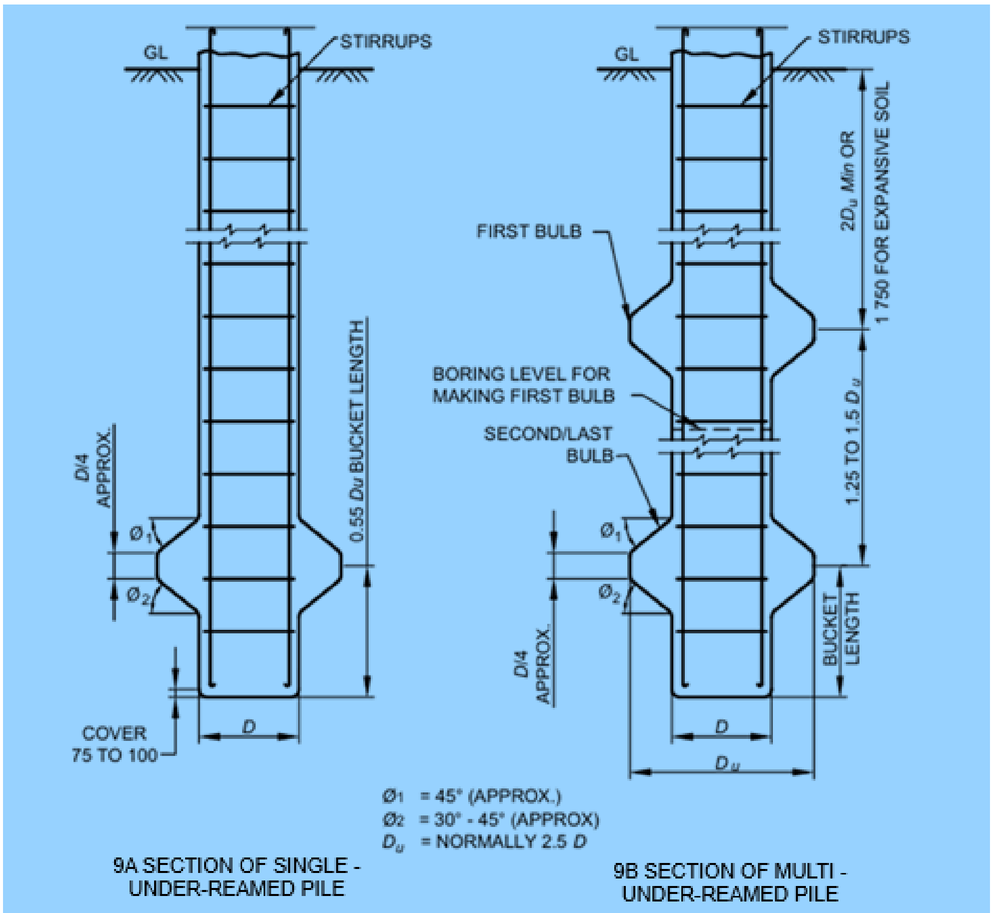
8.5.3.1.5 Under-reamed piles with more than two bulbs are not advisable without ensuring their feasibility in strata needing stabilization of boreholes by drilling mud. The number of bulbs in case of under-reamed bored compaction piles should not exceed two in such strata.

8.5.3.1.6 The minimum diameter of pile shaft shall be 250 mm. However, in case of strata/ground water consisting of excessive chemicals such as sulphates and chlorides, or piles with tremie concreting, the minimum diameter of the pile shaft shall be 300 mm.

8.5.3.1.7 Under-reamed batter piles in dry soil conditions can be constructed with batter not exceeding 15°.

8.5.3.1.8 The construction feasibility of under-ream/ bulb should be examined as per soil characteristics, particularly in case of clean/river sands.

8.5.3.1.9 For guidance, typical details of bored cast *in-situ* under-reamed pile foundations are shown in Fig. 9.


GL
STIRRUPS
D/4 APPROX.
Ø1
Ø2
0.55 Du BUCKET LENGTH
COVER
75 TO 100
D
GL
STIRRUPS
FIRST BULB
BORING LEVEL FOR
MAKING FIRST BULB
SECOND/LAST
BULB
2D_u Min OR
1 750 FOR EXPANSIVE SOIL
1.25 TO 1.5 D_u
BUCKET LENGTH
Ø1
Ø2
D/4 APPROX.
D
D_u

Ø1 = 45° (APPROX.)
Ø2 = 30° - 45° (APPROX)
D_u = NORMALLY 2.5 D

9A SECTION OF SINGLE - UNDER-REAMED PILE

9B SECTION OF MULTI - UNDER-REAMED PILE

FIG. 9 TYPICAL DETAILS OF BORED CAST IN-SITU UNDER-REAMED PILE FOUNDATION

8.5.3.2 *Safe load*

Safe load on a pile shall be taken as the least of the following:

a) By calculating the ultimate load from soil properties and applying a suitable factor of safety (*see* Annex J);

b) By load test on pile as good practice [C-2(40)]; and

c) From safe load tables.

8.5.3.2.1 *Load test*

Provisions of 8.2.3.3.1.3 shall generally apply.

8.5.3.2.2 In the absence of detailed subsoil investigations and pile load tests for minor and less important structures, a rough estimate of safe load on piles may be made from the safe load table given in the good practice [C-2(48)].

NOTE — Safe loads as given in the above referred Table are symptomatic. Safe load carrying capacity of pile shall be worked out for the actual geotechnical data using 6.2.3.1 of good practice [C-2(48)], subjected to confirmation by initial pile load test in accordance with good practice [C-2(39)] and other provisions in 6.2.3.2 of good practice [C-2(48)].

8.5.3.3 *Negative skin friction or dragdown force*

Provisions of 8.3.4 shall generally apply subject to the condition that the under-reamed bulb is provided below the strata susceptible to negative skin friction.

8.5.3.4 *Structural capacity*

Provisions of **8.3.5** shall generally apply except that the under-reamed pile stem is designed for axial capacity as a short column. Under-reamed piles under lateral loads and moments tend to behave more as rigid piles due to the presence of bulbs and therefore the analysis can be done on rigid pile basis. Nominally reinforced long single bulb piles which are not rigid may be analyzed as per the method given in Annex G or as per other accepted methods.

8.5.3.5 *Spacing*

Generally, the centre to centre spacing for bored cast *in-situ* under-reamed piles in a group should be two times the bulb diameter ($2D_u$). It shall not be less than 1.5 D_u. For under-grade beams, the maximum spacing of piles should generally not exceed 3 m. In under-reamed compaction piles, generally the spacing should not be less than 1.5 D_u. If the adjacent piles are of different diameter, the value of larger bulb diameter shall be considered for spacing.

8.5.3.6 *Pile groups*

In order to determine the load-carrying capacity of a group of piles, a number of efficiency equations are in use. However, it is difficult to establish the accuracy of these efficiency equations as the behaviour of pile group is dependent on many complex factors. It is desirable to consider each case separately on its own merits.

The load-carrying capacity of a pile group may be equal to or less than the load-carrying capacity of individual piles multiplied by the number of piles in the group.

In load bearing walls, piles should generally be provided under all wall junctions to avoid point loads on beams.

8.5.3.7 *Transient and overloading*

Provisions of **8.2.3.9** and **8.2.3.10** shall generally apply.

8.5.3.8 *Reinforcement*

8.5.3.8.1 The minimum area of longitudinal reinforcement shall be 0.4 percent of the cross-sectional area of the pile shaft and shall be provided throughout the length.

8.5.3.8.2 The main reinforcement of the pile shall extend above cut-off level for at least the development length to be embedded into the pile cap/grade beam.

8.5.3.8.3 The minimum diameter of the rings shall be 8 mm and the spacing of the rings shall be not less than 150 mm. Stiffener rings of suitable diameter and spacing should be provided in the reinforcing cage to impart adequate rigidity to the reinforcing cage during handling and installation. Stiffener rings preferably of 12 mm diameter at every 1.5 m centre to centre spacing should be provided along the entire length of the cage. Minimum 6 numbers of vertical bars shall be used for a circular pile and minimum diameter of vertical bar shall be 12 mm. The minimum clear horizontal spacing between the adjacent vertical bars shall be four times the maximum aggregate size in concrete. If required, the bars can be bundled to maintain such spacing.

8.5.3.8.4 Clear cover to all reinforcement including rings in pile shaft shall be not less than 50 mm, which shall be increased to 75 mm in case of aggressive environment of sulphates, etc. In addition, the clear cover of the main reinforcement from the pile tip shall be 75 mm to 100 mm.

8.5.3.9 The design of pile cap and grade beams shall conform to the requirements specified in **8.2.3.12** and **8.2.3.13** respectively.

8.5.4 For detailed information on under-reamed piles regarding control of pile, installation, reference shall be made to good practice [C-2(46)].

8.5.5 *Non-Destructive Testing*

For quality assurance of concrete piles, non-destructive integrity test may be carried out prior to laying of beam/caps, in accordance with accepted standard [C-2(44)].

8.6 Timber Piles

8.6.1 *General*

Piles find application in foundations to transfer loads from a structure to competent sub-surface strata having adequate load-bearing capacity. The load transfer mechanism from a pile to the surrounding ground is complicated and is not yet fully understood, although application of pile foundations is in practice over many decades. Broadly, piles transfer axial loads either substantially by friction along its shaft and/or by the end bearing. Piles are used where either of the above load transfer mechanism is possible depending upon the subsoil stratification at a particular site. Construction of pile foundation requires a careful choice of piling system depending upon the subsoil conditions, the load characteristics of the structure and the limitations of total settlement, differential settlement and any other special requirement of a project. The installation of piles demands careful control on position, alignment and depth and involves specialized skill and experience.

Timber piles, currently do not find extensive use in civil engineering works, however, these piles have been used for compaction of soils, for supporting and protecting water-front structures and also as pile foundations. The choice for using a timber pile is mainly governed by the availability of good quality structural timber, site conditions, particularly the water-table conditions. Timber piles, however, should be avoided because of two reasons, (a) to preserve the environment and green vegetative cover and (b) at most of the places in India, water table has gone down substantially which implies that the timber pile will be only partially under water and this condition is highly undesirable for durability of timber.

Use of treated or untreated piles will depend upon the site conditions and upon whether the work is of permanent or of temporary nature. The timber pile installed should have its entire length embedded under water so that the pile may not get deteriorated. They have the advantages of being comparatively light for their strength and are easily handled. However, they will not withstand as hard driving as steel or concrete piles. Timber has to be selected carefully and treated where necessary for use as piles, as the durability and performance would considerably depend upon the quality of the material and relative freedom from natural defects. If the piles are perennially under salt water condition, treatment of timber is not necessary since by immersion in salt water the life of the pile will be very long. Timber piles are generally used for single and two storeyed structures in back water area where bearing strata is available at a depth less than 12 m. Coconut/Palmyra tree trunks have also been used as timber piles in coastal areas.

8.6.2 *Materials*

8.6.2.1 *Timber*

The timber shall have the following characteristics:

a) Only structural timber shall be used for piles (*see* Part C 'Structural Design/Section 3 Timber and Bamboo, 3(A) Timber' of this NBCS);

b) The length of an individual pile shall be,

   1) the specified length ± 300 mm for piles up to and including 12 m in length; and

   2) the specified length ± 600 mm for piles above 12 m in length.

c) The ratio of heartwood diameter to the pile butt diameter shall be not less than 0.8; and

d) Piles to be used untreated shall have as little sapwood as possible.

8.6.3 *Design Considerations*

8.6.3.1 *General*

Pile foundations shall be designed in such a way that the load from the structure can be transmitted to the sub-surface with adequate factor of safety against shear failure of sub-surface and without causing such settlement, (differential or total), which may result in structural damage and/or functional distress under permanent/transient loading. The pile shaft should have adequate structural capacity to withstand all loads (vertical, lateral or otherwise) which are to be transmitted to the subsoil.

8.6.3.2 *Adjacent structures*

When working near existing structures, care shall be taken to avoid damage to such structures. In case of deep excavations adjacent to piles, proper shoring or other suitable arrangement shall be made to guard against undesired lateral movement of soil. Good practice [C-2(39)] may be used as a guide for studying qualitatively the effect of vibration on persons and structures.

8.6.3.3 *Pile capacity*

See **8.2.3.3**.

8.6.3.4 *Structural capacity*

8.6.3.4.1 The pile shall have necessary structural strength to transmit the loads imposed on it, ultimately to the soil. The structural capacity of the timber piles shall be based on the permissible compressive stress of the timber species.

8.6.3.4.2 The length of pile projected into the pile cap is critical for ensuring lateral load transfer and pull-out resistance. Effective transfer of lateral load may be possible with 100 mm to 200 mm projection into the pile cap concrete depending on the safe lateral load capacity. However, pull-out resistance that can be developed by such small penetration may be limited and the use of timber piles for resisting pull-out resistance may not be viable.

8.6.3.4.3 It is preferable to conduct an initial load test as given in good practice [C-2(40)] to assess the axial capacity, lateral capacity and pull-out capacity of piles. For compaction piles, tests should be done on a group of piles with the cap resting on the ground. The acceptance criteria shall also be as per the provisions given in good practice [C-2(40)]

8.6.3.5 For detailed information on timber piles regarding spacing, classification, control of pile driving, storing and handling, reference shall be made to good practice [C-2(49)].

9 DESIGN AND CONSTRUCTION OF COMBINED PILED RAFT FOUNDATIONS

9.1 General

This clause covers the design and construction of combined piled raft foundation (CPRF) for residential, commercial and industrial structures, tall structures, store houses, storage tanks, etc. The CPRF transmits the load to soil by resistance developed by the components of the foundation, that is, piles and raft, the raft being placed on competent ground. The piles develop resistance along the pile shaft by skin friction and at the pile tip by end bearing. The raft develops the resistance by generating the contact pressure below the raft.

CPRF shall not be used in cases where soil layers of relatively low stiffness (For example, very soft cohesive soil, organic soil, collapsible soil, liquefiable soil) are situated closely beneath the raft. Provisions of this standard shall not be applicable to layered soil with significantly high stiffness (modulus) contrast between the top and bottom layers.

9.2 Necessary Information

For satisfactory design and construction of a combined pile-raft foundation, the following information is necessary:

a) Details of site plan showing location of proposed and adjacent structures;

b) Details of plan and vertical cross-section of the proposed building with position of beam and columns;

c) Different load combinations and their intensity indicating design loads, preferably shown in schematic plan;

d) All the loads due to seismic, wind and water current, etc indicated separately;

e) Limiting values of performance parameters, such as allowable bearing pressure, allowable total settlement, allowable differential settlement, allowable angular distortion, that the foundation and superstructure can withstand;

f) Information on geological history, seismicity, seasonal variation of ground water, climatic factors, for example, sudden flooding, erosion, etc;

g) The design and construction of CPRF requires rigorous geotechnical investigations by using both field and laboratory techniques. The proper dimensioning of CPRF will purely depend up on the outcome of geotechnical investigations. The data obtained from the both the investigations, that is, preliminary investigation for feasibility study and detailed investigation for analyses and design shall be analysed by geotechnical experts;

h) *Geotechnical information* — Sub-surface profile with stratification details, engineering and index properties of founding media to be in accordance with good practice [C-2(8)] and [C-2(50)] and other relevant standards which are essential for the design of CPRF system. Any supplementary investigations should be carried out to obtain additional geotechnical information for design of CPRF;

j) *Extent of geotechnical investigations* — The structure and properties of the substrata and the groundwater conditions shall be known in sufficient detail for any piled-raft construction project. This is necessary to reliably assess the stability and serviceability of the pile and piled-raft foundations and of the overall structure as required by relevant Indian Standards and to assess the effects of foundations on their surroundings. The geotechnical investigations shall extend to sufficient depth below pile tip to record all ground formations and strata influencing the structure and its execution and to identify the load-bearing and deformation properties of the ground. The geotechnical investigations shall be in accordance with good practice [C-2(8)] and [C-2(50)];

k) The geotechnical investigation report and the geotechnical design report, respectively, shall contain all relevant data that can affect CPRF capacity, choice of the execution method and the pile installation. Design soil parameters shall be derived for the CPRF system. The ground information and the parameters related not only to pile capacity, but also to drilling ability, drivability, etc shall be provided;

m) The results of field test on single piles (both ultimate capacity and load- displacement curve). Static test as initial test can be used for design of CPRF, whereas dynamic test is not essential for CPRF design. Dynamic test may be used for additional check, if necessary, on later stage, but not directly related to CPRF design;

n) Dynamic properties of founding media to be taken from geotechnical investigation report; and

p) A review of performance of CPRF in similar locality or ground conditions, if available.

9.3 Design Considerations for Static Load

9.3.1 *General Design Considerations*

9.3.1.1 The design of CPRF should consider the following criteria:

a) Fluctuation in the water table condition and long-term stability of the bearing strata;

b) Consideration for handling sensitive clays and loose bearing soils;

c) Effect of soil excavations;

d) The soil stratigraphy shall be considered when calculating pile responses in the CPRF system;

e) Differential movement of the foundations between the old and new structures;

f) Wherever possible, the centre area of the foundation should be located directly beneath the centre of gravity of the imposed load or else effect of eccentricity should be considered;

g) The load carrying capacity of the combined system subjected to vertical, lateral and moment loadings, total and differential settlement; and

h) Some of the key design considerations are:

    1) Load carrying capacity of the combined system at the desired settlement level for vertical, lateral and moment loadings;

2) Maximum settlement;
3) Differential settlement;
4) Raft moments and shears for the structural design of the raft; and
5) Pile loads and moments, for the structural design of the piles.

9.3.2 *Stages of CPRF Design*

9.3.2.1 The three main stages of CPRF design are:

a) *Preliminary Stage* (*Feasibility Study*) — Assessment of the performance of raft without piles that includes estimation of vertical and lateral bearing capacity and the settlements. Assessment of the feasibility of using a pile raft and the required number of piles to satisfy the design requirement;

b) *General Pile Characteristics* (*Preliminary Design Stage*) — Pile should be designed for the combined resistances; and

c) *Final Detailed Design* — Final detailed design to obtain the number of piles, location and configuration, settlement, bending moment and shear forces in raft and the pile loads and moments.

9.3.3 *Design Steps*

Design philosophy is illustrated in Fig. 10 and the subsequent design steps to be followed are given in **9.3.3.1** to **9.3.3.5**, **9.3.4** and **9.3.5**.

9.3.3.1 The static pile formula based on the ground parameters of good practice [C-2(51)] can be used for estimation of ultimate load capacity of piles. The provision made in good practice [C-2(52)] as applicable should be followed for the design and construction of piles unless otherwise stated. The procedure for pile load testing should be as per good practice [C-2(40)]. Information obtained (load-settlement response) from pile load test shall be interpreted by geotechnical engineer to arrive at the allowable load with reference to a particular settlement. Pile loads and moment for the structural design of the piles should be considered.

9.3.3.2 The stability and capacity of raft based on the ground parameters as per good practice [C-2(34)] and [C-2(53)] can be estimated. The provision made in good practice [C-2(53)] should be followed for the design and construction of raft foundation unless otherwise stated. For estimation of raft settlement, the guidance given in good practice [C-2(54)] may be used. However, the calculation of settlement for entire CPRF system will be different as described in subsequent section of this standard. Raft moment and shear forces for structural design of raft should be considered.

9.3.3.3 The following are the design philosophies:

a) *Conventional Approach* — Piles are designed as a group while making some allowances for contribution of the raft, primarily to load carrying capacity;

b) *Settlement Control Approach* — Piles are placed strategically below the raft in order to reduce the total and differential settlement. However differential settlement reduction is more important than to reduce the overall average settlement; and

c) *Creep Piling Approach* — Piles are designed to operate at a working load at which significant creep starts to occur at some fraction, typically 70 percent to 80 percent, of the ultimate load capacity.

9.3.3.3.1 For CPRF, the design philosophy is generally governed by settlement control approach to meet the serviceability criteria.

9.3.3.4 The vertical load carrying capacity (Q_{CPRF}) of CPRF should be calculated as per Annex K.

9.3.3.5 Dimensionless factors for CPRF design with practical range of parameters are given in Table 6. This guideline should ensure the complete behavioural mechanism of CPRF system.

Table 6 Dimensionless Factors for Combined Piled Raft Foundations

(*Clause* 9.3.3.5)

Sl No.	Dimensionless Factors	Definition	Practical Range
(1)	(2)	(3)	(4)
i)	Pile slenderness ratio	L_p/D_p	10 to 100
ii)	Pile spacing ratio	S_p/D_p	2.5 to 8
iii)	Pile-soil stiffness ratio	$K_{ps} = E_p/E_s$	100 to 10 000
iv)	Raft plan aspect ratio	L_r/B_r	1 to 10
v)	Raft-soil stiffness ratio	$K_{rs} = \frac{4E_r B_r t_r^3(1-\vartheta_s^2)}{3\pi E_s L_r^4(1-\vartheta_r^2)}$	0.001 to 10

where

B_r = width of the raft;

D_p = diameter of the pile;

E_p = elastic modulus of pile material;

E_r = elastic modulus of raft material;

E_s = elastic modulus of soil;

L_p = length of the pile;

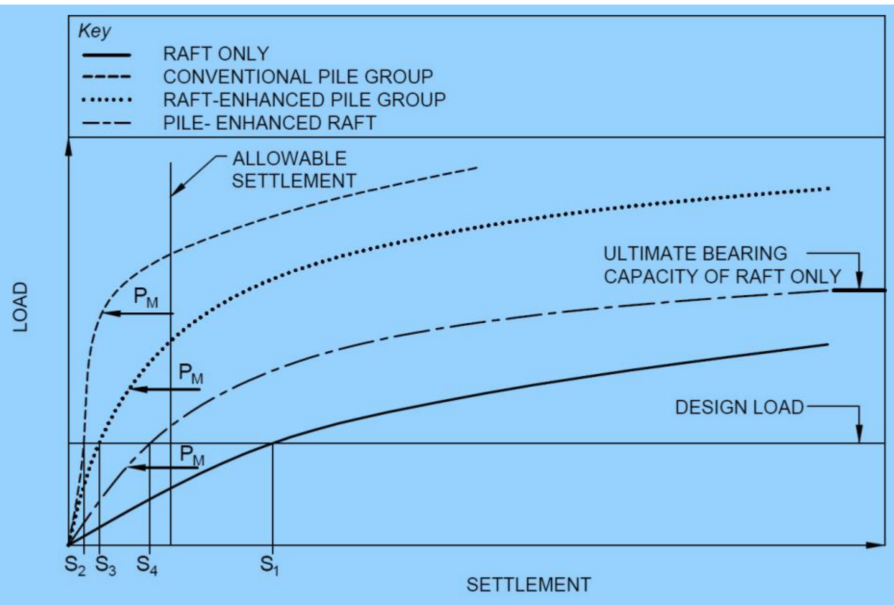
L_r = length of the raft;

S_p = spacing between the piles;

t_r = thickness of raft;

ϑ_r = poisson’s ratio of raft material; and

ϑ_s = poisson’s ratio of soil.



where
P_M = Pile capacity fully mobilized; and
S_1,S_2, etc = Settlement for raft, pile group, etc

FIG. 10(A) LOAD-SETTLEMENT BEHAVIOUR OF RAFTS, CONVENTIONAL PILE GROUPS AND DIFFERENT TYPES OF CPRF

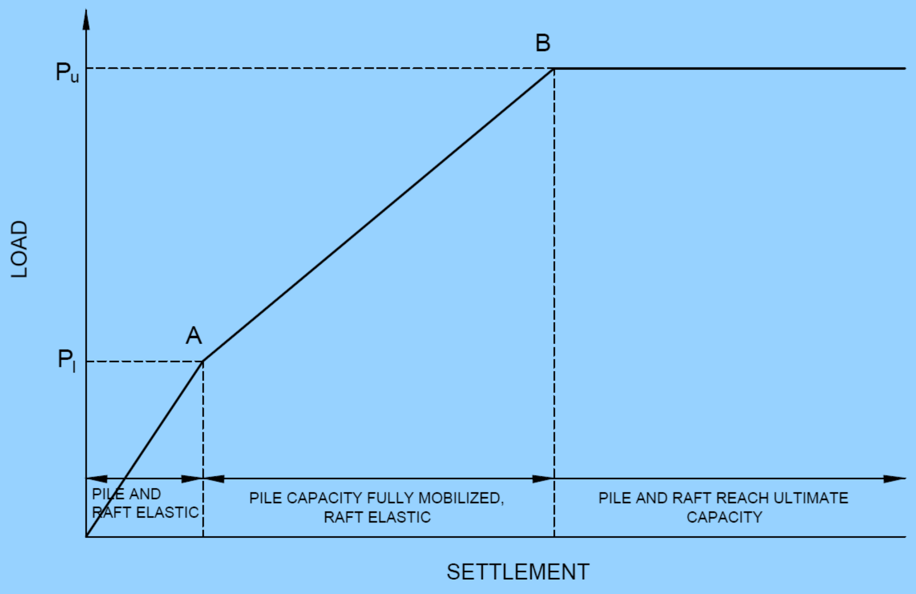


FIG.10(B) SIMPLIFIED LOAD SETTLEMENT CURVE OF A CPRF

FIG. 10 LOAD-SETTLEMENT BEHAVIOUR OF A CPRF

9.3.4 *Computational Model*

Analysis of CPRF shall be performed using computational model which will be able to simulate the appropriate behaviour of single pile. Later from the actual field test results on single pile, the computational model needs to be revised. The computational model shall capture all the interactions as mentioned in Fig. 2(A). Also, the superstructure effect shall be considered appropriately as shown in Fig. 11(A). The two features of estimating the stiffness of soil-pile-raft system are through estimation of pile spring stiffness and raft-soil spring stiffness. The iterative process of convergence of pile and raft response (if implicit) will only come after that. Fig. 11 presents the design model of CPRF system considering soil-pile-raft stiffness. Different values of pile stiffness can occur within a group of piles, depending on their position and on the relative stiffness of the raft.

9.3.4.1 *Estimation of pile spring stiffness*

Stiffness of spring representing the pile shall be estimated by dividing the load carried by pile top element in respective direction with the corresponding top displacement of the pile.

$$\text{Pile spring stiffness, } K_p = \frac{\text{Normal contact force at nodes}}{\text{Nodal displacement}}$$

9.3.4.2 *Estimation of raft-soil spring stiffness*

The soil spring stiffness shall be estimated from the load deformation behaviour of the founding medium as given below:

$$\text{Raft-soil Spring stiffness, } K_r = \frac{\text{Normal contact force at nodes}}{\text{Nodal displacement}}$$

9.3.5 *Allowable Settlement for Static Design Consideration*

For CPRF system, total settlement under gravity load should be restricted within 125 mm and the maximum angular distortion of raft as 1/500. There are four angular distortions (θ_{IL}, θ_{IIL}, θ_{IB} and θ_{IIB}) (Fig. 1) and maximum of these four angular distortions will govern CPRF design for Serviceability Limit State (SLS). The total settlement under gravity load may be taken only as a guide and the permissible total settlement should be decided as per serviceability criteria to fulfil the load sharing mechanism of CPRF system.

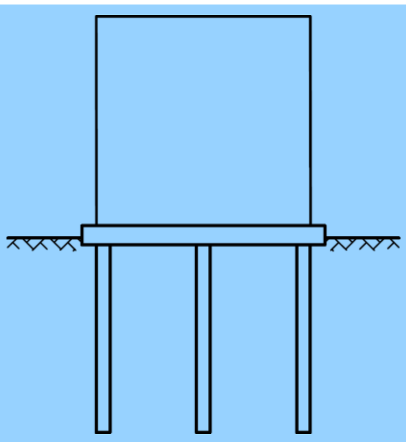


FIG. 11(A) RAFT–PILE–SOIL IN A CPRF

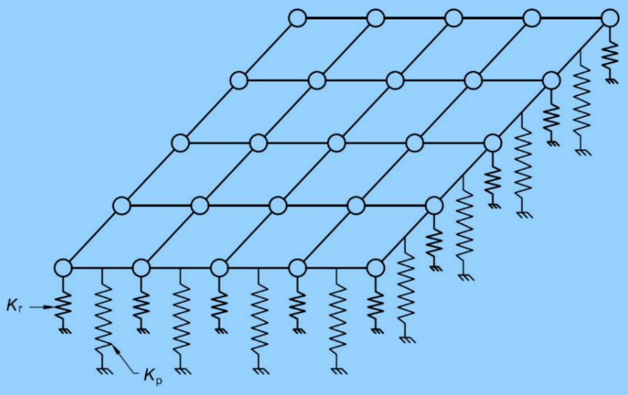


FIG.11(B) PILE AND RAFT-SOIL SPRINGS

FIG. 11 COMBINED ACTION OF SOIL-PILE SYSTEM (TYPICAL DESIGN MODEL)

9.4 Proof of Design and Construction of a CPRF

The examination of the design and the construction of a CPRF with respect to the geotechnical engineering aspects should be controlled by a geotechnical expert particularly qualified on this subject. This includes the construction for piles and deciding the foundation level. The protocols of the acceptance procedure and the measured values have to be included into the examination. The following aspects shall be considered:

a) Critical review of the soil investigation report (field and laboratory tests), including the selection of input parameters;

b) Evaluation of the computational model used for the design of the CPRF and the computation results by using independent comparative calculations. Apart from the independent comparative calculations, additional quality assurance measures in design should be ensured;

c) Assessment of the effects on the adjacent structures; and

d) Examination of the field monitoring (measuring) program within the construction process of the CPRF.

9.5 Monitoring of a CPRF

The load-settlement behaviour and the load transfer within a CPRF should be monitored for further use by a geotechnical expert. The monitoring comprises of geotechnical and geodetic measurements at the new building and also at the adjacent buildings for settlement. The monitoring of the contact pressure at the level of raft, axial load in selected piles, settlement at the level of raft, ground water table and pore-pressure may be adopted for important projects. The monitoring of a CPRF is an elementary and indispensable component of the safety concept and should be used for the following purposes:

a) Observational method should be followed for monitoring of the response of CPRF both during and post construction phases for projects of high importance;

b) Verification of the computational model and the computational approaches;

c) Detection of possible critical conditions in CPRF system;

d) Examination of the quality assurance during the construction and post construction process; and

e) Examination of distribution of loads may be implemented on piles in centre and edges to capture soil-pile-raft interactions.

The monitoring program should be designed by a geotechnical expert during the design phase depending on importance of the project, complexity of the ground condition and long-term performance. Summary of desired instrumentations and their locations should be highlighted in plan as well as sectional view of the foundation layout.

9.6 Structural Design

The general provision for load, shrinkage, creep and temperature effects and provision of design, reinforcement and detailing shall conform to good practice [C-2(47)] and other relevant standards.

9.7 Seismic Design

Design of the CPRF system considering the seismicity of the ground and entire structure and sub-structural system should be handled by experts to ensure conformity to various relevant standards. Both inertial and kinematic effects should be considered in the seismic design.

10 OTHER FOUNDATIONS, SUBSTRUCTURES AND FOUNDATIONS FOR SPECIAL STRUCTURES

10.1 Pier Foundations

10.1.1 *Design Considerations*

10.1.1.1 *General*

The design of concrete piers shall conform to the requirements for columns specified in Part C 'Structural Design/ Section 5 Structural Concrete' of this NBCS. If the bottom of the pier is to be belled so as to increase its load carrying capacity, such bell shall be at least 300 mm thick at its edge. The sides shall slope at an angle of not less than 60° with the horizontal. The least permissible dimensions shall be 600 mm, irrespective of the pier being circular, square or rectangular. Piers of smaller dimensions if permitted shall be designed as piles (*see* **8**).

10.1.1.2 *Plain concrete piers*

The height of the pier shall not exceed 6 times the least lateral dimension. When the height exceeds 6 times the least lateral dimension, buckling effect shall be taken into account, but in no case shall the height exceed 12 times the least lateral dimension.

When the height exceeds 6 times the least lateral dimension, the deduction in allowable stress shall be given by the following formula:

$$f_c' = f_c \ (1.3 - \frac{H}{20D})$$

where

f_c' = reduced allowable stress;

f_c = allowable stress;

D = least lateral dimension; and

H = height of pier.

NOTE — The above provision shall not apply for piers where the least lateral dimension is 1.8 m or greater.

10.1.1.3 *Reinforced concrete piers*

When the height of the pier exceeds 18 times its least dimension, the maximum load shall not exceed:

$$P' = P\,(1.5 - \frac{H}{36D})$$

where

D = least lateral dimension;

H = height of the pier measured from top of bell, if any, to the level of cut-off of pier;

P' = permissible load; and

P = permissible load when calculated as axially loaded short column.

10.2 Design and construction of machine foundations, diaphragm walls, etc, shall be carried out in accordance with good practice [C-2(55)].

11 GROUND IMPROVEMENT

11.1 In poor and weak subsoils, the design of conventional foundation for structures and equipment may present problems with respect to both sizing of foundation as well as control of foundation settlements. A viable alternative in certain situations, is to improve the subsoil to an extent such that the subsoil would develop an adequate bearing capacity and foundations constructed after subsoil improvement would have resultant settlements within acceptance limits. This method/technique is called ground improvement which is used to improve *in-situ* soil characteristics by improving its engineering performance as per the project requirement by altering its natural state, instead of having to alter the design in response to the existing ground limitations. The improvement is in terms of increase in bearing capacity, shear strength, reducing settlement and enhancing drainage facility, mitigating liquefaction potential, etc, of soil, as also in improving lateral capacity in case of deep foundations.

11.2 For provisions with regard to necessary data to be collected to establish the need for ground improvement at a site; considerations for establishing need for ground improvement methods; selection of ground improvement techniques; equipment and accessories for ground improvement; control of ground improvement works and recording of data, reference shall be made to accepted standard [C-2(56)]. Annex L presents various methods of ground improvement along with principles, applicability to various soil conditions, material requirements, equipment required, results likely to be achieved and limitations. This table may be referred to as guidance for selecting the proper method for a situation. *See also* accepted standard [C-2(56)] for details.

11.2.1 For provisions relating to ground improvement by reinforcing the ground using stone columns so as to meet the twin objective of increasing the bearing capacity with simultaneous reduction of settlements, reference shall be made to accepted standard [C-2(57)].

11.2.2 Whenever soft cohesive soil strata underlying a structure are unable to meet the basic requirements of safe bearing capacity and tolerable settlement, ground improvement is adopted to make it suitable for supporting the proposed structure. Both the design requirements that is shear strength and settlement under loading, can be fulfilled by consolidating the soil by applying a preload, if necessary, before the construction of the foundation. This consolidation of soil is normally accelerated with the use of vertical drains. For provisions relating to ground improvement by preconsolidation using vertical drains, reference shall be made to accepted standard [C-2(58)].

11.2.3 Use of suitable geo-synthetics/geo-textiles may be made in an approved manner for ground improvement, where applicable; *see also* accepted standards [C-2(59)].

12 GEOTECHNICAL INSTRUMENTATION

12.1 Geotechnical instrumentation is essential for monitoring the behaviour of soil, rock and structures in civil engineering projects, ensuring safety and design performance. A variety of instruments are deployed at specific locations, where they can provide critical data for various purposes. The data gathered from these instruments allows engineers to assess risks, verify design assumptions and implement corrective actions if necessary.

The typical list of geotechnical instruments, but not limited to these, along with their objectives, is provided in Table 7.

Table 7 Typical List of Geotechnical Instrumentation
(*Clause* 12.1)

Sl No. (1)	Instrumentation (2)	Objective (3)	Applicable for (4)
i)	Inclinometers	Measurement of lateral deflections	Deflection monitoring of deep excavations, shoring systems, landslide/slope movements, lateral load test on piles
ii)	Piezometers	Measurement of underground water pressure (pore water pressure)	To monitor groundwater conditions
iii)	Vibration monitors (Seismographs)	To monitor vibrations due to various construction activities	Monitoring of adjacent critical structures during general construction, demolition, pile driving, blasting etc.
iv)	Strain gauges	To measure strain in structural elements	Strain (force) measurement in pile foundations, struts

Table 7 (*Concluded*)

Sl No. (1)	**Instrumentation** (2)	**Objective** (3)	**Applicable for** (4)
v)	Load cells	To measure loads in various structural elements	Load measurement in rock bolts, foundation anchors, struts, pile foundation during load testing
vi)	Pressure pads/Pressure cells	monitoring long-term pressure imposed by soil on the foundation element	For embankments, rafts, retaining walls,
vii)	Extensometer	Deformation measurement	Measurement of deformation of soil, rock, or can be used during testing of pile foundation to measure deformation of piles at various levels
viii)	Permanent settlement markers	Settlement monitoring	Can be used for monitoring of settlement/ deflections of various structures such as raft, retaining system, slopes, etc.
ix)	Crackmeters	Measure displacement	To measure plate displacement during bi-directional static load test (BDSLT)

ANNEX A

(*Clauses* 7.4.1.11 *and* B-3.3)

DETERMINATION OF MODULUS OF ELASTICITY (E_s) AND POISSONS'S RATIO (μ)

A-1 DETERMINATION OF MODULUS OF ELASTICITY(E_s)

The modulus of elasticity is a function of composition of the soil, its void ratio, stress history and loading rate. In granular soils it is a function of the depth of the strata, while in cohesive soil it is markedly influenced by the moisture content. Due to its great sensitivity to sampling disturbance, accurate evaluation of the modulus in the laboratory is extremely difficult. For general cases, therefore, determination of the modulus may be based on field tests (*see* **A-2**). Where properly equipped laboratory and sampling facility is available, E_s may be determined in the laboratory (*see* **A-3**).

A-2 FIELD DETERMINATION

A-2.1 The value of E_s shall be determined from plate load test in accordance with accepted standard [C-2(9)].

$$E_s = qB\frac{(1-\mu^2)}{s}I_w$$

where

B = least lateral dimension of test plate;

influence ratio;

I_w = 0.82 for a square plate;

1.00 for a circular plate;

q = intensity of contact pressure;

s = settlement; and

μ = poisson's ratio

NOTE — While this procedure may be adequate for light or less important structures under normal conditions, relevant laboratory tests or field tests are essential in the case of unusual soil types and for all heavy and important structures. Plate load test, though useful in obtaining the necessary information about the soil with particular reference to design of foundation has some limitations. The test results reflect only the character of the soil located within a depth of less than twice the width of the bearing plate. Since the foundations are generally larger than the test plates, the settlement and shear resistance will depend on the properties of a much thicker stratum. Moreover, this method does not give the ultimate settlements particularly in case of cohesive soils. Thus, the results of the test are likely to be misleading, if the character of the soil changes at shallow depths, which is not uncommon. A satisfactory load test should, therefore, include adequate soil exploration {*see* good practice [C-2(8)]} with due attention being paid to any weaker stratum below the level of the footing. Another limitation is the concerning of the effect of size of foundation. For clayey soils the bearing capacity (from shear consideration) for a larger foundation is almost the same as that for the smaller test plate. But in dense sandy soils the bearing capacity increases with the size of the foundation. Thus, tests with smaller size plate tend to give conservative values in dense sandy soils. It may, therefore, be necessary to test with plates of at least three sizes and the bearing capacity results extrapolated for the size of the actual foundation (minimum dimensions in the case of rectangular footings).

A.2.1.1 The average value of E_s shall be based on a number of plate load tests carried out over the area, the number and location of the tests, depending upon the extent and importance of the structure.

A-2.1.2 *Effect of Size*

In granular soils the value of E_s corresponding to the size of the raft shall be determined as follows:

$$E_s = E_p \frac{B_f}{B_p} \left[\frac{B_f + B_p}{2B_f} \right]^2$$

Where B_f, B_p represent sizes of foundation and plate and E_p is the modulus determined by the plate load test.

A-2.2 For stratified deposits or deposits with lenses of different materials, results of plate load test will be unreliable and static cone penetration tests may be carried out to determine E_s.

A-2.2.1 Static cone penetration tests shall be carried out in accordance with accepted standard [C-2(41)]. Several tests shall be carried out at regular depth intervals up to a depth equal to the width of the raft and the results plotted to obtain an average value of E_s.

A-2.2.2 The value of E_s may be determined from the following relationship:

$$E_s = 2\, C_{kd}$$

where C_{kd} = cone resistance, in kN/m^2

A-3 LABORATORY DETERMINATION OF E_S

A-3.1 The value of E_s shall be determined by conducting triaxial test in the laboratory in accordance with accepted standard [C-2(60)] on samples collected with least disturbances.

A-3.2 In the first phase of the triaxial test, the specimen shall be allowed to consolidate fully under an all-round confining pressure equal to the vertical effective overburden stress for the specimen in the field. In the second phase, after equilibrium has been reached, further drainage shall be prevented and the deviator stress shall be increased from zero value to the magnitude estimated for the field loading condition. The deviator stress shall then be reduced to zero and the cycle of loading shall be repeated.

A-3.3 The value of E_s shall be taken as the tangent modulus at the stress level equal to one-half the maximum deviator stress applied during the second cycle of loading.

ANNEX B

(*Clauses* 7.4.1.11 *and* C-3)

DETERMINATION OF MODULUS OF SUB-GRADE REACTION

B-1 GENERAL

B-1 The modulus of subgrade reaction (k) as applicable to the case of load through a plate of size 300 mm × 300 mm or beams 300 mm wide on the soils is given in Table 8 for cohesionless soils and in Table 9 for cohesive soils. Unless more specific determination of k is done (*see* **B-2** and **B-3**), these value may be used for design of raft foundation in cases where the depth of the soil affected by the width of the footing may be considered isotropic and the extrapolation of plate load test results is valid.

B-2 FIELD DETERMINATION

B-2.1 In cases where the depth of the soil affected by the width of the footing may be considered as isotropic, the value of k may be determined in accordance with accepted standard [C-2(10)]. The test shall be carried out with a plate of size not less than 300 mm.

B-2.2 The average value of k shall be based on a number of plate load tests carried out over the area, the number and location of the tests depending upon the extent and importance of the structure.

B-3 LABORATORY DETERMINATION

B-3.1 For stratified deposits or deposits with lenses of different materials, evaluation of k from plate load test will be unrealistic and its determination shall be based on laboratory tests {*see* good practice [C-2(60)]}.

B-3.2 In carrying out the test, the continuing cell pressure may be so selected as to be representative of the depth of the average stress influence zone (about 0.5 B to B).

B-3.3 The value of k shall be determined from the following relationship:

$$k = 0.65 \times \sqrt[12]{\left(\frac{E_s B^4}{EI}\right)} \cdot \frac{E_s}{(1-\mu^2)} \cdot \frac{1}{B}$$

where

B = width of the footing;
E = young's modulus of foundation material;
E_s = modulus of elasticity of soil (*see* Annex A);
I = moment of inertia of the foundation; and
μ = poisson's ratio of soil.

B-4 CALCULATIONS

When the structure is rigid (*see* Annex C), the average modulus of subgrade reaction may also be determined as follows:

$$k_s = \frac{\text{Average contact pressure}}{\text{Average settlement of the raft}}$$

Table 8 Modulus of Subgrade Reaction (*k*) for Cohesionless Soils

(*Clause* B-1)

Sl No.	Soil Characteristic		Modulus of Subgrade Reaction (*k*)[1] kN/m³	
	Relative Density	Standard Penetration Test Value (N) (Blows per 300 mm)	For Dry or Moist State	For Submerged State
(1)	(2)	(3)	(4)	(5)
i)	Loose	< 10	15 000	9 000
ii)	Medium	10 to 30	15 000 to 47 000	9 000 to 29 000
iii)	Dense	30 and over	47 000 to180 000	29 000 to 108 000

Table 9 Modulus of Subgrade Reaction (*k*) for Cohesive Soils

(*Clause* B-1)

Sl No.	Soil Characteristic		Modulus of Subgrade Reaction (*k*)[1] kN/m³
	Consistency	Unconfined Compressive Strength kN/m²	
(1)	(2)	(3)	(4)
i)	Stiff	100 to 200	27 000
ii)	Very stiff	200 to 400	27 000 to 54 000
iii)	Hard	400 and over	54 000 to 108 000

---

[1] The above values apply to a square plate 300 mm × 300 mm or beams 300 mm wide.

[1] The values apply to a square plate 300 mm × 300 mm. The above values are based on the assumption that the average loading intensity does not exceed half the ultimate bearing capacity.

ANNEX C

(*Clauses* 7.4.4.1.2 (a), (b), 7.4.4.2 *and* B-4)

RIGIDITY OF SUPERSTRUCTURE AND FOUNDATION

C-1 DETERMINATION OF THE RIGIDITY OF THE STRUCTURE

The flexural rigidity *EI* of the structure of any section may be estimated according to the relation given below (*see also* Fig. 12)

$$EI = \frac{E_1 I_i b^2}{2H^2} + \sum \; E_2\, I_b \left[1 + \frac{(I_u{}' + I_1{}')b^2}{(I_b{}' + I_u{}' + I_f{}')l^2}\right]$$

where

b = length or breadth of the structure in the direction of bending, in m;

E_1 = modulus of elasticity of the infilling material (wall material), in kN/m^2;

E_2 = modulus of elasticity of the frame material, in kN/m^2;

H = total height of the infilling, in m;
h_1 = length of the lower column, in m;
h_u = length of the upper column, in m;
I_b = moment of inertia of the beam, in m^4;
$I_b{}'$ = $\frac{I_b}{l}$;
$I_f{}'$ = $\frac{I_f}{l}$;
I_i = moment of inertia of the infilling, in m^4;
$I_u{}'$ = $\frac{I_U}{h_U}$;
$I_1{}'$ = $\frac{I_L}{h_i}$;
I_1 = moment of inertia of the lower column, in m^4;
I_f = moment of inertia of the foundation beam or raft in m^4;
I_u = moment of inertia of the upper column, in m^4; and
l = spacing of the columns, in m.

NOTE — The summation is to be done over all the storeys including the foundation beam or raft. In the case of the foundation, $I_f{}'$ replaces $I_b{}'$ and I_1 becomes zero, whereas for the topmost beam I_u becomes zero.

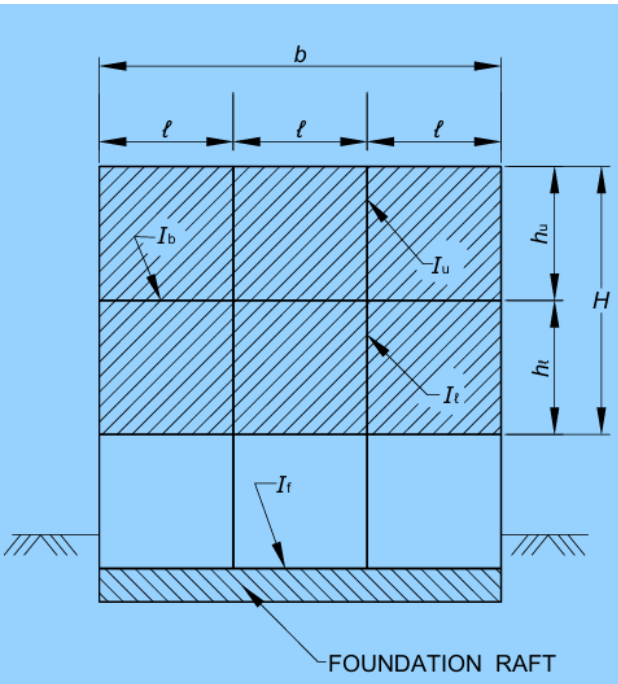


FIG. 12 DETERMINATION OF RIGIDITY OF STRUCTURE

C-2 RELATIVE STIFFNESS FACTOR, *K*

C-2.1 Whether a structure behaves as rigid or flexible depends on the relative stiffness of the structure and the foundation soil. This relation is expressed by the relative stiffness factor *K* given below:

a) For the whole structure, $K = \frac{EI}{E_s b^3 a}$;

b) For rectangular rafts, $K = \frac{E}{12E_s}\left(\frac{d}{b}\right)^3$; and

c) For circular rafts, $K = \frac{E}{12E_s}\left(\frac{d}{2R}\right)^3$

where

a = length perpendicular to the section under investigation, in m;

b = length of the section in the bending axis, in m;

d = thickness of the raft or beam, in m;

EI = flexural rigidity of the structure over the length (a), in kN/m^2;

E_s = modulus of compressibility of the foundation soil, in kN/m^2; and

R = radius of the raft, in m.

C-2.1.1 For $K > 0.5$, the foundation may be considered as rigid [*See* **7.4.4.1(a)**].

C-3 DETERMINATION OF CRITICAL COLUMN SPACING

Evaluation of the characteristics λ is made as follows:

$$\lambda = \sqrt[4]{\left(\frac{kB}{4E_c I}\right)}$$

where

B = width of raft B, in m;

E_c = modulus of elasticity of concrete in kN/m^2;

I = moment of inertia of raft, in m^4; and

k = modulus of subgrade reaction, in kN/m^3, for footing of width B, in m (*see* Annex B).

ANNEX D

(*Clause* 7.4.4.1.3)

CALCULATION OF PRESSURE DISTRIBUTION BY CONVENTIONAL METHOD

D-1 DETERMINATION OF PRESSURE DISTRIBUTION

The pressure distribution (q) under the raft shall be determined by the following formula:

$$q = \frac{Q}{A} \pm \frac{Qe_y{}'}{I_x{}'}y \pm \frac{Qe_x{}'}{I_y{}'}x$$

where

A = total area of the raft,

$\left.\begin{array}{l} e_x', \\ e_y' \\ I_x', \\ I_y' \end{array}\right\}$ = eccentricities and moments of inertia about the principal axes through the centroid of the section;

x, y = co-ordinates of any given point on the raft with respect to the *x* and *y* axes passing through the centroid of the area of the raft; and

Q = total vertical load on the raft.

I_x', I_y', e_x', e_y' may be calculated from the following equations:

$$I_x' = I_x - \frac{I_{\mathrm{xy}}^2}{I_y}$$

$$I_y' = I_y - \frac{I_{\mathrm{xy}}^2}{I_x}$$

$$e_x' = e_x - \frac{I_{\mathrm{xy}}}{I_x} e_y$$

$$e_y' = e_y - \frac{I_{\mathrm{xy}}}{I_y} e_x$$

where

$e_{\mathrm{x}}, e_{\mathrm{y}}$ = eccentricities in the x and y directions of the load from the centroid;

I_{xy} = $\int xy \cdot dA$ for the whole area about *x* and *y* axes through the centroid; and

$I_{\mathrm{x}}, I_{\mathrm{y}}$ = moment of inertia of the area of the raft respectively about the *x* and *y* axes through the centroid.

For a rectangular raft, the equation simplifies to :

$$q = \frac{Q}{A}\left(1 \pm \frac{12 e_y y}{b^2} \pm \frac{12 e_x x}{a^2}\right)$$

where

a and *b* = the dimensions of the raft in the x and y directions, respectively.

NOTE — If one or more of the values of (q) are negative as calculated by the above formula, it indicates that the whole area of foundation is not subject to pressure and only a part of the area is in contact with the soil and the above formula will still hold good, provided the appropriate values of I_{x}, I_{y}, I_{xy}, e_{x} and e_{y}, are used with respect to the area in contact with the soil instead of the whole area.

ANNEX E

[*Clause* 7.4.4.2(A)]

CONTACT PRESSURE DISTRIBUTION AND MOMENTS BELOW FLEXIBLE FOUNDATION

E-1 CONTACT PRESSURE DISTRIBUTION

E-1.1 The distribution of contact pressure is assumed to be linear with the maximum value attained under the columns and the minimum value at mid span.

E-1.2 The contact pressure for the full width of the strip under an interior column load located at a point *i* can be determined as [*see* Fig. 13(A)]:

$$p_i = \frac{5P_i}{\bar{l}} + \frac{48M_i}{(\bar{l})^2}$$

where

l = average length of adjacent span, in m;

M_i = moment under an interior columns loaded at I; and

P_i = column load, in t at point i.

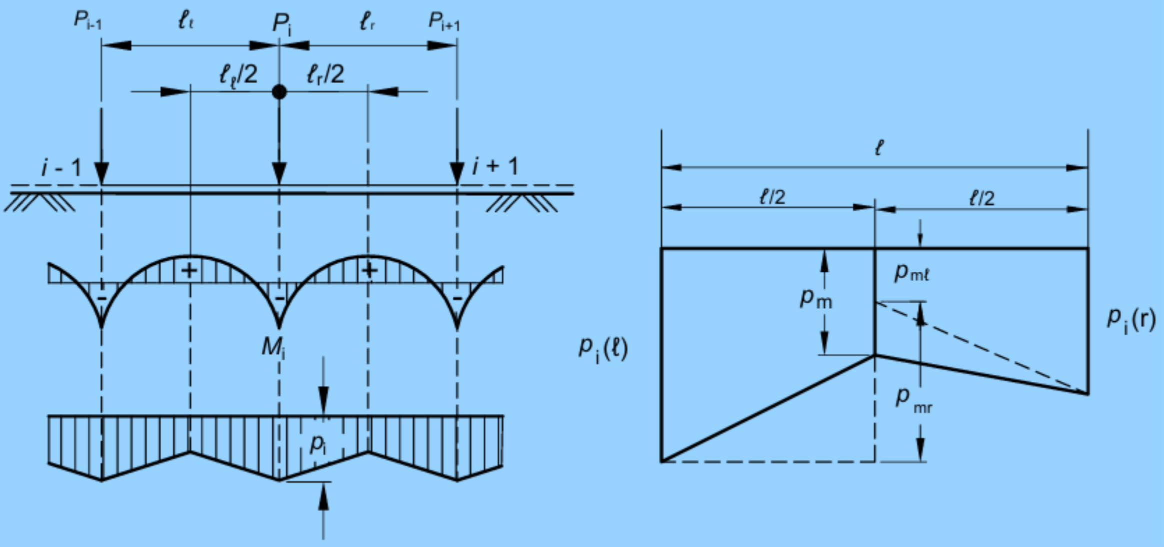
E-1.3 The minimum contact pressure for the full width of the strip at the middle of the adjacent spans can be determined as [*see* Fig. 13(A) and Fig. 13(B)]:

$$p_{\mathrm{ml}} = 2P_i\left(\frac{l_r}{l_l\bar{l}}\right) - p_i\left(\frac{\bar{l}}{l_l}\right)$$

$$p_{\mathrm{mr}} = 2P_i\left(\frac{l_l}{l_r\bar{l}}\right) - p_i\left(\frac{\bar{l}}{l_r}\right)$$

$$p_m = \frac{p_{\mathrm{ml}} + p_{\mathrm{mr}}}{2}$$

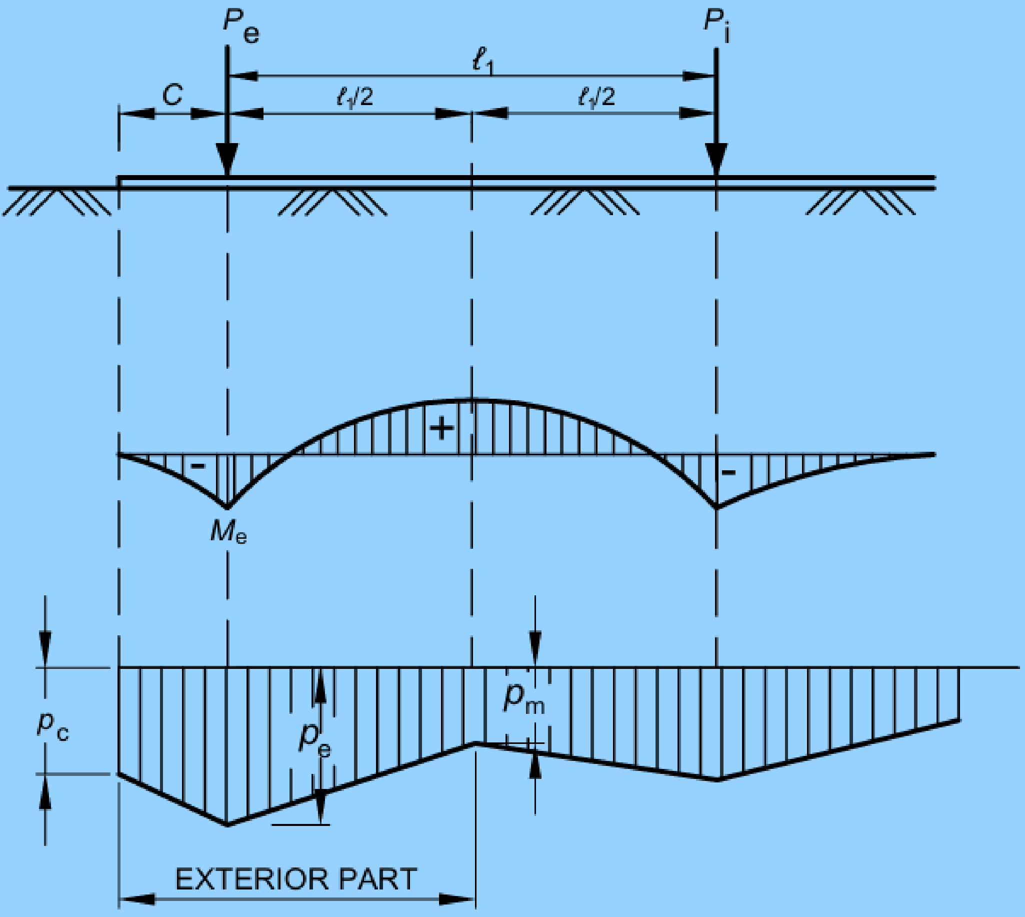
where l_r, l_l are as shown in Fig. 13(A).



P_{i-1}
ℓ_ℓ
P_i
ℓ_r
P_{i+1}
$\ell_\ell/2$
$\ell_r/2$
i - 1
i + 1
+
+
-
-
-
M_i
p_i
ℓ
$\ell/2$
$\ell/2$
$p_{m\ell}$
p_m
$p_i(\ell)$
$p_i(r)$
p_{mr}

FIG.13(A) MOMENT AND PRESSURE DISTRIBUTION AT INTERIOR COLUMN

FIG.13(B) PRESSURE DISTRIBUTION OVER AN INTERIOR SPAN



P_e
P_i
ℓ_1
C
$\ell_1/2$
$\ell_1/2$
+
-
-
M_e
p_c
p_e
p_m
EXTERIOR PART

FIG.13(C) MOMENT AND PRESSURE DISTRIBUTION AT EXTERIOR COLUMNS

FIG. 13 MOMENT AND PRESSURE DISTRIBUTION AT COLUMNS

E-1.4 If E-2.3(a) governs the moment under the exterior columns, contact pressures under the exterior columns and at end of strip can be determined as [*see* Fig. 13(C)]:

$$p_e = \frac{4P_e + \frac{6M_e}{C} - p_m l_1}{C + l_1}$$

$$p_c = -\frac{3M_e}{C^2} - \frac{p_e}{2}$$

where P_e, p_m, M_e, l_1, C are as shown in Fig. 13(C).

E-1.5 If E-2.3(b) governs the moment under the exterior columns, the contact pressures are determined as [*see* Fig. 13(C)] :

$$p_e = p_c \frac{4P_e - p_m l_1}{4C + l_1}$$

E-2 BENDING MOMENT DIAGRAM

E-2.1 The bending moment under an interior column located at *i* [*see* Fig. 11(A)] can be determined as :

$$M_i = -\frac{P_i}{4\lambda}(0.24\lambda\bar{l} + 0.16)$$

E-2.2 The bending moment at mid span is obtained as [*see* Fig. 11(A)]:

$$M_m = M_o + M_i$$

M_i = average of negative moments M_i at each end of the bay

M_o = moment of simply supported beam

= $\frac{l^2}{48}[p_i(l) + 4\overline{p_m} + p_i(r)]$.

where l, $p_i(l)$, $p_i(r)$, $\overline{p_m}$ are as shown in Fig. 11(B).

E-2.3 The bending moment M_e under exterior columns can be determined as the least of [*see* Fig. 13(C)]:

a) $M_{e1} = -\frac{P_e}{4\lambda}(0.13\lambda l_1 + 1.06\lambda C - 0.50)$; and

b) $M_{e2} = -\frac{(4P_e - p_m l_1)}{(4C + l_1)}\frac{C^2}{2}$;

ANNEX F

[*Clause* 7.4.4.2(b)]

FLEXIBLE FOUNDATION — GENERAL CONDITION

F-1 CLOSED FORM SOLUTION OF ELASTIC PLATE THEORY

F-1.1 For a flexible raft foundation with non-uniform column spacing and load intensity, solution of the differential equation governing the behaviour of plates on elastic foundation (Winkler type) gives radial moment (M_r) tangential moment (M_t) and deflection (w) at any point by the following expressions:

$$M_r = -\frac{P}{4}\left[Z_4\left(\frac{r}{L}\right) - (1-\mu)\frac{Z_3'\left(\frac{r}{L}\right)}{\left(\frac{r}{L}\right)}\right]$$

$$M_t = -\frac{P}{4}\left[\mu Z_4\left(\frac{r}{L}\right) + (1-\mu)\frac{Z_3'\left(\frac{r}{L}\right)}{\left(\frac{r}{L}\right)}\right]$$

$$w = \frac{PL^2}{4D}\cdot Z_3\left(\frac{r}{l}\right)$$

where

L = radius of effective stiffness;

= $\left(\frac{D}{k}\right)^{1/4}$;

P column load; and

r distance of the point under investigation from column load along radius.

where

D = flexural rigidity of the foundation;

k = modulus of subgrade reaction for footing of width B;

P = $\frac{Et^2}{12(1-\mu)^2}$

E = modulus of elasticity of the foundation material;

T = raft thickness; and

μ = possion’s ratio of the foundation material.

$\left.\begin{array}{l} Z_3\left(\frac{r}{L}\right), \\ Z_3'\left(\frac{r}{L}\right), \\ Z_4\left(\frac{r}{L}\right) \end{array}\right\}$ = functions of shear, moment and deflection (*see* Fig. 14)

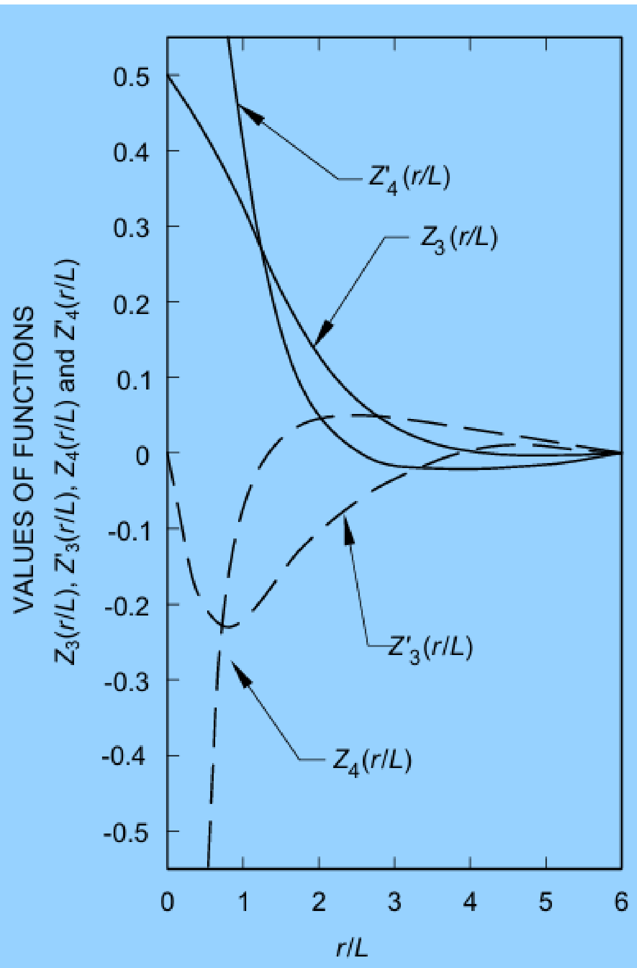


FIG.14 FUNCTIONS FOR SHEAR MOMENT AND DEFLECTION

F-1.2 The radial and tangential moments can be converted to rectangular co-ordinates:

$$M_x = M_r \cos^2 \varphi + M_t \sin^2 \varphi$$
$$M_y = M_r \sin^2 \varphi + M_t \cos^2 \varphi$$

where

Φ = angle with x-axis to the line jointing origin to the point under consideration.

F-1.3 The shear, Q per unit width of raft can be determined by :

$$Q = -\frac{P}{4L} Z_4' \left(\frac{r}{L}\right)$$

$Z_4' \left(\frac{r}{L}\right)$ = function for shear (*see* Fig. 14).

F-1.4 When the edge of the raft is located within the radius of influence, the following corrections are to be applied. Calculate moments and shears perpendicular to the edge of the raft within the radius of influence, assuming the raft to be infinitely large. Then apply opposite and equal moments and shears on the edge of the mat. The method for beams on elastic foundation may be used.

F-1.5 Finally, all moments and shears calculated for each individual column and wall are superimposed to obtain the total moment and shear values.

ANNEX G

(*Clauses* 8.2.3.3.1.1, 8.2.3.3.1.4 *and* 8.5.3.4)

LOAD CARRYING CAPACITY OF PILES — STATIC ANALYSIS

G-1 PILES IN GRANULAR SOILS

The ultimate load capacity (Q_u) of piles, in kN, in granular soils is given by the following formula:

$$Q_u = A_p(\tfrac{1}{2} D \gamma N_\gamma + P_D N_q) + \sum_{i=1}^{n} K_i \, P_{Di} \tan \delta_i A_{si} \qquad \ldots\ldots\ldots(1)$$

The first term gives end bearing resistance and the second term gives skin friction resistance.

where

A_{si} = surface area of pile shaft in the ith layer, in m^2;

A_p = cross-sectional area of pile tip, in m^2;

D = diameter of pile shaft, in m;

N_γ, N_q = bearing capacity factors depending upon the angle of internal friction, ϕ at pile tip;

K_i = coefficient of earth pressure applicable for the ith layer (*see* Note 3);

P_D = effective overburden pressure at pile tip, in kN/m^2 (*see* Note 5);

P_{Di} = effective overburden pressure for the ith layer, in kN/m^2;

$\sum_{i=1}^{n}$ = summation for layers 1 to n in which pile is installed and which contribute to positive skin friction;

δ_i = angle of wall friction between pile and soil for the ith layer; and

γ = effective unit weight of the soil at pile tip, in kN/m^3.

NOTES

1 N_γ factor can be taken for general shear failure according to good practice [C-2(34)].

2 N_q factor will depend on the nature of soil, type of pile, the L/B ratio and its method of construction. The values applicable for driven and bored piles are given in Fig. 15(A) and Fig. 15(B) respectively.

3 K_i, the earth pressure coefficient depends on the nature of soil strata, type of pile, spacing of piles and its method of construction. For bored piles in loose to dense sand with ϕ varying between 30°and 40°, K_i values in the range of 1 to 2 may be used for driven piles and in case of bored piles, K_i values in the range of 1 to 1.5 may be used.

4 δ, the angle of wall friction may be taken equal to the friction angle of the soil around the pile shaft.

5 In working out pile capacity by static formula, the maximum effective overburden at the pile tip should correspond to the critical depth, which may be taken as 15 times the diameter of the pile shaft for $\phi \leq 30°$ and increasing to 20 times for $\phi \geq 40°$.

6 For piles passing through cohesive strata and terminating in a granular stratum, a penetration of at least twice the diameter of the pile shaft should be given into the granular stratum.

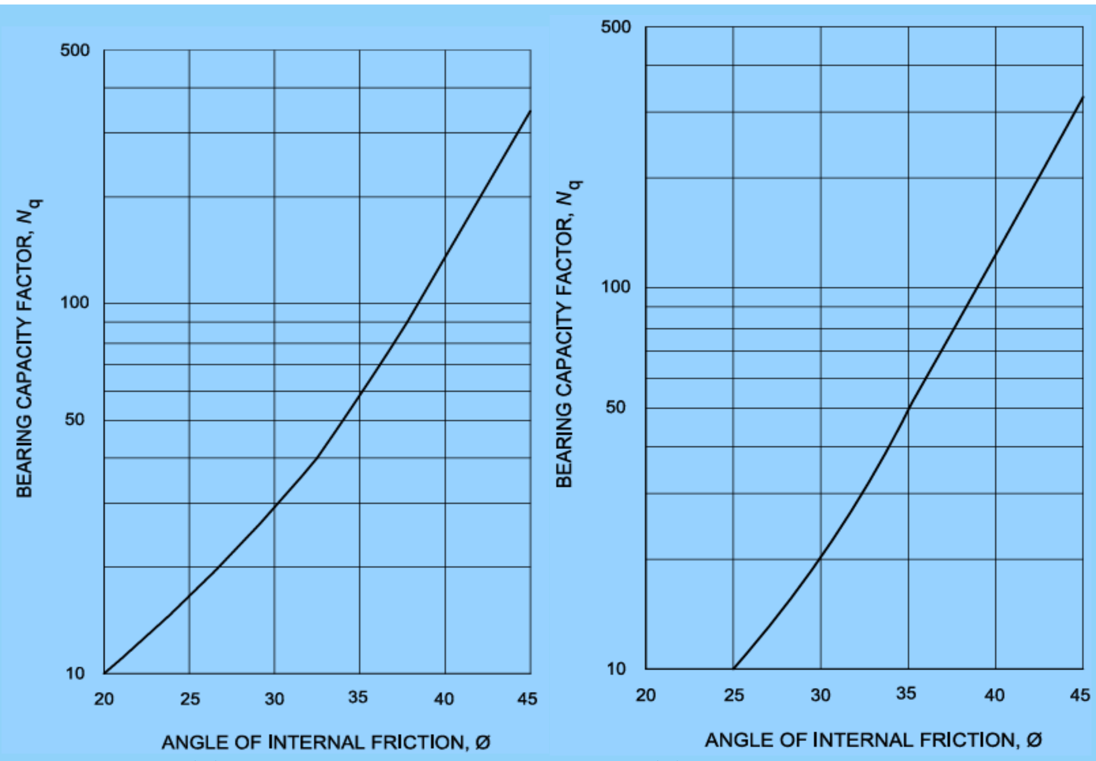


Fig.15(A) Bearing Capacity Factor, N_Q for Driven Piles

Fig.15(B) Bearing Capacity Factor, N_Q for Bored Piles

Fig. 15 Bearing Capacity Factor, N_Q

G-2 PILES IN COHESIVE SOILS

The ultimate load capacity (Q_u) of piles, in kN, in cohesive soils is given by the following formula:

$$Q_u = A_p N_c c_p + \sum_{i=1}^{n} \alpha ici Asi \qquad \text{..............(2)}$$

The first term gives end bearing resistance and the second term gives the skin friction resistance.

where

α_i = adhesion factor for the *i*th layer depending on the consistency of soil (*see* Note);

A_p = cross-sectional area of pile tip, in m^2;

A_{si} = surface area of pile shaft in the *i*th layer, in m^2;

c_i = average cohesion for the *i*th layer, in kN/m^2;

c_p = average cohesion at pile tip, in kN/m^2;

N_c = bearing capacity factor, may be taken as 9; and

$\sum_{i=1}^{n}$ = summation for layers 1 to *n* in which pile is installed and which contribute to positive skin friction.

NOTE — The value of adhesion factor, α_i depends on the undrained shear strength of the clay and may be obtained from Fig. 16.

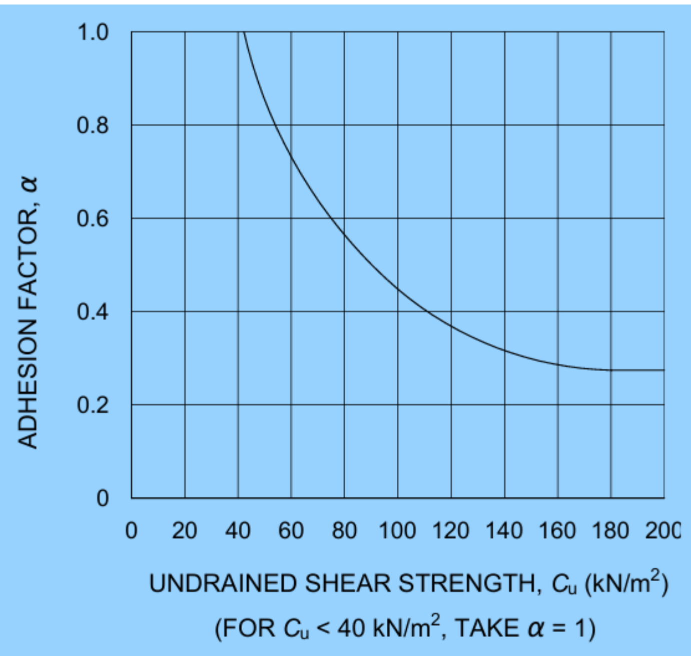


FIG. 16 VARIATION OF α WITH C_U

G-3 USE OF STATIC CONE PENETRATION DATA

G-3.1 When full static cone penetration data are available for the entire depth, the following correlation may be used as a guide for the determination of ultimate load capacity of a pile.

G-3.2 Ultimate end bearing resistance (q_u), in kN/m^2, may be obtained as:

$$q_u = \frac{\frac{q_{c0}+q_{c1}}{2} + q_{c2}}{2}$$

where

D = diameter of pile shaf;.

q_{c0} = average static cone resistance over a depth of 2D below the pile tip, in kN/m^2;

q_{c1} = minimum static cone resistance over the same 2D below the pile tip, in kN/m^2; and

q_{c2} = average of the envelope of minimum static cone resistance values over the length of pile of 8D above the pile tip, in kN/m^2.

G-3.3 Ultimate skin friction resistance can be approximated to local side friction (f_s), in kN/m^2, obtained from static cone resistance as given in Table 10.

Table 10 Side Friction for Different Soil Types

(*Clause* G-3.3)

Sl No. (1)	Type of Soil (2)	Local Side Friction, f_s kN/m^2 (3)
i)	q_c less than 1 000 kN/m^2	$q_c/30 < f_s < q_c/10$
ii)	Clay	$q_c/25 < f_s < 2q_c/25$
iii)	Silty clay and silty sand	$q_c/100 < f_s < q_c/25$
iv)	Sand	$q_c/100 < f_s < q_c/50$
v)	Coarse sand and gravel	$q_c/100 < f_s < q_c/150$

where q_c = cone resistance, in kN/m^2.

G-3.4 The correlation between standard penetration resistance, N (blows/30 cm) and static cone resistance, q_c, in kN/m^2, as given in Table 11 may be used for working out the end bearing resistance and skin friction resistance of piles. This correlation should only be taken as a guide and should preferably be established for a given site as they can vary substantially with the grain size, Atter berg limits, water table, etc.

Table 11 Co-Relation between N and q_c for Different Types of Soil

(*Clause* G-3.4)

Sl No. (1)	Type of Soil (2)	q_c/N (3)
i)	Clay	150 to 200
ii)	Silts, sandy silts and slightly cohesive silt-sand mixtures	200 to 250
iii)	Clean fine to medium sand and slightly silty sand	300 to 400
iv)	Coarse sand and sands with little gravel	500 to 600
v)	Sandy gravel and gravel	800 to 1 000

G-4 USE OF STANDARD PENETRATION TEST DATA FOR COHESIONLESS SOIL

G-4.1 The correlation suggested by Meyerhof using standard penetration resistance, N in saturated cohesionless soil to estimate the ultimate load capacity of driven pile is given below. The ultimate load capacity of pile (Q_u), in kN, is given as:

$$Q_u = 40\,N\frac{L_b}{D}A_p + \frac{\overline{N}A_s}{0.50} \quad \ldots\ldots\ldots\ldots(3)$$

The first term gives the end bearing resistance and the second term gives the frictional resistance.

where

A_s = surface area of pile shaft, in m^2;

A_p = cross-sectional area of pile tip, in m^2;

D = diameter or minimum width of pile shaft, in m;

L_b = length of penetration of pile in the bearing strata, in m;

$\overline{N}$ = average N along the pile shaft; and

N = average N values at pile tip;

NOTE — The end bearing resistance should not exceed 400 NA_p

G-4.2 For non-plastic silt or very fine sand the equation has been modified as:

$$Q_u = 30\, N \frac{L_b}{D} A_p + \frac{\overline{N} A_s}{0.60} \qquad (4)$$

The meaning of all terms is same as for equation 3.

G-4.3 The correlation suggested by Meyerhof using standard penetration resistance, N in saturated cohesionless soil to estimate the ultimate load capacity of bored pile is given below. The ultimate capacity of pile (Q_u), in kN, is given as:

$$Q_u = 13\, N \frac{L_b}{D} A_p + \frac{\overline{N} A_s}{0.50} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(5)$$

The first term gives end bearing resistance and the second term gives frictional resistance.

The meaning of all terms is same as for equation 3.

NOTE —The end bearing resistance should not exceed 130 NA_p.

G-4.4 For non-plastic silt or very fine sand the equation has been modified as:

$$Q_u = 10\, N \frac{L_b}{D} A_p + \frac{\overline{N} A_s}{0.60} \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(6)$$

The meaning of all terms is same as for equation 3.

G-5 FACTOR OF SAFETY

The minimum factor of safety for arriving at the safe pile capacity from the ultimate capacity obtained by using static formulae shall be 2.5.

G-6 PILES IN STRATIFIED SOIL

In stratified soil/C-ϕ soil, the ultimate load capacity of piles should be determined by calculating the skin friction and end bearing in different strata by using appropriate expressions given in G-1 and G-2.

G-7 PILES IN HARD ROCK

When the crushing strength of the rock is more than characteristic strength of pile concrete, the rock should be deemed as hard rock. Bored piles resting directly on hard rock may be loaded to their safe structural capacity.

G-8 PILES IN WEATHERED / SOFT ROCK

For bored piles founded in weathered/soft rock different empirical approaches are used to arrive at the socket length necessary for utilizing the full structural capacity of the pile.

Since it is difficult to collect cores in weathered/soft rocks, the method suggested by Cole and Stroud using 'N' values is more widely used. The allowable load on the pile, Q_a, in kN, by this approach, is given by:

$$Q_a = c_{u1} N_c \cdot \frac{\pi B^2}{4 F_s} + \alpha\, c_{u2} \cdot \frac{\pi B L}{F_s}$$

where

α = 0.9 (recommended value);

B = minimum width of pile shaft (diameter in case of circular piles),in m;

c_{u1} = shear strength of rock below the base of the pile, in kN/m^2 (*see* Fig. 17);

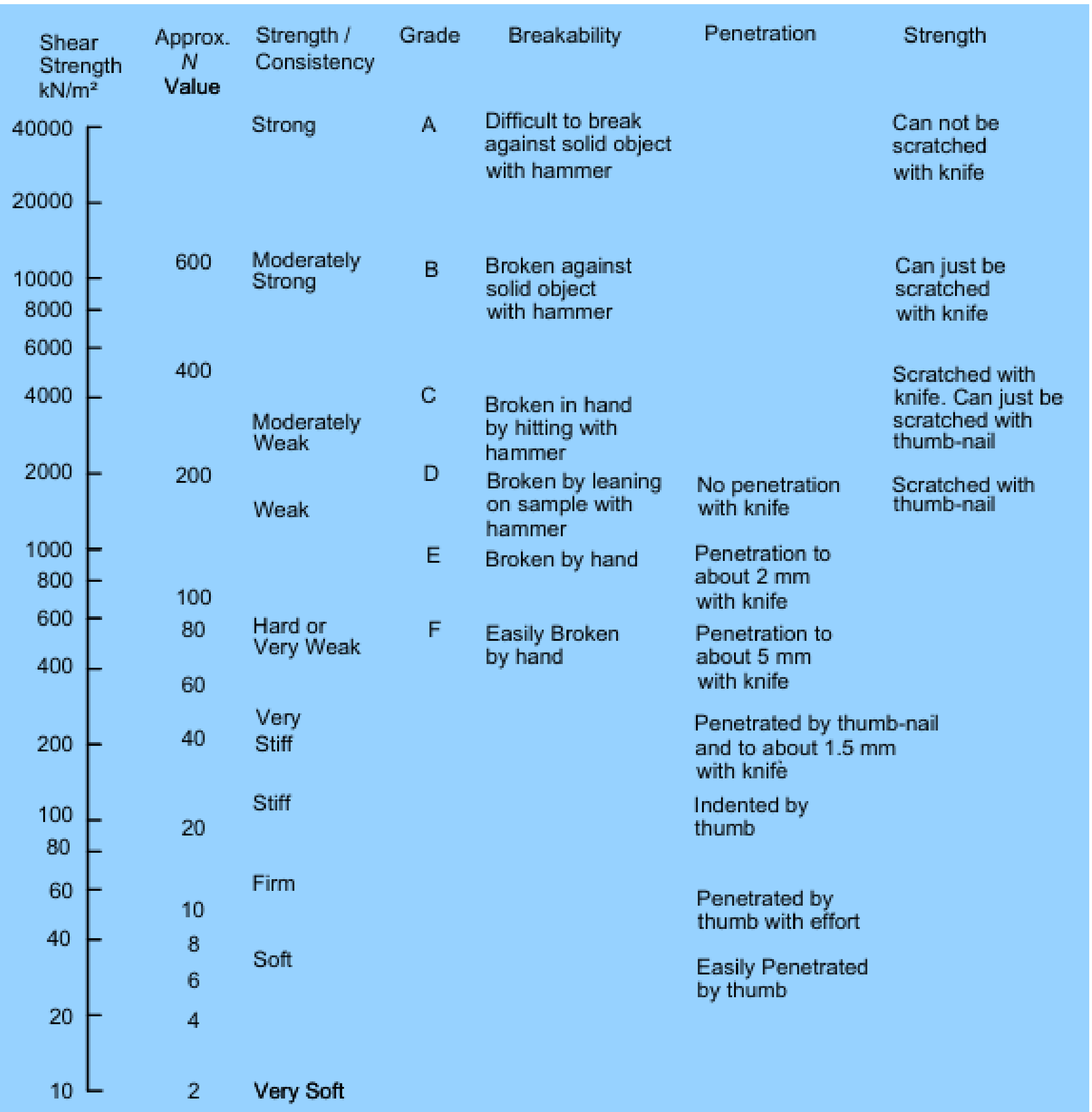
c_{u2} = average shear strength of rock in the socketed length of pile, in kN/m^2 (*see* Fig. 17);

F_s = factor of safety usually taken as 3;

L = socket length of pile, in m; and

N_c = bearing capacity factor taken as 9.

NOTE — For $N \geq 60$, the stratum is to be treated as weathered rock rather than soil.



NOTE – Standard penetration test may not be practicable for *N* values greater than 200. In such cases, design may be done on the basis of shear strength of rock.

FIG. 17 CONSISTENCY AND SHEAR STRENGTH OF WEATHERED ROCK

ANNEX H

(*Clause* 8.2.3.5.2)

ANALYSIS OF LATERALLY LOADED PILES

H-1 GENERAL

H-1.1 The ultimate resistance of a vertical pile to a lateral load and the deflection of the pile as the load builds up to its ultimate value are complex matters involving the interaction between a semi-rigid structural element and soil which deforms partly elastically and partly plastically. The failure mechanisms of an infinitely long pile and that of a short rigid pile are different. The failure mechanisms also differ for a restrained and unrestrained pile head condition.

Because of the complexity of the problem only a procedure for an approximate solution that is adequate in most of the cases is presented here. Situations that need a rigorous analysis shall be dealt with accordingly.

H-1.2 The first step is to determine, if the pile will behave as a short rigid unit or as an infinitely long flexible member. This is done by calculating the stiffness factor R or T for the particular combination of pile and soil.

Having calculated the stiffness factor, the criteria for behaviour as a short rigid pile or as a long elastic pile are related to the embedded length L_e of the pile. The depth from the ground surface to the point of virtual fixity is then calculated and used in the conventional elastic analysis for estimating the lateral deflection and bending moment.

H-2 STIFFNESS FACTORS

H-2.1 The lateral soil resistance for granular soils and normally consolidated clays which have varying soil modulus is modelled according to the equation:

$$\frac{p}{y} = \eta_h z$$

where

η_h = modulus of subgrade reaction for which the recommended values are given in Table 12;

p = lateral soil reaction per unit length of pile at depth z below ground level; and

y = lateral pile deflection.

H-2.2 The lateral soil resistance for over-consolidated clays with constant soil modulus is modelled according to the equation:

$$\frac{p}{y} = K$$

where

$$K = \frac{k_1}{1.5} \times \frac{0.3}{B}$$

where k_1 is Terzaghi's modulus of subgrade reaction as determined from load deflection measurements on a 30 cm square plate and B is the width of the pile (diameter in case of circular piles). The recommended values of k_1 are given in Table 13.

Table 12 Modulus of Subgrade Reaction for Granular Soils and Normally Consolidated Clays, η_h, kN/m^3

(*Clause* H-2.1 *and* H-2.3.1)

Sl No.	**Soil Type**	***N* (Blows/30 cm)**	**Range of η_h** kN/m^3 × 10^3	
			Dry	Submerged
(1)	(2)	(3)	(4)	(5)
i)	Soft organic silt	—	—	0.15
ii)	Soft normally consolidated clay	0 to 4	—	0.35 to 0.7
iii)	Very loose sand	0 to 4	< 0.4	< 0.2
iv)	Loose sand	4 to 10	0.4 to 2.5	0.2 to 1.4
v)	Medium sand	10 to 35	2.5 to 7.5	1.4 to 5.0
vi)	Dense sand	> 35	7.5 to 20.0	5.0 to 12.0

NOTE — The η_h values may be interpolated for intermediate standard penetration values, *N*.

Table 13 Modulus of Subgrade Reaction for Cohesive Soil, k_1, KN/m^3

(*Clauses* H-2.2 *and* H-2.3.2)

Sl No.	**Soil consistency**	**Unconfined compression strength, q_u** kN/m^2	**Range of k_1** kN/m^3 × 10^3
(1)	(2)	(3)	(4)
i)	Soft	25 to 50	4.5 to 9.0
ii)	Medium stiff	50 to 100	9.0 to 18.0
iii)	Stiff	100 to 200	18.0 to 36.0
iv)	Very stiff	200 to 400	36.0 to 72.0
v)	Hard	> 400	>72.0

NOTE — For q_u less than 25, k_1 may be taken as zero, which implies that there is no lateral resistance.

H-2.3 Stiffness Factors

H-2.3.1 *For Piles in Sand and Normally Consolidated Clays*

$$\text{Stiffness factor } T\text{, in m} = \sqrt[5]{\frac{EI}{\eta_h}}$$

where

E = young’s modulus of pile material, in MN/m^2;

I = moment of inertia of the pile cross-section, in m^4; and

η_h = modulus of subgrade reaction variation, in MN/m^3 (*see* Table 12).

H-2.3.2 *For Piles in Over-Consolidated Clays*

$$\text{Stiffness factor } R\text{, in m} = \sqrt[4]{\frac{EI}{KB}}$$

where

B = width of pile shaft (diameter in case of circular piles), in m;

E = young's modulus of pile material, in MN/m^2;

I = moment of inertia of the pile cross-section, in m^4; and

K = $\frac{k_1}{1.5} \times \frac{0.3}{B}$, (*See* Table 13 for values of k_1, in MN/m^3, *See also* Note).

NOTE — Table 13 shall be referred if the average unconfined compression strength, q_u is greater than or equal to 100 kN/m^2.

H-3 CRITERIA FOR SHORT RIGID PILES AND LONG ELASTIC PILES

Having calculated the stiffness factor T or R, the criteria for behaviour as a short rigid pile or as a long elastic pile are related to the embedded length L_e as given in Table 14.

Table 14 Criteria for Behaviour of Pile Based on its Embedded Length

(*Clause* H-3)

Sl No.	**Type of Pile Behaviour**	**Relation of Embedded Length with Stiffness Factor**	
		Linearly Increasing	Constant
(1)	(2)	(3)	(4)
i)	Short (rigid) pile	$L_e \leq 2T$	$L_e \leq 2R$
ii)	Long (elastic) pile	$L_e \geq 4T$	$L_e \geq 3.5R$

NOTE — The intermediate L shall indicate a case between rigid pile behaviour and elastic pile behaviour.

H-4 DEFLECTION AND MOMENTS IN LONG ELASTIC PILES

H-4.1 Equivalent cantilever approach gives a simple procedure for obtaining the deflections and moments due to relatively small lateral loads. This requires the determination of depth of virtual fixity, z_f.

The depth to the point of fixity may be read from the plots given in Fig. 18. e is the effective eccentricity of the point of load application obtained either by converting the moment to an equivalent horizontal load or by actual position of the horizontal load application. R and T are the stiffness factors described earlier.

H-4.2 The pile head deflection, y shall be computed using the following equations:

Deflection, $y = \frac{H(e+z_f)^3}{3EI} \times 10^3$ …….for free head pile

Deflection, $y = \frac{H(e+z_f)^3}{12EI} \times 10^3$ …….for fixed head pile

where

e	cantilever length above ground/bed to the point of load application, in m;
E	young's modulus of pile material, in kN/m^2;
H	lateral load, in kN;
I	moment of inertia of the pile cross section, in m^4;
y	deflection of pile head, in mm; and
z_f	depth to point of fixity, in m.

H-4.3 The fixed end moment of the pile for the equivalent cantilever may be determined from the following expressions.

Fixed end moment, $M_F = H(e + z_f)$ ……….for free head pile

Fixed end moment, $M_F = \frac{H(e+z_f)}{2}$ ……….for fixed head pile

The fixed head moment, M_F of the equivalent cantilever is higher than the actual maximum moment M in the pile. The actual maximum moment may be obtained by multiplying the fixed end moment of the equivalent cantilever by a reduction factor, m, given in Fig. 19.

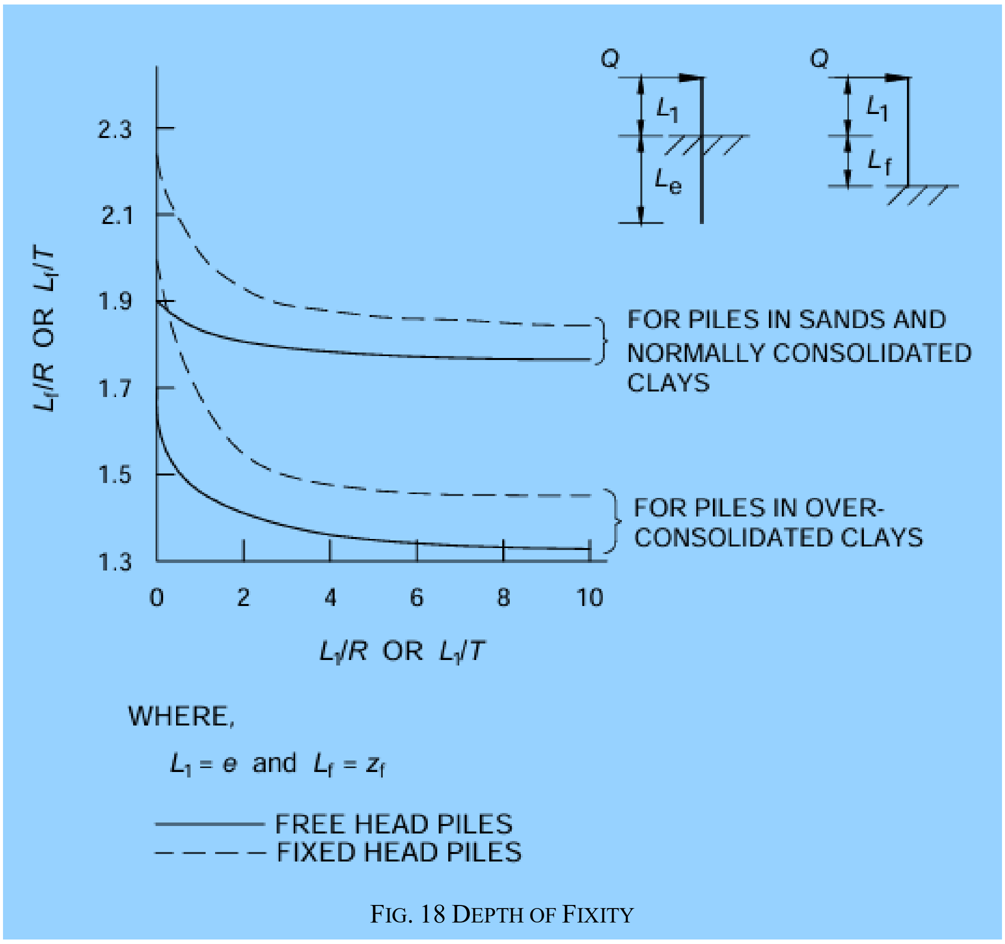
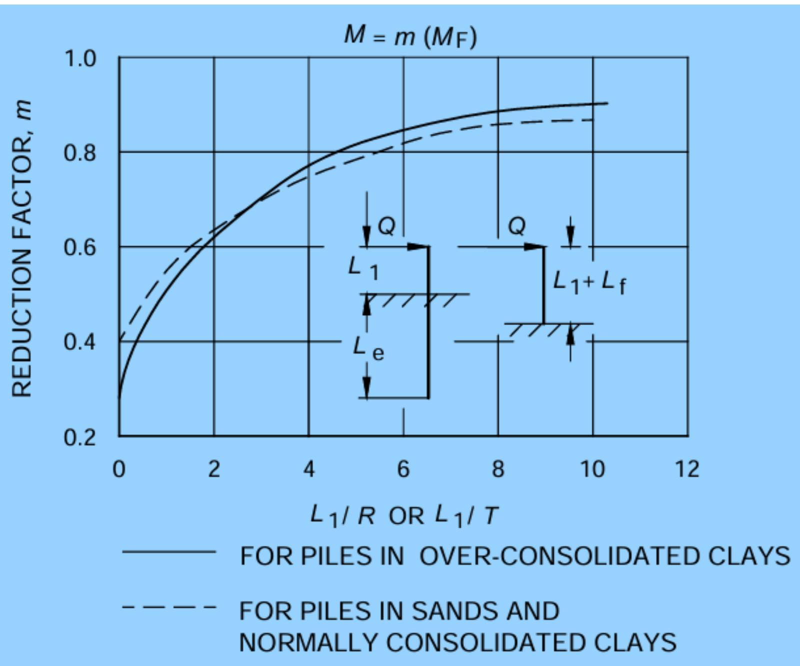
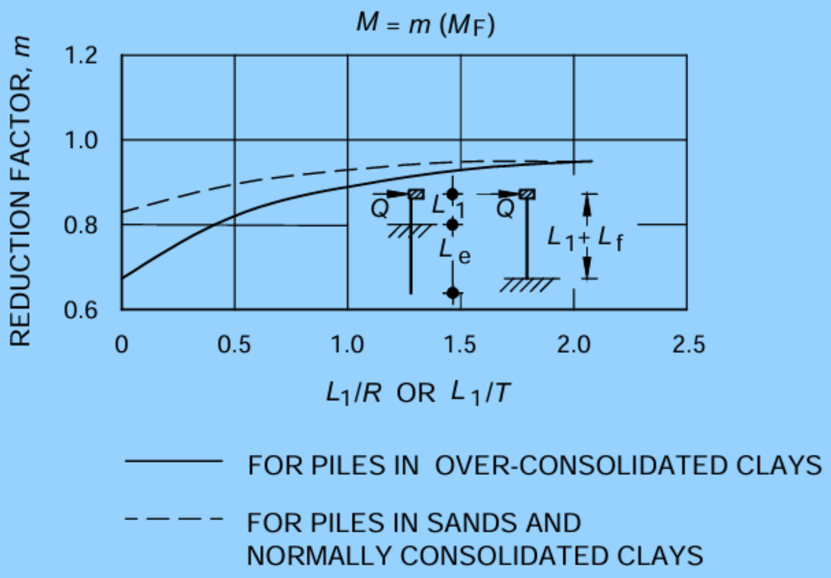


FIG. 18 DEPTH OF FIXITY



19A FOR FREE HEAD PILE



19B FOR FIXED HEAD PILE

FIG. 19 DETERMINATION OF REDUCTION FACTORS FOR COMPUTATION OF MAXIMUM MOMENT IN PILE

ANNEX J

(*Clause* 8.5.3.2)

LOAD CARRYING CAPACITY OF UNDER-REAMED PILES FROM SOIL PROPERTIES

J-1 ULTIMATE LOAD CAPACITY

The ultimate load capacity of a pile can be calculated from soil properties. The soil properties required are strength parameters, cohesion, angle of internal friction and soil density.

a) *Clayey soils* — For cohesive soils, the ultimate load carrying capacity of an under-reamed pile may be worked out from the following expression:

$$Q_u = A_p N_c C_p + A_a N_c C'_a + C'_a A'_s + \alpha C_a A_s$$

where

A_a = $(\pi/4)(D_u^2 - D^2)$, where D_u and D are the under-reamed and stem diameter, respectively, in m;

A_p = cross-sectional area of the pile stem at the pile tip, in m^2;

A_s = surface area of the stem, in m^2;

A'_s = surface area of the cylinder circumscribing the under-reamed bulbs, in m^2;

α = reduction factor (usually taken 0.5 for clays);

C_a = average cohesion of the soil along the pile stem, in kN/m^2;

C'_a = average cohesion of the soil around the under-reamed bulbs;

C_p = cohesion of the soil around toe, in kN/m^2;

N_c = bearing capacity factor, usually taken as 9; and

Q_u = ultimate bearing capacity of pile, in kN.

NOTES

1 The above expression holds for the usual spacing of under-reamed bulbs spaced at not more than one and a half times their diameter.

2 If the pile is with one bulb only, the third term will not occur. For calculating uplift load, the first term will not occur in the formula.

3 In case of expansive soil, top 2 m strata should be neglected for computing skin friction.

b) *Sandy soils*

$$Q_u = A_p\,(\frac{1}{2}D.\gamma.N_\gamma + \gamma.d_f.N_q) + A_a\,[\frac{1}{2}D_u.n.\gamma.N_\gamma + \gamma.N_q.(\sum_{r=1}^{r=n} d_r)] + \frac{1}{2}.\pi.D.\gamma.K\tan\delta\,.(d_1{}^2 + d_f{}^2 - d_n{}^2)$$

where

A_a = $\pi/4\ (D_u^2 - D^2)$ where D_u is the under-reamed bulb diameter, in m;

A_p = $\pi\ D^2/4$, where D is stem diameter, in m;

d_1 = depth of the centre of the first under-reamed bulb, in m;

d_f = total depth of pile below ground level, in m;

d_n = depth of the centre of the last under-reamed bulb, in m;

d_r = depth of the centre of different under-reamed bulbs below ground level, in m;

K = earth pressure coefficient (usually taken as 1.75 for sandy soils);

n = number of under-reamed bulbs;

N_Y, N_q = bearing capacity factors, depending upon the angle of internal friction;

γ = average unit weight of soil (submerged unit weight in strata below water table), in kN/m^3; and

δ = angle of wall friction (may be taken as equal to the angle of internal friction $\emptyset$)

NOTES

1 For uplift bearing on pile tip, A_p will not occur.

2 N_Y will be as specified in good practice [C-2(34)] and N_q will be taken from Fig. 15(B).

c) *Soil strata having both cohesion and friction* — In soil strata having both cohesion and friction or in layered strata having two types of soil, the bearing capacity may be estimated using both the formulae. However, in such cases load test will be a better guide.

d) *Compaction piles in sandy strata* — For bored compaction piles in sandy strata, the formula in (b) shall be applied but with the modified value of $\emptyset_1$ as given below:

$$\Phi_1 = (\Phi + 40)/2$$

where

$$\Phi = \text{angle of internal friction of virgin soil.}$$

The values of N_Y, N_q and δ are taken corresponding to Φ_1. The value of the earth pressure coefficient K will be 3.

e) *Piles resting on rock* — For piles resting on rock, the bearing component will be obtained by multiplying the safe bearing capacity of rock with bearing area of the pile stem plus the bearing provided by the bulb portion.

NOTE — To obtain safe load in compression and uplift from ultimate load capacity generally the factors of safety will be 2.5 and 3, respectively.

ANNEX K

(*Clause* 9.3.3.4)

LOAD CARRYING CAPACITY

K-1 LOAD CARRYING CAPACITY OF CPRF SYSTEM

K-1.1 The ultimate vertical capacity shall be taken as the least of:

a) the capacity of the block containing the piles, plus that of the portion of the raft outside the periphery of the pile group;

b) the sum of the capacity of the raft, $Q_{\text{unpiled-raft}}$ and of all the piles $Q_{\text{pile-group}}$ in the system, expressed as, $Q_{\text{CPRF}} = 0.8\,(Q_{\text{unpiled-raft}} + Q_{\text{pile-group}})$; and

c) the capacity of CPRF system considering pile-soil-raft interactions. The capacity of CPRF should be expressed as:

$$\mathrm{Q}_{\mathrm{CPRF}} = \alpha_{pr}\alpha_{pp}\sum_{n=1}^{n} Q_{single\ pile} + \alpha_{rp}Q_{unpiled\ raft}$$

In the above expression:

1) $Q_{unpiled\ raft}$ should be calculated based on good practice [C-2(34)];

2) $Q_{single\ pile}$ should be calculated based on good practice [C-2(51)]; and

3) α_{pp}, α_{rp} and α_{pr} are the pile-pile, raft-pile and pile-raft interaction factors, respectively. These interaction factors may be suitably taken from various relevant literature.

ANNEX L

(*Clause* 11.2)

SOIL IMPROVEMENT METHODS

L-1 SUMMARY OF SOIL IMPROVEMENT METHODS

	Method	Principle	Most Suitable Soil Conditions/ Types	Maximum Effective Treatment Depth	Special Materials Required	Special Equipment Required	Properties of Treated Material	Special Advantages and Limitation	Relative Cost
In-Situ Deep compaction of Cohesionless Soils	Blasting	Shock waves and vibrations cause liquefaction; displacement with settlement to higher density	Saturated, clean sands: partly saturated sands and silts (collapsible loss) after flooding	> 30 m	Explosives, backfill to plug drill holes, hole casings	Jetting or drilling machine	Can obtain relative densities to 70 to 80, may get variable density strength gain	Rapid, inexpensive, can treat any size areas: variable properties, no improvement near surface, dangerous	Low
	Vibratory Probe	Densification by vibration; liquefaction induced settlement under overburden	Saturated or dry clean sand	20 m (Ineffective above 3 m to 4 m depth)	None	Vibratory pile driver and 750 mm dia open steel pipe	Can obtain relative densities of up to 80 percent. Ineffective in some sands	Rapid, simple, good underwater, soft under layers may damp vibrations, difficult to penetrate, stiff over layers, not good in partly saturated soils	Moderate
	Vibro-compaction	Densification by vibration and compaction of backfill material	Cohesionless soils with less than 20 fines	30 m	Granular backfill, water supply	Vibroflot, crane, pumps	Can obtain high relative densities, good uniformity	Useful in saturated and partly saturated soils, uniformity	Moderate
In-Situ Deep compaction of Cohesionless Soils	Compaction piles	Densification by displacement of pile volume and by vibration during driving	Loose sandy soils: partly saturated clayey soils, loess	> 20 m	Pile material (often sand or soil plus cement mixture)	Pile driver, special sand pile equipment	Can obtain high densities, good uniformity	Useful in soils with fines, uniform compaction, easy to check results, slow, limited improvement in upper 1 m to 2 m	Moderate to high

Table (*Continue*)

	Method	**Principle**	**Most Suitable Soil Conditions/ Types**	**Maximum Effective Treatment Depth**	**Special Materials Required**	**Special Equipment Required**	**Properties of Treated Material**	**Special Advantages and Limitation**	**Relative Cost**
In-Situ Deep compaction of Cohesionless Soils	Blasting	Shock waves and vibrations cause liquefaction; displacement with settlement to higher density	Saturated, clean sands: partly saturated sands and silts (collapsible loss) after flooding	> 30 m	Explosives, backfill to plug drill holes, hole casings	Jetting or drilling machine	Can obtain relative densities to 70 to 80, may get variable density strength gain	Rapid, inexpensive, can treat any size areas: variable properties, no improvement near surface, dangerous	Low
	Vibratory Probe	Densification by vibration; liquefaction induced settlement under overburden	Saturated or dry clean sand	20 m (Ineffective above 3 m to 4 m depth)	None	Vibratory pile driver and 750 mm dia open steel pipe	Can obtain relative densities of up to 80 percent. Ineffective in some sands	Rapid, simple, good underwater, soft under layers may damp vibrations, difficult to penetrate, stiff over layers, not good in partly saturated soils	Moderate
	Vibro-compaction	Densification by vibration and compaction of backfill material	Cohesionless soils with less than 20 fines	30 m	Granular backfill, water supply	Vibroflot, crane, pumps	Can obtain high relative densities, good uniformity	Useful in saturated and partly saturated soils, uniformity	Moderate
In-Situ Deep compaction of Cohesionless Soils	Compaction piles	Densification by displacement of pile volume and by vibration during driving	Loose sandy soils: partly saturated clayey soils, loess	> 20 m	Pile material (often sand or soil plus cement mixture)	Pile driver, special sand pile equipment	Can obtain high densities, good uniformity	Useful in soils with fines, uniform compaction, easy to check results, slow, limited improvement in upper 1 m to 2 m	Moderate to high

Table (*Continue*)

	Method	Principle	Most Suitable Soil Conditions/ Types	Maximum Effective Treatment Depth	Special Materials Required	Special Equipment Required	Properties of Treated Material	Special Advantages and Limitation	Relative Cost
	Displacements grout	Highly viscous grout acts as radical hydraulic jack when pumped in under high pressure	Soft, fine-grained soils; foundation soils with large voids or cavities	Unlimited, but a few metre usual	Soil, cement water	Batching equipment, high pressure pumps, hoses	Grout bulbs within compressed soil matrix	Good for correction of differential settlements, filling large voids; careful control required	Low material high injection
	Electro-kinetic injection	Stabilization chemicals moved into soil by electro-osmosis or colloids into pores by electrophoresis	Saturated silts; silty clays (clean sands in case of colloid injection)	Unknown	Chemicals stabilizer colloidal void fillers	d.c. power supply, anodes, cathodes	Increased strength, reduced compressibility reduced liquefaction potential	Existing soil and structures not subjected to high pressures; not good in soils with high conductivity	Expansive
	Jet grouting	High speed jets at depth excavate, inject and mix stabilizer with soil to form columns or panels	Sands, silts, clays	—	Water, stabilizing chemicals	Special jet nozzle, pumps, pipes and hoses	Solidified columns and walls	Useful in soils that can't be permeation grouted, precision in locating treated zones	--

Table (*Continue*)

	Method	Principle	Most Suitable Soil Conditions/ Types	Maximum Effective Treatment Depth	Special Materials Required	Special Equipment Required	Properties of Treated Material	Special Advantages and Limitation	Relative Cost
Precompression	Preloading with/without drain	Load is applied sufficiently in advance of construction so that compression of soft soils is completed prior to development of the site	Normally consolidated soft clays, silts, organic deposits, completed sanitary landfills	—	Earth fill or other material for loading the site; sand or gravel for drainage blanket	Earth moving equipment, large water tanks or vacuum drainage systems sometimes used; settlement markers, piezometers	Reduced water content and void ratio, increased strength	Easy, theory well developed, uniformity; requires long time (vertical drains can be used to reduce consolidation time)	Low (moderate, if vertical drains are required)
	Surcharge fills	Fill in excess of that required permanently is applied to achieve a given amount of settlement in a shorter time; excess fill then removed	Normally consolidated soft clays, silts, organic deposits, completed sanitary landfills	—	Earth fill or other material for loading the site; sand or gravel for drainage blanket	Earth moving equipment; settlement markers, piezometers	Reduced water content, void ratio and compressibility increased strength	Faster than preloading without surcharge, theory well developed, extra material handling; can use vertical drains to reduce consolidation time	Moderate
	Electro-osmosis	d. c. current causes water flow from anode towards cathode where it is removed	Normally consolidated silts and silty clays	—	Anodes (usually rebars or aluminium) cathodes (well points or rebars)	d. c. power supply, wiring, metering systems	Reduced water content and compressibility, increased strength, electrochemical hardening	No fill loading required, can be used in confined area, relatively fast; non-uniform properties between electrodes; not good in highly conductive soils	High

Table (*Continue*)

	Method	**Principle**	**Most Suitable Soil Conditions/ Types**	**Maximum Effective Treatment Depth**	**Special Materials Required**	**Special Equipment Required**	**Properties of Treated Material**	**Special Advantages and Limitation**	**Relative Cost**
Admixtures	Remove and replace	Foundation soil excavated, improved by drying or admixture and re-compacted	Inorganic soils	10 m	Admixture stabilizers	Excavating, mixing and compaction equipment, dewatering system	Increased strength and stiffness, reduced compressibility	Uniform, controlled foundation soil when replaced; may require large area dewatering	High
	Structural fills	Structural fill distributes loads to underlying soft soils	Use over soft clays or organic soils, marsh deposits	—	Sand, gravel fly ash, bottom ash, slag, expanded aggregate, clam shell or oyster shell, incinerator ash	Mixing and compaction equipment	Soft subgrade protected by structural load-bearing fill	High strength, good load distribution to underlying soft soils	Low to high
	Mix-in-place piles and walls	Lime cement or asphalt introduced through rotating auger or special in-place mixer	All soft or loose inorganic soils	>20 m	Cement lime asphalt, or chemical stabilizer	Drill rig, rotary cutting and mixing head, additive pro-portioning equipment	Solidified soil piles for walls of relatively high strength	Use native soil, reduced lateral support requirements during excavation; difficult quality control	Moderate to high

Table (Continue)

	Method	Principle	Most Suitable Soil Conditions/ Types	Maximum Effective Treatment Depth	Special Materials Required	Special Equipment Required	Properties of Treated Material	Special Advantages and Limitation	Relative Cost
Thermal	Heating	Drying at low temperatures; alteration of clays at intermediate temperatures (400 to 600 °C); fusion at high temperatures (>1 000 °C)	Fine-grained soils, especially partly saturated clays and silts, loess	15 m	Fuel	Fuel tanks, burners, blowers	Reduced water content, plasticity, water sensitivity; increased strength	Can obtain irreversible improvements in properties; can introduce stabilizers with hot gases	High
	Freezing	Freeze soft, wet ground to increase its strength stiffness	All soils	Several metre	Refrigerant	Refrigeration system	Increased strength and stiffness, reduced permeability	No good in flowing ground water, temporary	High
Reinforcement	Vibro replacement sand/stone columns	Hole jetted into soft, fine-grained soil and backfilled with densely compacted gravel or sand	Soft clays and alluvial deposits	20 m	Gravel or crushed rock backfill	Vibroflot, crane or vibrocat, water	Increased bearing capacity, reduced settlement	Faster than precompression, avoids dewatering required for remove and replace; limited bearing capacity	Moderate to high
	Root piles, soils nailing	Inclusions used to carry tension, shear, compression	All soils	—	Reinforcing bars, cement grout	Drilling and grouting equipment	Reinforced zone behaves as a coherent mass	*In-situ* reinforcement for soils that can't be grouted or mixed in-place with admixtures	Moderate to high

Table (*Concluded*)

	Method	Principle	Most Suitable Soil Conditions/ Types	Maximum Effective Treatment Depth	Special Materials Required	Special Equipment Required	Properties of Treated Material	Special Advantages and Limitation	Relative Cost
	Strips and membranes	Horizontal tensile strips, membranes buried in soil under embankments, gravel base courses and footings	All soils	Can construct earth structures to heights of several metres	Metal or plastic strips, geotextiles	Excavating, earth handling and compaction equipment	Self-supporting earth structures, increased bearing capacity, reduced deformations	Economical, earth structures coherent, can tolerate deformations; increased allowable bearing pressure	Low to moderate

LIST OF STANDARDS

The following list records those standards which are acceptable as ‘good practice’ and ‘accepted standards’ in the fulfilment of the requirements of this NBCS. The latest version of a standard shall be adopted at the time of enforcement of this NBCS. The standards listed may be used for conformance with the requirements of the referred clauses in this NBCS.

In the following list, the number appearing in the first column within parentheses indicates the number of the reference in this Part/Section of this NBCS.

	IS No.	*Title*
(1)	IS 1892 : 2021	Subsurface investigation for foundations — Code of practice (*second revision*)
	IS 2131 : 2025	Standard penetration test of soil — Method of test (*second revision*)
	IS 2132 : 1986	Code of practice for thin walled tube sampling of soils (*second revision*)
	IS 4434 : 1978	Code of practice for *in-situ* vane shear test for soils (*first revision*)
	IS 4968	Method for subsurface sounding for soils
	(Part 1) : 1976	Dynamic method using 50 mm cone without bentonite slurry (*first revision*)
	(Part 2) : 1976	Dynamic method using cone and bentonite slurry (*first revision*)
	(Part 3) : 1976	Static cone penetration test (*first revision*)
	IS 8763:1978	Guide for undisturbed sampling of sands
	IS 9214 : 1979	Method for determination of modulus of subgrade reaction (*k*-value) of soils in the field
(2)	IS 19235 : 2025	Geotechnical engineering services — Requirements
(3)	IS 6926 : 1996	Diamond core drilling — Site investigation for river valley projects — Code of practice (*first revision*)
(4)	IS 10208 : 1982	Specification for diamond core drilling equipment
(5)	IS 4078 : 1980	Code of practice for indexing and storage of drill cores (*first revision*)
(6)	IS 2131 : 2025	Standard penetration test of soil — Method of test (*second revision*)
(7)	IS 4434 : 1978	Code of practice for *In-situ* vane shear test for soils (*first revision*)
(8)	IS 1892 : 2021	Subsurface investigation for foundations — Code of Practice (*second revision*)
(9)	IS 1888 : 1982	Method of load tests on soils (*second revision*)
(10)	IS 9214 : 1979	Method for determination of modulus of subgrade reaction (*K* value) of soils in the field
(11)	IS 1888:1982	Method of load test on soils (*second revision*)
(12)	IS 5249 : 1992	Determination of dynamic properties of soil — Method of test (*second revision*)
(13)	IS 4968	Method for subsurface sounding for soils
(14)	(Part 1) : 1976	Dynamic method using 50 mm cone without bentonite slurry (*first revision*)

(15)	(Part 2) : 1976	Dynamic method using cone and bentonite slurry (*first revision*)
(16)	(Part 3) : 1976	Static cone penetration test
(17)	IS 10042 : 1981	Code of practice for site-investigations for foundation in gravel boulder deposits
(18)	IS 15736 : 2007	Geological exploration by geophysical method (electrical resistivity) — Code of practice
(19)	IS 3043 : 2018	Code of practice for earthing (*second revision*)
(20)	IS 15681:2006	Geological exploration by geophysical method (seismic refraction) — Code of practice
(21)	IS 13372	Seismic testing of rock mass — Code of practice
(22)	(Part 1) : 1992	Within a borehole
(23)	(Part 2) : 1992	Between the borehole
(24)	IS 5529 (Part 1) : 2013	*In-situ* permeability test: Part 1 Test in overburden
(25)	IS 2470 (Part 1) : 1985	Code of practice for installation of septic tanks: Part 1 Design criteria and construction (*second revision*)
(26)	IS 5529 (Part 2): 2006	*In-situ* permeability test: Part 2 Tests in bedrock (*second revision*)
(27)	IS 2720 (Part 31) : 1990	Methods of tests for soils field determination of California bearing ratio (*first revision*)
(28)	IS 2720	Methods of tests for soils:
	(Part 1) : 1983	Preparation of dry soil samples for various tests (*second revision*)
	(Part 2) : 1973	Determination of water content (*second revision*)
	(Part 3/Sec 1) : 1980	Determination of specific gravity, Section 1 Fine grained soils (*first revision*)
	(Part 3/Sec 2) : 1980	Determination of specific gravity, Section 2 Fine, medium and coarse grained soils (*first revision*)
	(Part 4) : 1985	Grain size analysis (*second revision*)
	(Part 5) : 1985	Determination of liquid and plastic limit (*second revision*)
	(Part 10) : 1991	Determination of unconfined compressive strength (*second revision*)
	(Part 11) : 1993	Determination of the shear strength parameters of a specimen tested in unconsolidated undrained triaxial compression without the measurement of pore water pressure(*first revision*)
	(Part 12) : 1981	Determination of shear strength parameters of soil from consolidated undrained triaxial compression test with measurement of pore water pressure (*first revision*)
	(Part 13) : 1986	Direct shear test (*second revision*)
	(Part 15) : 1986	Determination of consolidation properties (*first revision*)
	(Part 28) : 1974	Determination of dry density of soils, in-place, by the sand replacement method (*first revision*)
	(Part 29) : 1975	Determination of dry density of soils in-place, by the core cutter method (*first revision*)

	(Part 33) : 1971	Determination of the density in-place by the ring and water replacement method
	(Part 34):1972	Determination of density of soils in-place by rubber-balloon method
	(Part 39/Sec 1) : 1977	Direct shear test for soils containing gravel, Section 1 Laboratory test
(29)	IS 1498 : 1970	Classification and identification of soils for general engineering purposes (*first revision*)
(30)	IS 401 : 2001	Preservation of timber — Code of practice (*fourth revision*)
(31)	IS 15180 : 2002	Guidelines for use in prediction of subsidence and associated parameters in coal mines having nearly horizontal single seam workings
(32)	IS 14243	Selection and development of site for building in hill areas — Guidelines
	(Part 1) : 1995	Microzonation of urban centres
	(Part 2) : 1995	Selection and development
(33)	IS 11134 : 1984	Code of practice for setting out of buildings
(34)	IS 3764 : 1992	Excavation work — Code of safety (*first revision*)
(35)	IS 1904 : 2021	General requirements for design and construction of foundations in soils — Code of practice (*fourth revision*)
(36)	IS 6403 : 1981	Code of practice for determination of bearing capacity of shallow foundations (*first revision*)
(37)	IS 12070 : 1987	Code of practice for design and construction of shallow foundations on rocks
(38)	IS 1080 : 1985	Code of practice for design and construction of shallow foundations in soils (other than raft, ring and shell) (*second revision*)
(39)	IS 11089 : 1984	Code of practice for design and construction of ring foundations
(40)	IS 9456 : 1980	Code of practice for design and construction of conical and hyperbolic paraboloidal types of shell foundations
(41)	IS 2974 (Part 1) : 1982	Code of practice for design and construction of machine foundations: Part 1 Foundations for reciprocating type machines (*second revision*)
(42)	IS 2911 (Part 4) : 2013	Design and construction of pile foundations — Code of practice: Part 4 Load test on piles (*second revision*)
(43)	IS 14593 : 1998	Design and construction of bored cast *in-situ* piles founded on rocks — Guidelines
(44)	IS 4968	Method for subsurface sounding for soils:
	(Part 1) : 1976	Dynamic method using 50 mm cone without bentonite slurry (*first revision*)
	(Part 2) : 1976	Dynamic method using cone and bentonite slurry (*first revision*)
	(Part 3) : 1976	Static cone penetration test (*first revision*)
(45)	IS 2911	Design and construction of pile foundations — Code of practice
	(Part 1/Sec 1) : 2010	Concrete piles, Section 1 Driven cast *in-situ* concrete piles (*second revision*)
	(Part 1/Sec 2) : 2010	Concrete piles, Section 2 Bored cast *in-situ* concrete piles (*second revision*)

(46)	IS 14893 : 2021	Low strain non-destructive integrity testing of piles — Guidelines (*first revision*)
(47)	IS 2911 (Part 1/Sec 3) : 2010	Design and construction of pile foundations — Code of practice, Concrete piles, Section 3 Driven precast concrete piles (*second revision*)
(48)	IS 2911 (Part 1/Sec 4) : 2010	Design and construction of pile foundations — Code of practice, Concrete piles, Section 4 Precast concrete piles in prebored holes (*first revision*)
(49)	IS 456 : 2000	Plain and reinforced concrete — Code of practice (*fourth revision*)
(50)	IS 2911 (Part 3) : 2021	Design and construction of pile foundations — Code of practice, Under-reamed piles (*second revision*)
(51)	IS 2911 (Part 2) : 2021	Design and construction of pile foundations — Code of practice, Timber piles (*second revision*)
(52)	IS 1892 : 2021	Subsurface investigation for foundations — Code of practice (*second revision*)
	IS 2720	Methods of test for soils:
	(Part 1) : 1983	Preparation of dry soil samples for various tests (*second revision*)
	(Part 2) : 1973	Determination of water content (*second revision*)
	(Part 3/Sec 1) : 1980	Determination of specific gravity, Section 1 Fine grained soils (*first revision*)
	(Part 3/Sec 2) : 1980	Determination of specific gravity, Section 2 Fine, medium and coarse grained soils (*first revision*)
	(Part 4) : 1985	Grain size analysis (*second revision*)
	(Part 5) : 1985	Determination of liquid and plastic limits (*second revision*)
	(Part 6) : 1972	Determination of shrinkage factors (*first revision*)
	(Part 7) : 1980	Determination of water content — Dry density relation using light compaction (*second revision*)
	(Part 8) : 1983	Determination of water content — Dry density relation using heavy compaction (*second revision*)
	(Part 9) : 1992	Determination of dry density — Moisture content relation by constant mass of soil method (*first revision*)
	(Part 10) : 1991	Determination of unconfined compressive strength (*second revision*)
	(Part 11) : 1993	Determination of the shear strength parameters of a specimen tested in unconsolidated undrained triaxial compression without the measurement of pore water pressure (*first revision*)
	(Part 12) : 1981	Determination of shear strength parameters of soil from consolidated undrained triaxial compression test with measurement of pore water pressure (*first revision*)
	(Part 13) : 1986	Direct shear test (*second revision*)
	(Part 14) : 1983	Determination of density index (relative density) of cohesionless soils (*first revision*)
	(Part 15) : 1986	Determination of consolidation properties (*first revision*)
	(Part 16) : 1987	Laboratory determination of cbr (*second revision*)
	(Part 17) : 1986	Laboratory determination of permeability (*first revision*)
	(Part 18) : 1992	Determination of field moisture equivalent (*first revision*)
	(Part 19) : 1992	Determination of centrifuge moisture equivalent (*first revision*)
	(Part 20) : 1992	Determination of linear shrinkage (*first revision*)

	(Part 21) : 1977	Determination of total soluble solids (*first revision*)
	(Part 22) : 1972	Determination of organic matter (*first revision*)
	(Part 23) : 1976	Determination of calcium carbonate
	(Part 24) : 1976	Determination of cation exchange capacity (*first revision*)
	(Part 25) : 1982	Determination silica sesquioxide ratio (*first revision*)
	(Part 26) : 1987	Determination of pH value (*second revision*)
	(Part 27) : 1977	Determination of total soluble sulphates (*first revision*)
	(Part 28) : 1974	Determination of dry density of soils in place, by the sand replacement method (*first revision*)
	(Part 29) : 1975	Determination of dry density of soils in place, by the core cutter method (*first revision*)
	(Part 30) : 1980	Laboratory vane shear test
	(Part 31) : 1990	Field determination of california bearing ratio (*first revision*)
	(Part 33) : 1971	Determination of the density in-place by the ring and water replacement method
	(Part 34) : 1972	Determination of density of soils in-place by rubber-balloon method
	(Part 35) : 1974	Measurement of negative pore water pressure
	(Part 36) : 1987	Laboratory determination of permeability of granular soils (constant head) (*first revision*)
	(Part 37) : 1976	Determination of sand equivalent values of soils and fine aggregates
	(Part 38) : 1976	Compaction control test (hilf method)
	(Part 39/Sec 1) : 1977	Direct shear test for soils containing gravel, Section 1 Laboratory test
	(Part 39/Sec 2) : 1979	Direct shear test for soils containing gravel, Section 2 In-situ shear test
	(Part 40) : 1977	Determination of free swell index of soils
	(Part 41) : 1977	Measurement of swelling pressure of soils
(53)	IS 2911	Code of practice for design and construction of pile foundations:
	(Part 1/Sec 1) : 2010	Concrete piles, Section 1 Driven cast in-situ concrete piles (*second revision*)
	(Part 1/Sec 2) : 2010	Concrete piles, Section 2 Bored cast in-situ concrete piles (*second revision*)
	(Part 1/Sec 3) : 2010	Concrete piles, Section 3 Precast driven concrete piles (*second revision*)
	(Part 1/Sec 4) : 2010	Concrete piles, Section 4 Precast concrete piles in prebored holes (*first revision*)
	(Part 2) : 1980	Timber piles (*first revision*)
	(Part 3) : 1980	Under-reamed pile foundation (*first revision*)
	(Part 4) : 2013	Load test on piles (*second revision*)
(54)	IS 2911	Code of practice for design and construction of pile foundations:
	(Part 1/Sec 1) : 2010	Concrete piles, Section 1 Driven cast in-situ concrete piles (*second revision*)
	(Part 1/Sec 2) : 2010	Concrete piles, Section 2 Bored cast in-situ concrete piles (*second revision*)
	(Part 1/Sec 3) : 2010	Concrete piles, Section 3 Precast driven concrete piles (*second revision*)

	(Part 1/Sec 4) : 2010	Concrete piles, Section 4 Precast concrete piles in prebored holes (*first revision*)
(55)	IS 2950 (Part 1):1981	Code of practice for design and construction of raft foundations: Part 1 design (*second revision*)
(56)	IS 8009 (Part 1) : 1976	Code of practice for calculation of settlement of foundations: Part 1 Shallow foundations subjected to symmetrical static vertical loads
(57)	IS 2974	Code of practice for design and construction of machine foundation:
	(Part 1) : 1982	Foundations for reciprocating type machine (*second revision*)
	(Part 2) : 1980	Foundations for impact type machines (hammer foundations) (*first revision*)
	(Part 3) : 1992	Foundations for rotary type machines (medium and high frequency) (*second revision*)
	(Part 4) : 1979	Foundations for rotary type machines of low frequency (*first revision*)
	(Part 5) : 1987	Foundations for impact machines other than hammers (forging and stamping press; pig breakers, drop crusher and jolter) (*first revision*)
	IS 13301 : 1992	Vibration isolation for machine foundations — Guidelines
	IS 9556 : 1980	Code of practice for design and construction of diaphragm walls
(58)	IS 13094 : 2021	Selection of ground improvement techniques for weak soils — Guidelines (*first revision*)
(59)	IS 15284	Design and construction for ground improvement — Guidelines:
	(Part 1) : 2003	Stone columns
(60)	(Part 2) : 2004	Preconsolidation using vertical drains
(61)	IS 13162 (Part 2) : 2024	Geotextiles — Methods of test: Part 2 Determination of resistance to exposure of ultra-violet light and water (Xenon arc type apparatus) (*first revision*)
	IS 13321 (Part 1) : 2022	Geosynthetics: Part 1 Terms and definitions
	IS 13325 : 1992	Determination of tensile properties of extruded polymer geogrids using the wide strip — Test method
	IS 13326 (Part 1) : 2025	Geosynthetics — Determination of friction characteristics: Part 1 Direct shear test (*first revision*)
	IS 14293 : 2024	Geotextiles — Method for determination of trapezoid tearing strength (*first revision*)
	IS 14294 : 2024	Geotextiles — Method for determination of apparent opening size by dry sieving technique (*first revision*)
	IS 14324 : 2025	Geotextiles and geotextile-related products — Determination of water permeability characteristics normal to the plane, without load (*first revision*)
	IS 14706 : 2024	Geosynthetics — Sampling and preparation of test specimens (*first revision*)
	IS 14714 : 2024	Geotextiles — Determination of abrasion resistance (*first revision*)
	IS 14715	Jute geotextiles:
	(Part 1) : 2016	Strengthening of sub-grade in roads — Specification (*second revision*)
	(Part 2) : 2016	Control of bank erosion in rivers and waterways — Specification (*second revision*)

	IS 14716 : 2021	Geosynthetics test method for the determination of mass per unit area of geotextiles and geotextile-related products (*first revision*)
	IS 14739 : 2021	Geotextiles and geotextile-related products determination of tensile creep and creep rupture behaviour (*first revision*)
	IS 14986 : 2001	Jute geo-grid for rain water erosion control in road and railway embankments and hill slopes
	IS 15060 : 2018	Geosynthetics — Tensile test for joint seams by wide-width strip method (*first revision*)
(62)	IS 2720	Methods of tests for soils:
	(Part 11) : 1993	Determination of the shear strength parameters of a specimen tested in unconsolidated undrained triaxial compression without the measurement of pore water pressure (*first revision*)
	(Part 12) : 1981	Determination of shear strength parameters of soil from consolidated undrained triaxial compression test with measurement of pore water pressure (*first revision*)

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART C STRUCTURAL DESIGN

SECTION 3 TIMBER AND BAMBOO: 3A TIMBER

BUREAU OF INDIAN STANDARDS

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National Building Code Sectional Committee, CED 46

FOREWORD

This NBCS (Part C/Subsection 3A) deals with the structural design aspect of timber structures. In this Subsection, the various species of Indian timber, classified into three groups depending on the structural properties influencing the design most, are included.

This Section was first published in 1970 which was subsequently revised in 1983, 2005 and 2016 as a part of National Building Code of India. In the 1983 version of this code, timber was covered under Section 3 of Part 6 under the title ‘Wood’, which did not cover bamboo. In the version of 2005, the scope of Section 3 was enlarged as Section 3 Timber and Bamboo, which was subdivided into Subsection 3A ‘Timber’ and Subsection 3B ‘Bamboo’. This Subsection pertains to 3A ‘Timber’.

In the first revision of 1983, provisions of this Subsection were updated and design of nailed laminated timber beams, were included and information on bolted construction joints was added. In the second revision of 2005, a number of terminologies related to timber for structural purpose were added, strength data of additional species of timber were included, requirements for structural timber and preferred cut sizes thereof were modified, requirements for glued laminated construction and finger joints and also for laminated veneer lumber were introduced. Brief details were included for structural sandwiches, glued laminated beams, lamella roofing, nail and screw holding power of timber, structural use of plywood and trussed rafter. Further, guidelines for protection against termite attack in buildings were also incorporated in the last revision of this Subsection. Also, keeping into consideration the dwindling forest resources, brief details on use of plantation timbers including certain fast growing species and suitable guidelines in terms of their seasoning, sawing, treatment, etc and also use of finger jointing and glued laminated timber was introduced in the last revision so as to effect judicious use of timber.

The third revision of 2016 addressed several significant changes, including modifications to definitions of various terms to align with prevailing engineering practices and the addition of new terminologies related to structural timber. The permissible lateral strength (in double shear) of mild steel common wire was updated to include various new timber species, with modified strength values for certain existing species based on the latest research. Guidance on increased permissible lateral strength for mild steel nails clenched across the grain, as opposed to nails with points cut flush, was incorporated. Design provisions for timber connector joints were further updated, along with data on block shear test results of glued timber joints based on indigenous studies. Additionally, information on the strength properties of glued finger joints from indigenous research was included for design guidance. A new figure illustrating possible orientations of planks in glue-laminated beams (glulam) was added, as well as a design outline for horizontally laminated beams. Updates were also made to the design provisions for trussed rafters, including data on lateral load-bearing strength of common wire nails in plywood-to-wood joints. Provisions for lamella roofing design were detailed and the composite nail/screw-holding power of specific Indian timbers was provided for design guidance.

In this revision, this publication has been renamed as National Building Construction Standards (NBCS).

As a result of experience gained in implementation of 2016 version and feedback received as well as formulation of new standards in the field and revision/updation of some of the existing standards, a need to revise this Subsection was felt. This revision has, therefore, been brought out to take care of these aspects.

The significant changes incorporated in this revision include the following:

a) Cross-laminated timber components including material specifications, dimensions, and fire resistance requirements;

b) Mass timber construction and its components given in 21;

c) Fire safety enhancements and fire-resistant assembly methods for mass timber, ensuring compliance with structural and fire safety standards;

d) Focus on sustainability with introduction of life cycle assessment (LCA) to evaluate the environmental impact of timber from production to disposal; and

e) Introduction of mechanical properties of foreign timber species, to support informed design, specification and safe application.

Reference may be made to Part F ‘Fire and Life Safety’ of this NBCS for fire protection of the timber buildings.

The information contained in this Subsection is largely based on the following Indian Standards:

IS 399 : 1963	Classification of commercial timbers and their zonal distribution (*revised*)
IS 883 : 2016	Design of structural timber in building — Code of practice for (*fifth revision*)
IS 1150 : 2000	Trade names and abbreviated symbols for timber species (*third revision*)
IS 2366 : 1983	Code of practice for nail-jointed timber construction (*first revision*)
IS 4891 : 1988	Specification for preferred cut sizes of structural timber (*first revision*)
IS 4983 : 1968	Code of practice for design and construction of nailed laminated timber beams
IS 11096 : 1984	Code of practice for design and construction of bolt jointed timber construction
IS 14616 : 1999	Laminated veneer lumber — Specification

As the regulation of land development and buildings is a State subject and is dealt by the States and local bodies such as urban local bodies within their jurisdiction through building regulatory documents like building regulations, building byelaws and fire regulations, this document is voluntary in nature and is non-binding. The implementation depends on adoption by concerned parties or stipulations in a contract or by appropriate adoption by the concerned authorities.

For the purpose of deciding whether a particular requirement of this Subsection is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 ‘Rules for rounding off numerical values (*second revision*)’. The number of significant places retained in the rounded off value should be the same as that of the specified value in this Subsection.

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Important Explanatory Note for Users of this NBCS

In any Part/Section of this NBCS, where reference is made to **'good practice'** in relation to design, constructional procedures or other related information, and where reference is made to '**accepted standard'** in relation to material specification, testing, or other related information, the Indian Standards listed at the end of the Part/Section shall be used as a guide to the interpretation.

At the time of publication, the editions indicated in the standards were valid. All standards are subject to revision and parties to agreements based on any Part/Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

In the list of standards given at the end of a Subsection, the number appearing within parentheses in the first column indicates the number of the reference of the standard in the Part/Section.

For example:

a) Good practices [C-3A(1)] refers to the Indian Standard(s) give at serial number (1) of the list of standards given at the end of this Part C/Subsection 3A, that is, IS 707 : 2011 'Timber technology and utilization of wood, bamboo and cane — Glossary of terms (*third revision*)'.

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART C STRUCTURAL DESIGN

SECTION 3 TIMBER AND BAMBOO: 3A TIMBER

1 SCOPE

1.1 This NBCS (Part C/Subsection 3A) covers the general principles involved in the design of structural timber in buildings, including elements of structures connected by fasteners/fastening techniques.

1.2 This shall not be interpreted to prevent the use of material or methods of design or construction not specifically mentioned herein; and the methods of design may be based on analytical and engineering principles, or reliable test data, or both, that demonstrate the safety and serviceability of the resulting structure. The classification of timber into strength groups should not be interpreted as preventing the use of design data desired for a particular timber or grade of timber on the basis of reliable tests.

2 TERMINOLOGY

For the purpose of this Subsection, the following definitions and those given in the accepted standard [C-3A(1)], shall apply.

2.1 Structural Purpose Definitions

2.1.1 *Beam*, *Built-up Laminated* — A beam made by joining layers of timber together with mechanical fastenings, so that the grain of all layers is essentially parallel.

2.1.2 *Beam*, *Glued-Laminated* — A beam made by bonding layers of veneers or timber with an adhesive, so that grain of all laminations is essentially parallel.

2.1.3 *Bressummer* — A beam, across broad opening, sustaining super structure.

2.1.4 *Diaphragm*, *Structural* — A structural element of large extent placed in a building as a wall, or roof, and made use of to resist horizontal forces such as wind or earthquakes-acting parallel to its own plane.

2.1.5 *Duration of Load* — Period during which a member or a complete structure is stressed as a consequence of the loads applied.

NOTE — Timber is stronger under loads of brief duration than under permanently applied loads.

2.1.6 *Edge Distance* — The distance measured perpendicular to grain from the centre of the connector to the edge of the member.

2.1.7 *End Distance* — The distance measured parallel to grain of the member from the centre of the connector to the closest end of timber.

2.1.8 *Finger Joint* — End joint formed by machining a number of similar, tapered, symmetrical fingers in the ends of timber member, which are then bonded together.

2.1.9 *Finger Jointed Timber* — Timber containing adhesively bonded finger joints spaced at manufacturer specified minimum spacing.

2.1.10 *Fundamental or Ultimate Stress* — The stress which is determined on small clear specimen of timber, in accordance with accepted standards [C-3A(2)]; and does not take into account the effect of naturally occurring characteristics and other factors.

2.1.11 *Glue* — A substance capable of holding materials together by surface attachment.

2.1.12 *Glued Laminated* (*Glulam*) — A wood structural element comprising of sawn wood lamination bonded together with adhesives and in which the grains of all laminations are parallel longitudinally.

2.1.12.1 *Glued laminated*, *horizontally* — Glued laminated timber where gluing planes are perpendicular to the largest dimension of the transverse section, that is, in cross-wise direction.

2.1.12.2 *Glued laminated*, *vertically* — Glued laminated timber where gluing planes are perpendicular to the smallest dimension of the transverse section.

2.1.13 *Inside Location* — Position in buildings in which timber remains continuously dry or protected from weather.

2.1.14 *Isoptera* — An order of social insects consisting of the termites.

2.1.15 *Lamella Roof* — A roof or frame, made up of relatively short members, called lamellas, forming a network of framing timbers. This network forms a barrel-like structure of mutually braced and stiffened units, arching over the building between supports, and together with the sheathing forms a diaphragm for resistance of vertical and lateral loads.

2.1.16 *Laminations* — Thin elements of wood of appreciable width and length which, when superimposed on each other and fastened together with their grains essentially parallel make up cross section of considerable depth or width.

2.1.17 *Laminated Veneer Lumber* — A structural composite made by laminating veneers, 1.5 mm to 4.2 mm thick, with suitable adhesive and with the grain of veneers in successive layers aligned along the longitudinal (length) dimension of the composite.

2.1.18 *Latewood* — The portion of the wood that is formed in the later part of growth season and consists of thicker walled cells.

2.1.19 *Loaded Edge Distance* — The distance measured from the centre to the edge towards which the load induced by the connector acts, and the unloaded edge distance is the one opposite to the loaded edge.

2.1.20 *Location* — A term generally referred to as exact place where a timber is used in building.

2.1.21 *Mechanically Laminated* — A wood structural element comprising of laminations which are not glued but which are held together with mechanical fastenings such as nails or bolts and in which all laminations have the grains approximately parallel longitudinally.

2.1.22 *Outside Location* — Position in buildings in which timbers are occasionally subjected to wetting and drying as in the case of open sheds and outdoor exposed structures.

2.1.23 *Permissible Stress* — Stress obtained by applying factor of safety to the ultimate stress.

2.1.24 *Sandwich*, *Structural* — A layered construction comprising a combination or relatively high-strength facing material intimately bonded to and acting integrally with a low density core material.

2.1.25 *Spaced Column* — Two column sections adequately connected together by glue, bolts, screws or otherwise.

2.1.26 *Stressed Skin* — A form of construction in which the outer skin, in addition to its normal functioning of providing a surface covering, acts integrally with the framing members contributing to the strength of the unit as a whole.

2.1.27 *Structure*, *Permanent* — Structural units in timber which are constructed for a long duration and wherein adequate protection and design measures have initially been incorporated to render the structure serviceable for the required life.

2.1.28 *Structure*, *Temporary* — Structures which are erected for a short period, such as hutments at project sites, for rehabilitation, temporary defence constructions, exhibition structures, etc.

2.1.29 *Structural Element* — The component timber members and joints which make up a resulting structural assembly.

2.1.30 *Structural Grades* — Grades defining the maximum size of strength reducing natural characteristics (knots, sloping grain, etc) deemed permissible in any piece of structural timber within designated structural grade classification.

2.1.31 *Structural Timber* — Timber in which strength is related to the anticipated in-service use as a controlling factor in grading and selection and/or stiffness.

2.1.32 *Stud* — One of a series of slender wood structural members placed vertically as supporting members in a wall partition, or similar structural unit.

2.1.33 *Termite* — An insect of the order *Isoptera* which may burrow in the wood or wood products of a building for food or shelter.

2.1.34 *Wet Location* — Position in buildings in which timbers are almost continuously damp or wet in contact with the earth or water, such as piles and timber foundations.

2.2 Definitions of Defects in Timber

2.2.1 *Check* — A separation of fibres extending along the grain which is confined to one face of a piece of wood.

2.2.2 *Compression Wood* — Abnormal wood which is formed on the lower sides of branches and inclined stems of coniferous trees. It is darker and harder than normal wood but relatively low in strength for its weight. It can be usually identified by wide eccentric growth rings with abnormally high proportion of growth latewood.

2.2.3 *Dead Knot* — A knot in which the layers of annual growth are not completely intergrown with those of the adjacent wood. It is surrounded by pitch or bark. The encasement may be partial or complete.

2.2.4 *Decay or Rot* — Disintegration of wood tissue caused by fungi (wood destroying) or other micro-organisms.

2.2.5 *Decayed Knot* — A knot softer than the surrounding wood and containing decay.

2.2.6 *Diameter of Knot* — The maximum distance between the two points farthest apart on the periphery of a round knot, on the face on which it becomes visible. In the case of a spike or a splay knot, the maximum width of the knot visible on the face on which it appears shall be taken as its diameter.

2.2.7 *Discolouration* — A change from the normal colour of the wood which does not impair the strength of the wood.

2.2.8 *Knot* — A branch base or limb embedded in the tree or timber by natural growth.

2.2.9 *Knot Hole* — A hole left as a result of the removal of a knot.

2.2.10 *Live Knot* — A knot free from decay and other defects, in which the fibres are firmly intergrown with those of the surrounding wood. (*Synonyms:* 'Intergrown knot'; *cf.* 'Dead knot')

2.2.11 *Loose Grain* (*Loosened Grain*) — A defect on a flat sawn surface caused by the separation or raising of wood fibres along the growth rings; *cf.* 'Raised grain'.

2.2.12 *Loose Knot* — A knot that is not held firmly in place by growth or position, and that cannot be relied upon to remain in place; *cf.* 'Tight knot'.

2.2.13 *Mould* — A soft vegetative growth that forms on wood in damp, stagnant atmosphere. It is the least harmful type of fungus, usually confined to the surface of the wood.

2.2.14 *Pitch Pocket* — Accumulation of resin between growth rings of coniferous wood as seen on the cross-section.

2.2.15 *Sap Stain* — Discolouration of the sapwood mainly due to fungi.

2.2.16 *Sapwood* — The outer layer of log, which in the growing tree contain living cells and food material. The sapwood is usually lighter in colour and is readily attacked by insects and fungi.

2.2.17 *Shake* — A partial or complete separation between adjoining layers of tissues as seen in end surfaces.

2.2.18 *Slope of Grain* — The inclination of the fibres to the longitudinal axis of the member.

2.2.19 *Sound Knot* — A tight knot free from decay, which is solid across its face and at least as hard as the surrounding wood.

2.2.20 *Split* — A crack extending from one face of a piece of wood to another and runs along the grain of the piece.

2.2.21 *Tight Knot* — A knot so held by growth or position as to remain firm in position in the piece of wood; *cf.* 'Loose knot'.

2.2.22 *Wane* — The original rounded surface of a tree remaining on a piece of converted timber.

2.2.23 *Warp* — A deviation in sawn timber from a true plane surface or distortion due to stresses causing departure from a true plane.

2.2.24 *Worm Holes* — Cavities caused by worms.

3 SYMBOLS

For the purpose of this Subsection, the following letter symbols shall have the meaning indicated against each:

a = Projected area of bolt in main member (t' x d_3), mm^2

B = Width of the beam, mm

C = Concentrated load, N

D = Depth of beam, mm

D_1 = Depth of beam at the notch, mm

D_2 = Depth of notch, mm

d = Dimension of least side of column, mm

d_1 = Least overall width of box column, mm

d_2 = Least overall dimension of core in box column, mm

d_3 = Diameter of bolt, mm

d_f = Bolt-diameter factor

E = Modulus of elasticity in bending, N/mm^2

e = Length of the notch measured along the beam span from the inner edge of the support to the farthest edge of the notch, mm

F = Load acting on a bolt at an angle to grain, N

f_{ab} = Calculated bending stress in extreme fibre, N/mm^2

f_{ac} = Calculated average axial compressive stress, N/mm^2

f_{at} = Calculated axial tensile stress, N/mm^2

f_b = Permissible bending stress on the extreme fibre, N/mm^2

f_c = Permissible stress in axial compression, N/mm^2

f_{cn} = Permissible stress in compression normal (perpendicular) to grain, N/mm^2

f_{cp} = Permissible stress in compression parallel to grain, N/mm^2

$f_{c\theta}$ = Permissible compressive stress in the direction of the line of action of the load, N/mm^2

f_t = Permissible stress in tension parallel to grain, N/mm^2 [extreme fibre stress in bending-tension (f_b) is safe practical estimate of tensile strength due to mode of failure in beams]

H = Horizontal shear stress, N/mm^2

I = Moment of inertia of a section, mm^4

K = Coefficient in deflection depending upon type and criticality of loading on beam

K_1 = Modification factor for change in slope of grain

K_2 = Modification factor for change in duration of loadings

K_3, K_4, K_5, K_6 = Form factors

K_7 = Modification factor for bearing stress

K_8 = Constant equal to $0.584\sqrt{\frac{E}{f_{cp}}}$

K_9 = Constant equal to $\frac{\pi}{2}\sqrt{\frac{UE}{5q\,f_{cp}}}$

K_{10} = Constant equal to $0.584\sqrt{\frac{2.5E}{f_{cp}}}$

l or L = Span of a beam or truss, mm

M = Maximum bending moment in beam, N-mm

N = Total number of bolts in the joint

n = Shank diameter of the nail, mm

P = Load on bolt parallel to grain, N

p_1 = Ratio of the thickness of the compression flange to the depth of the beam

Q = Static moment of area above or below the neutral axis about neutral axis, mm^3

q = Constant for particular thickness of plank

q_1 = Ratio of the total thickness of web or webs to the overall width of the beam

R = Load on bolt perpendicular (normal) to grain, N

S = Unsupported overall length of column, mm

t = Nominal thickness of planks used in forming box type column, mm

t' = Thickness of main member, mm

U = Constant for a particular thickness of the plank

V = Vertical end reaction or shear at a section, N

W = Total uniform load, N

x = Distance from reaction to load, mm

y = Factor determining the value of form factor K_4

δ = Deflection at middle of beam, mm

θ = Angle of load to grain direction

Z = Section modulus of beam, mm^3

λ_1 = Percentage factor for t'/d_3 ratio, parallel to grain

λ_2 = Percentage factor for t'/d_3 ratio, perpendicular to grain

4 MATERIALS

4.1 Species of Timber

The species of timber recommended for structural purposes are given in Table 1 along with their permissible stresses and properties. For information on mechanical properties of certain foreign timber species, reference may be made to Annex A.

Table 1 Safe Permissible Stresses for the Species of Timber

[*Clauses* 4.1, 4.2, 4.7.2(b), 5.4.1, 5.4.2, 5.4.2.2, 6.5.8.3.1(b), 10.2.3 *and* 15.3]

Sl No.	**Species**		**Locality from where Tested**	**Average Density at 12 Percent Moisture Content** Kg/m^3	**Modulus of Elasticity (All Grades and All Locations) × 10^3** N/mm^2	**Permissible Stress for Grade I** N/mm^2											**Preservative Characters**		**Refracteriness to Air Seasoning3)**
	Botanical Name	Trade Name				Bending-Tension Along Grain, Extreme Fibre Stress			Shear all Locations		Compression Parallel to Grain			Compression Perpendicular to Grain			Durability Class1)	Treat-ability Grade2)	
						Inside Location	Outside Location	Wet Location	Horizontal	Along Grain	Inside Location	Outside Location	Wet Location	Inside Location	Outside Location	Wet Location			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
i)	**GROUP A:**																		
	a) *Acacia catectou*	Khair (KHA)	Uttar Pradesh	1 009	13.44	20.1	16.8	13.4	1.6	2.2	13.8	12.3	10.1	7.7	6.0	4.9	I	–	A
	b) *Acacia chundra*	Red kutch	Madhya Pradesh	1 086	16.79	26.5	22.0	17.6	2.2	3.2	17.9	15.9	13.0	10.9	8.4	6.9	–	–	A
	c) *Albizia odoratissima*	Kala siris (KSI)	Chennai	737	13.54	18.7	15.6	12.5	1.5	2.2	13.3	11.8	9.6	7.3	5.6	4.6	I	e	B
	d) *Bruguiera spp.*	Bruguiera (BSV) (Mangrove)	Andaman	897	17.68	21.9	18.3	14.6	1.2	1.7	14.3	12.7	10.4	5.5	4.3	3.5	III	–	–
	e) *Grewia tiliifolia*	Dhaman (DHA)	Chennai	788	14.82	18.3	15.2	12.2	1.3	1.9	12.0	10.7	8.7	6.0	4.7	3.8	III	d	B
	f) *Hopea utilis* (*Balano carpus utilis*)	Karung	Chennai	987	16.91	25.1	20.9	16.7	1.5	2.2	16.4	14.6	11.9	9.3	7.3	5.9	–	–	–

Table 1 (*Continued*)

Sl No.	**Species**		**Locality from where Tested**	**Average Density at 12 Percent Moisture Content** Kg/m^3	**Modulus of Elasticity (All Grades and All Locations) × 10^3** N/mm^2	**Permissible Stress for Grade I** N/mm^2											**Preservative Characters**		**Refracteriness to Air Seasoning**$^{3)}$
	Botanical Name	Trade Name				Bending-Tension Along Grain, Extreme Fibre Stress			Shear all Locations		Compression Parallel to Grain			Compression Perpendicular to Grain			Durability Class$^{1)}$	Treat-ability Grade$^{2)}$	
						Inside Location	Outside Location	Wet Location	Horizontal	Along Grain	Inside Location	Outside Location	Wet Location	Inside Location	Outside Location	Wet Location			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
	g) *Hopea glabra*	Hopea (HOP)	Chennai	1 081	14.79	21.3	17.8	14.2	1.5	2.2	14.5	12.9	10.6	9.9	7.7	6.3	I	–	A
	h) *Hopea parviflora*	Hopea (HOP)	Chennai	923	13.03	18.6	15.5	12.4	1.3	1.8	13.2	11.8	9.6	9.2	7.3	6.0	I	e	A
	j) *Manilota polyandra (Syn. Cynometra polyandra)*	Ping (PIG)	Assam	903	13.20	19.1	15.9	12.7	1.3	1.8	1.2	10.4	8.5	5.7	4.4	3.6	III	b	A
	k) *Mesua ferrea*	Mesua (MES)	Assam	965	16.30	23.3	19.4	15.5	1.2	1.8	15.5	13.8	11.3	5.9	4.6	3.7	I	–	A
	m) *Mimusops littoralis*	Bullet-wood (BUL)	Southern Andaman	1 103	17.39	22.7	18.9	15.1	1.5	2.1	14.2	12.7	10.4	11.3	8.8	7.2	I	–	A
	n) *Pesciloneuron indicum*	Ballagi (BAL)	Chennai	1 139	16.29	22.4	18.7	15.0	1.5	2.2	14.7	13.1	10.7	8.7	6.8	5.5	I	e	A
	p) *Pterocarpus Scantalinus*	Red sanders (MA)	Chennai	1 121	12.73	25.0	20.9	16.7	1.7	2.5	18.1	16.1	13.2	11.8	9.2	7.5	–	–	A
	q) *Sageraea elliptica*	Chooi (COC)	Andaman	869	15.06	21.5	17.9	14.3	1.1	1.5	12.5	11.1	9.1	5.3	4.1	3.4	–	–	A

Table 1 (*Continued*)

Sl No.	**Species**		**Locality from where Tested**	**Average Density at 12 Percent Moisture Content** Kg/m^3	**Modulus of Elasticity (All Grades and All Locations) × 10^3** N/mm^2	**Permissible Stress for Grade I** N/mm^2											**Preservative Characters**		**Refracteriness to Air Seasoning**3)
	Botanical Name	Trade Name				Bending-Tension Along Grain, Extreme Fibre Stress			Shear all Locations		Compression Parallel to Grain			Compression Perpendicular to Grain			Durability Class1)	Treat-ability Grade2)	
						Inside Location	Outside Location	Wet Location	Horizontal	Along Grain	Inside Location	Outside Location	Wet Location	Inside Location	Outside Location	Wet Location			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
	r) *Stereospermun celonoides*	Padri (PAD)	Chennai	731	12.94	19.0	15.8	12.7	1.1	1.6	11.9	10.6	8.7	4.0	3.1	2.6	III	–	B
	s) *Vitex altissima*	Milla (MIL)	Maharashtra	937	13.01	18.2	15.2	12.1	1.2	1.7	12.6	11.2	9.2	9.5	7.4	6.1	I	e	A
ii)	**GROUP B:**																		
	a) *Albizzia lebbeck*	Kokko (KOK)	Andaman	642	11.17	13.4	11.2	9.0	1.1	1.5	9.0	8.0	6.5	4.4	3.4	2.8	I	e	B
	b) *Anogeissus latifolia*	Dhaura, Axle wood (AXL) (Bakli)	Uttar Pradesh	892	10.55	16.1	13.4	10.7	1.1	1.6	9.1	8.1	6.6	4.7	3.7	3.0	I	e	A
	c) *Artocarpus hirsulus*	Aini (AIH)	Chennai	600	10.45	15.0	12.5	10.0	0.7	1.1	10.4	9.2	7.5	3.3	2.6	2.1	I	–	B
	d) *Acacia nilotica*	Babul (BAB)	Uttar Pradesh	797	-	-	12.9	10.3	1.4	2.1	8.9	7.9	6.4	5.2	4.0	3.3	I	b	B
	e) *Acacia ferruginea*	Safed khair	Maharashtra	993	12.28	23.0	19.2	15.3	1.7	2.4	13.9	12.4	10.1	9.9	7.7	6.3	–	–	–

Table 1 (*Continued*)

Sl No.	**Species**		**Locality from where Tested**	**Average Density at 12 Percent Moisture Content** Kg/m³	**Modulus of Elasticity (All Grades and All Locations) × 10³** N/mm²	**Permissible Stress for Grade I** N/mm²											**Preservative Characters**		**Refracteriness to Air Seasoning3)**
	Botanical Name	Trade Name				Bending-Tension Along Grain, Extreme Fibre Stress			Shear all Locations		Compression Parallel to Grain			Compression Perpendicular to Grain			Durability Class1)	Treat-ability Grade2)	
						Inside Location	Outside Location	Wet Location	Horizontal	Along Grain	Inside Location	Outside Location	Wet Location	Inside Location	Outside Location	Wet Location			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
	f) *Acrocarpus fraxinifolius*	Mundani (MUN)	Chennai	690	12.59	16.1	13.4	10.8	1.2	1.8	10.5	9.4	7.7	4.6	3.6	2.9	III	c	B
	g) *Aglaia odulis*	Aglaia (AGL)	Assam	815	12.56	18.2	15.2	12.1	1.4	2.0	10.1	8.9	7.3	4.4	3.4	2.8	–	–	A
	h) *Anogeissus acuminota*	Yon	Orissa	844	11.67	17.6	14.7	11.7	1.3	1.8	10.8	9.6	7.9	5.1	4.0	3.3	–	–	A
	j) *Atalanlia monophylla*	Jungli-nimbu (JHI)	Orissa	897	10.31	16.7	13.9	11.1	1.5	2.1	11.3	10.0	8.2	6.3	4.9	4.0	–	–	–
	k) *Altingia excelsa*	Jutili (JUT)	Assam	795	11.37	17.1	14.3	11.4	1.2	1.8	11.0	9.8	8.0	6.8	5.3	4.4	II	e	A
	m) *Amoora spp.*	Amari (AMA)	West Bengal	625	1.05	13.4	1.1	9.2	0.9	1.3	8.4	7.4	6.0	3.7	2.9	2.4	II	d	B
	n) *Bucklandia populnea* (*Syn. Exbucklandia populnea*)	Pipli (PIP)	West Bengal	672	9.89	12.8	10.7	8.6	1.1	1.5	7.9	7.0	5.7	3.5	2.7	2.2	III	e	C
	p) *Cassia fistula*	Amaltas (AMT)	Uttar Pradesh	865	11.80	19.2	16.0	12.8	1.4	2.0	12.3	10.9	8.9	7.2	5.6	4.6	I	–	A

Table 1 (*Continued*)

Sl No.	**Species**		**Locality from where Tested**	**Average Density at 12 Percent Moisture Content** Kg/m^3	**Modulus of Elasticity (All Grades and All Locations) × 10^3** N/mm^2	**Permissible Stress for Grade I** N/mm^2											**Preservative Characters**		**Refracteriness to Air Seasoning$^{3)}$**
	Botanical Name	Trade Name				Bending-Tension Along Grain, Extreme Fibre Stress			Shear all Locations		Compression Parallel to Grain			Compression Perpendicular to Grain			Durability Class$^{1)}$	Treat-ability Grade$^{2)}$	
						Inside Location	Outside Location	Wet Location	Horizontal	Along Grain	Inside Location	Outside Location	Wet Location	Inside Location	Outside Location	Wet Location			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
	q) *Carallia lucida*	Maniawaga	Assam	748	12.60	18.4	15.3	12.3	1.2	1.7	11.4	10.1	8.3	5.9	4.6	3.8	–	–	–
	r) *Canarium strictum*	Dhup	Chennai	655	11.86	13.3	11.1	8.9	0.9	1.2	8.1	7.2	5.9	2.8	2.2	1.8	III	–	C
	s) *Cassia sienea*	Kasod	Madhya Pradesh	820	10.50	15.4	12.8	10.9	1.0	1.4	10.8	9.6	7.9	5.5	4.3	3.5	–	–	-
	t) *Casuerina equisetifolia*	Casuarina (CAS)	Orissa	769	11.44	14.6	12.2	9.8	1.3	1.8	8.2	7.3	5.9	4.0	3.1	2.5	III	e	A
	u) *Celophyllum temculosum*	Poon (POO)	Maharashtra	657	9.77	13.4	11.2	9.0	0.8	1.1	8.6	7.7	6.3	2.8	2.2	1.8	II	–	B
	v) *Chloroxylon swielenia*	Satin wood (CFI)	Madhya Pradesh	865	11.69	18.2	15.1	12.1	1.4	2.0	10.9	9.7	8.0	6.3	4.9	4.0	III	–	A
	w) *Cullenia resayoana* (*Syn. C. execelsa*)	Karani (KAP)	Chennai	625	12.43	14.7	12.3	9.8	0.6	0.9	9.0	8.0	6.6	2.7	2.1	1.7	III	b	C
	y) *Diploknema butyracea* (*Syn. Bassia butyrance*)	Hill mahua (HMA)	Southern Andaman	780	10.64	15.3	12.8	10.2	1.0	1.5	9.9	8.8	7.2	6.6	5.2	4.2	–	–	–
	z) *Dyscxylum malebaricum*	White ceda (WCE)	Chennai	745	10.92	13.2	11.0	8.8	1.0	1.4	8.0	7.1	5.8	3.1	2.4	1.9	I	–	B

Table 1 (*Continued*)

Sl No.	**Species**		**Locality from where Tested**	**Average Density at 12 Percent Moisture Content** Kg/m^3	**Modulus of Elasticity (All Grades and All Locations) × 10^3** N/mm^2	**Permissible Stress for Grade I** N/mm^2											**Preservative Characters**		**Refractoriness to Air Seasoning** 3)
	Botanical Name	Trade Name				Bending-Tension Along Grain, Extreme Fibre Stress			Shear all Locations		Compression Parallel to Grain			Compression Perpendicular to Grain			Durability Class 1)	Treat-ability Grade 2)	
						Inside Location	Outside Location	Wet Location	Horizontal	Along Grain	Inside Location	Outside Location	Wet Location	Inside Location	Outside Location	Wet Location			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
	aa) *Dipterocarpus grandiflorus*	Gurjan (GUR)	Northern Andaman	758	11.71	12.5	10.5	8.4	0.8	1.1	7.9	7.1	5.8	2.7	2.1	1.7	I	–	B
	ab) *Dipterocarpus macrocarpus*	Hollong (HOL)	Assam	726	13.34	14.5	12.0	9.6	0.8	1.1	8.8	7.9	6.4	3.5	2.7	2.2	III	a	B
	ac) *Dichopsis polyantha* (*Syn. Palaquium polyanthum*)	Tali (TAL)	Assam	734	11.24	14.9	12.4	10.0	1.1	1.6	9.9	8.8	7.2	4.7	3.7	3.0	–	–	B
	ad) *Dichopsis elliptica* (*Syn. Palaquium ellipticum*)	Pali (PAL)	Chennai	606	11.86	13.9	11.6	9.3	0.7	1.0	8.5	7.5	6.2	2.9	2.2	1.8	I	e	B
	ae) *Diospyros micropylla*	Ebony (EBO)	Maharashtra	776	12.15	14.2	11.9	9.5	0.9	1.3	8.3	7.3	6.0	3.3	2.6	2.1	–	–	A
	af) *Diospyros pyrrhocarpus*	Ebony (EBO)	Northern Andaman	843	9.93	13.5	11.2	9.0	1.0	1.4	7.9	7.0	5.7	4.0	3.1	2.5	III	–	A
	ag) *Dipterocarpus bourdilloni*	Gurjan (GUR)	Kerala	699	12.71	13.6	11.3	9.0	0.7	1.0	7.8	6.9	5.7	2.5	1.9	1.6	–	–	B

Table 1 (*Continued*)

Sl No.	**Species**		**Locality from where Tested**	**Average Density at 12 Percent Moisture Content** Kg/m^3	**Modulus of Elasticity (All Grades and All Locations) × 10^3** N/mm^2	**Permissible Stress for Grade I** N/mm^2											**Preservative Characters**		**Refracteriness to Air Seasoning**[3)]
	Botanical Name	Trade Name				Bending-Tension Along Grain, Extreme Fibre Stress			Shear all Locations		Compression Parallel to Grain			Compression Perpendicular to Grain			Durability Class[1)]	Treat-ability Grade[2)]	
						Inside Location	Outside Location	Wet Location	Horizontal	Along Grain	Inside Location	Outside Location	Wet Location	Inside Location	Outside Location	Wet Location			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
	ah) *Eucalyptus globulus*	Eucalyptus (Blue gum) (BLN)	Chennai	912	14.83	15.9	13.2	10.6	10.3	1.5	9.0	8.0	6.5	3.4	2.6	2.1	I	e	A
	aj) *Eucalyptus ougenioides*	Eucalyptus	Chennai	853	11.47	16.4	13.6	10.9	1.2	1.7	11.3	10.0	8.2	7.6	5.9	4.8	–	–	–
	ak) *Eugenia gardnery*	Jaman (JAM)	Chennai	952	11.94	14.8	12.3	9.8	1.1	1.6	9.2	8.2	6.7	5.8	4.5	3.7	III	d	–
	am) *Eugenia jambolana*	Jaman (JAM)	Uttar Pradesh	778	10.94	16.0	13.3	10.6	1.2	1.7	9.7	8.6	7.1	4.7	3.7	3.0	–	–	–
	an) *Gluta travancorice*	Gluta (GLU)	Chennai	726	12.73	13.5	11.3	9.0	0.9	1.3	9.0	8.0	6.6	4.0	3.1	2.5	I	–	A
	ap) *Grewia veslita*	Dhaman (DHA)	West Bengal	758	12.00	15.4	12.6	10.3	1.4	2.0	9.1	8.1	6.6	4.1	3.2	2.6	III	d	B
	aq) *Heritiera spp.*	Sundri (SUN)	Assam	872	13.37	17.9	14.9	11.9	1.3	1.8	11.0	9.8	8.0	6.5	5.0	4.1	I	–	A
	ar) *Kingiodendron pinnatum* (*Syn. Hardwickia pinnata*)	Piney (PIN)	Chennai	617	10.62	13.2	11.0	8.8	0.4	1.3	8.2	7.3	6.0	2.9	2.2	1.8	–	–	B

Table 1 (*Continued*)

Sl No.	**Species**		**Locality from where Tested**	**Average Density at 12 Percent Moisture Content** Kg/m^3	**Modulus of Elasticity (All Grades and All Locations) $\times 10^3$** N/mm^2	**Permissible Stress for Grade I** N/mm^2											**Preservative Characters**		**Refracteriness to Air Seasoning 3)**
	Botanical Name	Trade Name				Bending-Tension Along Grain, Extreme Fibre Stress			Shear all Locations		Compression Parallel to Grain			Compression Perpendicular to Grain			Durability Class 1)	Treatability Grade 2)	
						Inside Location	Outside Location	Wet Location	Horizontal	Along Grain	Inside Location	Outside Location	Wet Location	Inside Location	Outside Location	Wet Location			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
	as) *Kayea floribund*	Karal	Assam	813	10.88	16.8	14.0	1.1	1.1	1.6	10.1	9.0	7.3	4.4	3.4	2.8	III	–	–
	at) *Lagerstromia lanceolata*	Benteak (BEN)	Chennai	617	10.76	12.7	10.6	8.5	0.8	1.2	8.2	7.3	5.9	3.4	2.6	2.2	I	e	B
	au) *Lagerstromia parviflora*	Lendi (LEN)	Uttar Pradesh	734	10.97	14.3	11.9	9.5	1.1	1.6	8.7	7.7	6.3	3.7	2.9	2.4	I	e	A
	av) *Mimusops elengi*	Bakul (BKL)	Chennai	885	12.39	17.3	14.4	11.5	1.3	1.8	11.0	9.8	8.0	5.6	4.3	3.6	I	–	A
	aw) *Machilus macrantha*	Machilus (MAC)	West Bengal	692	10.00	12.4	10.3	8.3	1.0	1.5	8.2	7.3	6.0	3.5	2.7	2.2	III	e	B/C
	ay) *Miliuse tyomentosa (Syn. Saccopapetalum tomentosum)*	Hoom (HOO)	Maharashtra	745	11.06	14.8	12.3	9.9	0.9	1.3	9.7	8.6	7.0	3.5	2.7	2.2	III	–	B
	az) *Pommetia pinnata*	–	Andaman	788	12.90	14.3	11.9	9.5	1.1	1.6	9.1	8.0	6.6	4.0	3.1	2.5	–	–	–
	ba) *Pterocarpus dolbergioides*	Padauk (PAD)	Northern Andaman	721	11.24	17.1	14.3	11.4	1.0	1.5	12.0	10.7	8.7	5.5	4.3	3.5	I	c	B
	bb) *Mesua assamica*	Kayea	Assam	842	12.83	17.4	14.5	11.6	1.0	1.4	11.7	10.4	8.5	5.3	4.1	3.3	II	e	–

Table 1 (*Continued*)

Sl No.	**Species**		**Locality from where Tested**	**Average Density at 12 Percent Moisture Content** Kg/m³	**Modulus of Elasticity (All Grades and All Locations) × 10³** N/mm²	**Permissible Stress for Grade I** N/mm²											**Preservative Characters**		**Refracteriness to Air Seasoning³⁾**
	Botanical Name	Trade Name				Bending-Tension Along Grain, Extreme Fibre Stress			Shear all Locations		Compression Parallel to Grain			Compression Perpendicular to Grain			Durability Class¹⁾	Treat-ability Grade²⁾	
						Inside Location	Outside Location	Wet Location	Horizontal	Along Grain	Inside Location	Outside Location	Wet Location	Inside Location	Outside Location	Wet Location			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
	bc) *Pterocarpus marsupium*	Bijasal (BIJ)	Maharashtra	803	10.25	14.9	12.4	9.9	0.9	1.3	9.1	8.1	6.6	4.1	3.2	2.6	I	e	B
	bd) *Fraxlnus macrantha*	Ash (ASH)	Uttar Pradesh	712	10.69	15.0	12.5	10.0	1.2	1.7	8.5	7.6	6.2	4.3	3.3	2.7	III	–	B
	be) *Fraxlnus execlsior*	Ash (ASH)	Punjab	719	10.41	14.8	12.3	9.8	1.2	1.7	8.1	7.2	5.8	3.3	2.6	2.1	III	–	B
	bf) *Planchonia valida* (*Syn. P. andamanica*)	Red bombwe (RBO)	Andaman	913	13.10	16.1	13.4	10.7	1.0	1.4	10.8	9.6	7.9	4.9	3.8	3.1	III	–	–
	bg) *Quercus lamellosa*	Oak	West Bengal	87	12.44	14.5	12.1	9.7	1.2	1.7	8.7	7.8	6.4	3.8	2.9	2.4	II	c	A
	bh) *Quercus griffithii*	Oak	Meghalaya	974	10.06	13.1	10.9	8.8	1.1	1.6	8.0	7.1	5.8	4.6	3.6	2.9	–	–	A
	bj) *Quercus incane*	Oak	Punjab	1 008	10.82	15.8	13.1	10.5	1.2	1.8	8.7	7.8	6.3	5.0	3.9	3.2	–	–	A
	bk) *Quercus lineate*	Oak	West Bengal	874	12.63	15.2	12.7	10.1	1.2	1.7	9.6	8.6	7.0	5.3	4.1	3.4	II	c	A

Table 1 (*Continued*)

Sl No.	**Species**		**Locality from where Tested**	**Average Density at 12 Percent Moisture Content** Kg/m^3	**Modulus of Elasticity (All Grades and All Locations) × 10^3** N/mm^2	**Permissible Stress for Grade I** N/mm^2											**Preservative Characters**		**Refractoriness to Air Seasoning**$^{3)}$
	Botanical Name	Trade Name				Bending-Tension Along Grain, Extreme Fibre Stress			Shear all Locations		Compression Parallel to Grain			Compression Perpendicular to Grain			Durability Class$^{1)}$	Treat-ability Grade$^{2)}$	
						Inside Location	Outside Location	Wet Location	Horizontal	Along Grain	Inside Location	Outside Location	Wet Location	Inside Location	Outside Location	Wet Location			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
	bm) *Quercus semecarpifolia*	–	Punjab	834	11.58	15.8	13.1	10.5	1.3	1.8	8.3	7.3	6.0	3.8	2.9	2.4	–	–	A
	bn) *Shorea robusta*$^{4)}$	Sal (SAL)	Madhya Pradesh	805	12.67	16.9	14.0	11.2	0.9	1.3	10.6	9.4	7.7	4.6	3.5	2.9	I	e	A
	bp) *Soymida fabrifuga*	Rohini (ROH)	Chennai	1 116	12.22	21.5	17.9	14.4	1.6	2.3	15.0	13.3	10.9	12.9	10.0	8.2	I	–	A
	bq) *Shorea talura*	–	Maharashtra	721	12.20	16.8	14.0	11.2	1.1	1.6	12.6	11.2	9.2	6.8	5.3	4.3	–	–	–
	br) *Plerygota alata (Syn. Sterculia alata)*	Narikel (NAR)	Assam	593	10.95	13.4	11.8	8.9	0.8	1.2	8.2	7.3	6.0	2.7	2.1	1.7	III	–	C
	bs) *Syzygium cumini*	Jaman (JAM)	Assam	841	10.55	14.8	12.4	9.9	1.1	1.6	9.0	8.0	6.5	6.9	5.4	4.4	II	e	A
	bt) *Terminalia bellirica*	Bahera (BAH)	Uttar Pradesh	729	10.19	13.6	11.3	9.0	1.0	1.4	8.4	.7.5	6.1	3.7	2.8	2.3	III	b	B
	bu) *Terminalia chebula*	Myrobalan (MYR)	–	918	12.37	17.1	14.2	11.4	1.1	1.6	1.2	10.4	8.5	6.7	5.2	4.3	II	c	A

Table 1 (*Continued*)

Sl No.	**Species**		**Locality from where Tested**	**Average Density at 12 Percent Moisture Content** Kg/m^3	**Modulus of Elasticity (All Grades and All Locations) × 10^3** N/mm^2	**Permissible Stress for Grade I** N/mm^2											**Preservative Characters**		**Refracteriness to Air Seasoning$^{3)}$**
	Botanical Name	Trade Name				Bending-Tension Along Grain, Extreme Fibre Stress			Shear all Locations		Compression Parallel to Grain			Compression Perpendicular to Grain			Durability Class$^{1)}$	Treat-ability Grade$^{2)}$	
						Inside Location	Outside Location	Wet Location	Horizontal	Along Grain	Inside Location	Outside Location	Wet Location	Inside Location	Outside Location	Wet Location			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
	bv) *Terminalia citrina*	–	Assam	755	11.89	17.1	14.3	11.4	1.1	1.6	10.8	9.6	7.9	5.0	3.9	3.2	–	–	–
	bw) *Terminalia manii*	Black-chuglam (BCH)	Southern Andaman	822	12.66	16.8	14.0	11.2	1.1	1.6	10.3	9.2	7.5	5.1	4.0	3.2	II	a	B
	by) *Tectona grandis*	Teak (TEA)	Uttar Pradesh	660	9.97	15.5	12.9	10.3	1.2	1.6	9.4	8.3	6.8	4.5	3.5	2.8	I	e	B
	bz) *Terminalia paniculate*	Kindal (KIN)	Maharashtra	765	10.57	13.1	10.9	8.7	0.9	1.3	8.6	7.7	6.3	3.6	2.8	2.3	I	c	A
	ca) *Alreminalia alata*	Laurel (LAU), Sain	Chennai	906	10.54	15.1	12.5	10.0	1.1	1.6	9.4	8.4	6.8	6.2	4.8	4.0	I	b	A
	cb) *Terminalia bilata*	White-chuglam (WCH)	Southern Andaman	690	12.38	15.5	13.0	10.4	0.9	1.2	9.8	8.7	7.1	3.6	2.8	2.3	III	e	B
	cc) *Thespesia populnea*	Bhendi (BHE)	Maharashtra	766	10.36	18.9	15.8	12.6	1.3	1.9	11.3	10.0	8.2	4.4	3.4	2.8	–	–	B
	cd) *Xylia xylocarpa*	Irul (IRU)	Maharashtra	839	11.63	16.2	13.5	10.8	1.3	1.8	10.9	9.7	7.9	7.8	6.0	4.9	I	e	A

Table 1 (*Continued*)

Sl No.	Species		Locality from where Tested	Average Density at 12 Percent Moisture Content Kg/m^3	Modulus of Elasticity (All Grades and All Locations) × 10^3 N/mm^2	Permissible Stress for Grade I N/mm^2											Preservative Characters		Refracteriness to Air Seasoning3)
	Botanical Name	Trade Name				Bending-Tension Along Grain, Extreme Fibre Stress			Shear all Locations		Compression Parallel to Grain			Compression Perpendicular to Grain			Durability Class1)	Treat-ability Grade2)	
						Inside Location	Outside Location	Wet Location	Horizontal	Along Grain	Inside Location	Outside Location	Wet Location	Inside Location	Outside Location	Wet Location			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
	ce) *Zanthoxylum budranga*	Mullilam (MUL)	West Bengal	587	10.65	14.7	12.2	9.8	0.9	1.2	9.5	8.4	6.9	3.4	2.6	2.1	I	e	B
	cf) *Adina oligocephala*	-	Arunachal	715	11.17	15.2	12.7	10.1	1.2	1.7	10.3	9.2	7.5	4.0	3.1	2.4	–	–	–
	cg) *Castanopsis indica*	Chestnut	Meghalaya	688	12.54	14.8	12.3	9.9	1.0	1.4	9.8	8.7	7.1	3.4	2.7	2.2	–	–	B
	ch) *Eucalyptus citriodara*	Eucalyptus	Nilgiri	831	12.12	17.3	14.4	11.5	1.4	2.0	11.0	9.8	8.0	4.2	3.3	2.7	–	–	–
	cj) *Eucalyptus citriodata*	Eucalyptus	Ooty	725	9.35	15.4	12.9	10.3	1.0	1.4	8.6	7.6	6.3	3.0	2.4	2.0	–	–	–
	ck) *Eucalytus tereticornis*	Eucalyptus	Chennai	777	11.05	16.7	13.9	11.1	1.0	1.4	9.7	8.6	7.1	3.4	2.6	2.2	III	e	–
iii)	**GROUP C:**																		
	a) *Tbizia procera*	White siris	Uttar Pradesh	643	9.02	13.4	11.2	8.9	1.0	1.4	8.5	7.6	6.2	4.3	3.3	2.7	I	c	B
	b) *Artocarpus lakocha*	Lakooch (LAK)	Uttar Pradesh	647	6.14	10.0	8.3	6.7	1.0	1.4	5.3	4.7	3.8	2.8	2.2	1.8	I	–	B

Table 1 (*Continued*)

Sl No.	**Species**		**Locality from where Tested**	**Average Density at 12 Percent Moisture Content** Kg/m^3	**Modulus of Elasticity (All Grades and All Locations) × 10^3** N/mm^2	**Permissible Stress for Grade I** N/mm^2											**Preservative Characters**		**Refracteriness to Air Seasoning**3)
	Botanical Name	Trade Name				Bending-Tension Along Grain, Extreme Fibre Stress			Shear all Locations		Compression Parallel to Grain			Compression Perpendicular to Grain			Durability Class1)	Treat-ability Grade2)	
						Inside Location	Outside Location	Wet Location	Horizontal	Along Grain	Inside Location	Outside Location	Wet Location	Inside Location	Outside Location	Wet Location			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
	c) *Artocarpus hetarophyllus* (*Syn. A. Integrifolia*)	Jack, kathal (KAT)	Chennai	617	9.46	13.9	11.6	9.2	1.0	1.5	9.3	8.3	6.8	4.5	3.5	2.9	I	d	B
	d) *Aphanamixis polystachya* (*Syn. Amoora rehituka*)	Pitraj (PIT)	West Bengal	668	8.98	12.3	10.2	8.2	1.1	1.5	8.0	7.1	5.8	4.0	3.1	2.6	I	–	B
	e) *Adina cordifolia*4)	Haldu (HAL)	Uttar Pradesh	663	8.54	13.3	11.1	8.9	1.0	1.4	8.7	7.7	6.3	4.4	3.4	2.8	III	a	B
	f) *Anthocephyalus chinensis* (*Syn. A. Cadamba)*	Kadam (KAD)	–	485	1.88	9.7	8.1	5.4	0.7	1.0	5.9	5.3	4.3	1.9	1.5	1.2	III	a	–
	g) *Arlocarpus chaplasha*	Chaplash (CHP)	Assam	515	9.11	13.2	11.0	8.8	0.9	1.2	8.5	7.5	6.2	3.6	2.8	2.3	III	d	B
	h) *Acacia leucophloea*	Hiwar (HIW)	Madhya Pradesh	737	7.85	13.4	11.2	9.0	1.0	1.5	7.5	6.7	5.4	4.5	3.5	2.8	–	–	A
	j) *Acacia melanoxylone*	Black wood	Chennai	630	9.45	13.0	10.8	8.7	1.1	1.5	7.6	6.8	5.5	3.2	2.5	2.0	–	–	–

Table 1 (*Continued*)

Sl No.	**Species**		**Locality from where Tested**	**Average Density at 12 Percent Moisture Content** Kg/m^3	**Modulus of Elasticity (All Grades and All Locations) × 10^3** N/mm^2	**Permissible Stress for Grade I** N/mm^2											**Preservative Characters**		**Refracteriness to Air Seasoning**[3)]
	Botanical Name	Trade Name				Bending-Tension Along Grain, Extreme Fibre Stress			Shear all Locations		Compression Parallel to Grain			Compression Perpendicular to Grain			Durability Class[1)]	Treat-ability Grade[2)]	
						Inside Location	Outside Location	Wet Location	Horizontal	Along Grain	Inside Location	Outside Location	Wet Location	Inside Location	Outside Location	Wet Location			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
	k) *Acacia mearnsii* (*Syn. A. mollissima*)	Black wattle	Chennai	669	6.10	10.4	8.6	6.9	0.8	1.2	6.0	5.4	4.4	2.3	1.8	1.5	–	–	–
	m) *Accer spp.*	Maple (MAP)	Punjab, Uttar Pradesh	551	7.35	9.9	8.2	6.5	0.9	1.3	5.5	4.9	4.0	2.1	1.7	1.4	III	–	B
	n) *Aegla marmalos* (*Syn. Intsia bijuga*)	Bael (BEL)	Uttar Pradesh	890	8.81	13.5	11.2	9.0	1.4	2.0	8.8	7.8	6.4	6.8	5.3	4.3	III	–	B
	p) *Afzelia bijuga*	-	Andaman	705	9.16	13.2	11.0	8.8	1.1	1.5	7.9	7.1	5.8	4.0	3.1	2.6	–	–	–
	q) *Ailanthus grandis*	Gokul (GOK)	West Bengal	404	7.94	8.3	6.9	5.5	0.6	0.8	5.3	4.7	3.9	1.1	0.9	0.7	III	–	C
	r) *Anogeissus pendula*	Kardhai (KAH)	Uttar Pradesh	929	9.75	17.0	14.2	11.4	1.3	1.8	9.8	8.7	7.1	6.5	5.1	4.2	III	–	A
	s) *Areca nut*	-	Kerala	833	9.48	15.2	12.7	10.2	1.2	1.6	10.8	9.6	7.8	7.3	5.7	4.7	–	–	–
	t) *Albizia lucida*	-	Arunachal Pradesh	566	8.51	10.7	8.9	7.1	8.2	1.2	7.3	6.3	5.3	2.3	1.8	1.5	–	–	–
	u) *Azadirachta indica*	Neem (NEE)	Uttar Pradesh	836	8.52	14.6	12.1	9.7	1.3	1.8	10.0	8.9	7.3	5.0	3.9	3.2	–	–	–

Table 1 (*Continued*)

Sl No.	**Species**		**Locality from where Tested**	**Average Density at 12 Percent Moisture Content** Kg/m^3	**Modulus of Elasticity (All Grades and All Locations) × 10^3** N/mm^2	**Permissible Stress for Grade I** N/mm^2											**Preservative Characters**		**Refracteriness to Air Seasoning**[3]
	Botanical Name	Trade Name				Bending-Tension Along Grain, Extreme Fibre Stress			Shear all Locations		Compression Parallel to Grain			Compression Perpendicular to Grain			Durability Class[1]	Treatability Grade[2]	
						Inside Location	Outside Location	Wet Location	Horizontal	Along Grain	Inside Location	Outside Location	Wet Location	Inside Location	Outside Location	Wet Location			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
	v) *Boswellia seriata*	Salai (SAA)	Bihar	551	7.21	9.4	7.9	6.3	0.7	1.1	5.5	4.9	4.0	2.1	1.6	1.3	I	e	C
	w) *Bridelia retusa*	Kassi (KAS)	Bihar	584	9.42	11.6	9.7	7.7	0.9	1.3	7.1	6.3	5.1	4.0	3.1	2.6	I	e	B
	y) *Betula lnoides*	Birch (BIR)	West Bengal	625	9.23	9.6	8.0	6.4	0.8	1.1	5.7	5.0	4.1	2.2	1.7	1.4	–	–	B
	z) *Bischofia javanica*	Uriam Bishopwood (URI)	Chennai	769	8.84	9.6	8.2	6.5	0.8	1.1	5.9	5.3	4.3	3.6	2.8	2.3	III	–	A
	aa) *Burserra serrata* (*Syn. Protium serratum*)	Muntenga (MUR)	Arunachal Pradesh	756	1.17	15.5	13.3	10.5	0.9	1.3	10.1	9.0	7.4	5.3	4.1	3.4	II	c	–
	ab) *Careya arbersa*	Kumbi (KUM)	Uttar Pradesh	889	8.37	13.1	10.9	8.8	1.0	1.5	7.7	6.8	5.6	5.3	4.1	3.4	I	e	A
	ac) *Cedrus deodara*	Deodar (DEO)	Himachal Pradesh	557	9.48	10.2	8.7	7.2	0.7	1.0	7.8	6.9	5.7	2.7	2.1	1.7	I	c	C
	ad) *Cupressus torulosa*	Cypress (CYP)	Uttar Pradesh	506	8.41	8.8	7.6	6.2	0.6	0.8	6.9	6.2	5.0	2.4	1.8	1.5	I	e	C

Table 1 (*Continued*)

Sl No.	**Species**		**Locality from where Tested**	**Average Density at 12 Percent Moisture Content** Kg/m^3	**Modulus of Elasticity (All Grades and All Locations) × 10^3** N/mm^2	**Permissible Stress for Grade I** N/mm^2											**Preservative Characters**		**Refracteriness to Air Seasoning**3)
	Botanical Name	Trade Name				Bending-Tension Along Grain, Extreme Fibre Stress			Shear all Locations		Compression Parallel to Grain			Compression Perpendicular to Grain			Durability Class1)	Treat-ability Grade2)	
						Inside Location	Outside Location	Wet Location	Horizontal	Along Grain	Inside Location	Outside Location	Wet Location	Inside Location	Outside Location	Wet Location			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
	ae) *Castanopsis hystrix*	Indian chestnut (ICH)	West Bengal	624	9.85	10.6	8.8	7.0	0.8	1.2	6.4	5.7	4.6	2.7	2.1	1.7	II	b	B
	af) *Chukrasia vclutina* (*Syn. C. Tabularis*)	Chickrassy (CHI)	West Bengal	666	8.35	11.8	9.8	7.9	1.1	1.5	7.1	6.3	5.2	3.9	3.1	2.5	II	c	B
	ag) *Calophyllum wightianum*	Poon (POO)	Maharashtra	689	8.68	13.5	11.2	9.0	1.0	1.4	8.7	7.8	6.4	4.0	3.1	2.5	II	–	B
	ah) *Canarium strictum*	White dhup	Assam	569	10.54	10.1	8.4	6.7	0.7	1.1	6.2	5.5	4.5	2.1	1.6	1.3	III	–	C
	aj) *Chlorophora excelsa*	-	Chennai	471	6.57	10.2	8.5	6.8	0.5	0.7	6.4	5.6	4.6	2.0	1.6	1.3	–	–	–
	ak) *Cocosnucifera*	Coconut (COC)	Kerala	761	7.34	9.2	7.7	6.1	0.7	1.1	9.5	8.4	6.9	3.9	3.0	2.5	–	–	–
	am) *Dalbergia latifolia*	Rosewood (ROS)	Madhya Pradesh	884	8.39	12.9	10.8	8.6	1.1	1.6	8.0	7.1	5.8	4.2	3.3	2.7	I	–	B
	an) *Dalbergia sissee*	Sisso (SIS)	Punjab	799	7.14	12.8	10.7	8.5	1.3	1.8	8.2	7.3	6.0	4.2	3.3	2.7	I	e	B
	ap) *Dillemia indica*	Dillenia (DIL)	West Bengal	617	8.61	12.1	10.0	8.0	0.8	1.2	7.3	6.5	5.3	2.7	2.1	1.7	III	a	B

Table 1 (*Continued*)

Sl No.	**Species**		**Locality from where Tested**	**Average Density at 12 Percent Moisture Content** Kg/m^3	**Modulus of Elasticity (All Grades and All Locations) × 10^3** N/mm^2	**Permissible Stress for Grade I** N/mm^2											**Preservative Characters**		**Refracteriness to Air Seasoning3)**
	Botanical Name	Trade Name				Bending-Tension Along Grain, Extreme Fibre Stress			Shear all Locations		Compression Parallel to Grain			Compression Perpendicular to Grain			Durability Class1)	Treat-ability Grade2)	
						Inside Location	Outside Location	Wet Location	Horizontal	Along Grain	Inside Location	Outside Location	Wet Location	Inside Location	Outside Location	Wet Location			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
	aq) *Dillenia pentagyne*	Dillenia (DIL)	West Bengal	622	7.56	11.8	9.9	7.9	0.9	1.3	7.1	6.3	5.2	3.5	2.7	2.2	III	d	B
	ar) *Diospyres melanoxylon*	Ebony (EBO)	Maharashtra	818	7.69	10.9	9.1	7.3	0.9	1.2	7.0	6.2	5.1	3.3	2.6	2.1	II	–	A
	as) *Duabanga grandiflora* (*Syn. D. Sonneratioides*)	Lampati (LAP)	West Bengal	485	8.38	9.8	8.2	6.5	0.6	0.9	6.4	5.7	4.7	1.8	1.4	1.1	III	c	C
	at) *Elesocarpus tuberculatus*	Rudrak (RUD)	Chennai	466	8.74	9.7	8.1	6.4	0.7	1.0	6.3	5.6	4.6	2.0	1.5	1.3	–	–	C
	au) *Eucalyptus hybrid*	Mysore gum (MGU)	Chennai	753	6.00	10.2	8.5	6.8	0.9	1.2	7.3	6.5	5.3	4.0	3.1	2.5	III	e	–
	av) *Calitres rhomboidea* (*Syn. Frenela rhomboidea*)	–	Chennai	607	6.48	9.2	7.7	6.1	0.7	1.0	6.9	6.1	5.0	4.0	3.1	2.6	–	–	–
	aw) *Garuga pinnata*	Garuga (GAU)	Uttar Pradesh	571	7.58	11.7	9.7	7.8	1.0	1.5	7.2	6.4	5.3	3.4	2.6	2.1	I	e	B
	ay) *Gmelina arborea*	Gamari (GAM)	Uttar Pradesh	501	7.02	9.8	8.2	6.6	0.8	1.2	5.7	5.0	4.1	4.2	3.2	2.7	I	e	B

Table 1 (*Continued*)

Sl No.	**Species**		**Locality from where Tested**	**Average Density at 12 Percent Moisture Content** Kg/m^3	**Modulus of Elasticity (All Grades and All Locations) × 10^3** N/mm^2	**Permissible Stress for Grade I** N/mm^2											**Preservative Characters**		**Refractoriness to Air Seasoning**3)
	Botanical Name	Trade Name				Bending-Tension Along Grain, Extreme Fibre Stress			Shear all Locations		Compression Parallel to Grain			Compression Perpendicular to Grain			Durability Class1)	Treat-ability Grade2)	
						Inside Location	Outside Location	Wet Location	Horizontal	Along Grain	Inside Location	Outside Location	Wet Location	Inside Location	Outside Location	Wet Location			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
	az) *Gardonia latifolia*	Gardenia (GAI)	Madhya Pradesh	705	7.13	14.1	11.7	9.4	1.2	1.7	8.4	7.4	6.1	4.6	3.6	3.0	–	–	–
	ba) *Hardwickis binata*	Anjan (ANJ)	Madhya Pradesh	852	6.64	14.1	11.8	9.4	1.3	1.8	9.0	8.0	6.5	7.4	5.6	4.7	I	e	–
	bb) *Heloptelea integrifolia*	Kanju (KAN)	Uttar Pradesh	592	7.46	12.0	10.0	8.0	0.9	1.3	6.7	6.0	4.9	2.8	2.2	1.8	III	b	B
	bc) *Heterrophragma rexburghii*	Palang (PAL)	Madhya Pradesh	616	8.69	12.3	10.2	8.2	0.7	1.0	7.9	7.0	5.7	3.4	2.6	2.1	–	–	–
	bd) *Juglans spp.*	Walnut (WAL)	Uttar Pradesh	565	9.00	9.9	8.3	6.6	0.9	1.2	5.8	5.2	4.2	2.2	1.7	1.4	III	–	B
	be) *Lagerstrosmia speciosa* (*Syn. L. flesregihal*)	Jarul (JAAR)	Northern Andaman	622	8.53	12.1	10.1	8.1	0.8	1.8	7.7	6.8	5.6	3.4	2.6	2.2	II	e	B
	bf) *Lannea grandis* (*Syn. L.coromandelica*)	Jhingan (JHI)	Uttar Pradesh	557	5.63	8.5	7.1	5.7	0.6	0.9	4.9	4.4	3.6	2.2	1.7	1.4	III	e	B
	bg) *Leucanena leucocephala*	Subabul (SUB)	Uttar Pradesh	673	6.32	11.6	9.7	7.8	1.0	1.5	7.4	6.6	5.4	3.8	3.0	2.4	–	–	–

Table 1 (*Continued*)

Sl No.	**Species**		**Locality from where Tested**	**Average Density at 12 Percent Moisture Content** Kg/m^3	**Modulus of Elasticity (All Grades and All Locations) × 10^3** N/mm^2	**Permissible Stress for Grade I** N/mm^2											**Preservative Characters**		**Refracteriness to Air Seasoning**[3)]
	Botanical Name	Trade Name				Bending-Tension Along Grain, Extreme Fibre Stress			Shear all Locations		Compression Parallel to Grain			Compression Perpendicular to Grain			Durability Class[1)]	Treat-ability Grade[2)]	
						Inside Location	Outside Location	Wet Location	Horizontal	Along Grain	Inside Location	Outside Location	Wet Location	Inside Location	Outside Location	Wet Location			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
	bh) *Lophopatalum wightianum*	Banati (BAN)	Chennai	460	7.33	8.5	7.5	5.6	0.5	0.8	5.3	4.7	3.8	1.8	1.4	1.1	III	–	C
	bj) *Madhuca longifolia varlatifolia* (*Syn. Bassia latifolia*)	Mahua (MAU)	Madhya Pradesh	936	8.82	13.0	10.8	8.7	1.0	1.4	7.5	6.7	5.5	6.3	4.9	4.0	I	e	A
	bk) *Mangifera indica*	Mango, Aam (MAN)	Orissa	661	9.12	12.2	10.2	8.2	1.0	1.4	7.3	6.5	5.3	3.1	2.4	2.0	III	a	C
	bm) *Machilus macrantha*	Machilus (MAC)	Chennai	521	7.63	10.2	8.5	6.8	0.7	1.0	6.3	5.6	4.6	2.4	1.9	1.5	III	e	B
	bn) *Mallotus philippinensis*	Raini (RAI)	Uttar Pradesh	662	7.51	10.8	9.0	7.2	1.0	1.4	6.0	5.4	4.4	2.9	2.3	1.8	III	–	B
	bp) *Manglietia insignia*	-	Assam	449	10.37	10.9	9.1	7.3	0.7	1.0	8.0	7.1	5.8	3.4	2.6	2.1	–	–	–
	bq) *Michelia montana*	Champ (CHM)	West Bengal	512	8.25	10.9	9.1	7.3	0.7	1.0	6.6	5.9	4.8	2.8	2.2	1.8	I	–	B

Table 1 (*Continued*)

Sl No.	**Species**		**Locality from where Tested**	**Average Density at 12 Percent Moisture Content** Kg/m^3	**Modulus of Elasticity (All Grades and All Locations) × 10^3** N/mm^2	**Permissible Stress for Grade I** N/mm^2											**Preservative Characters**		**Refracteriness to Air Seasoning**[3]
	Botanical Name	Trade Name				Bending-Tension Along Grain, Extreme Fibre Stress			Shear all Locations		Compression Parallel to Grain			Compression Perpendicular to Grain			Durability Class[1]	Treat-ability Grade[2]	
						Inside Location	Outside Location	Wet Location	Horizontal	Along Grain	Inside Location	Outside Location	Wet Location	Inside Location	Outside Location	Wet Location			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
	br) *Mitragyna pervifolia* (*Syn. Stephagyne pervifolia*)	Kaim (KAI)	Uttar Pradesh	651	7.82	12.6	10.5	8.4	1.0	1.5	7.9	7.0	5.7	3.7	2.9	2.4	III	b	B
	bs) *Michelia excelsa*	Champ (CHM)	West Bengal	513	10.12	9.8	8.2	6.5	0.7	1.0	6.1	5.5	4.5	1.6	1.3	1.0	II	e	B
	bt) *Miliusa velutnia*	Domsal (DOM)	Uttar Pradesh	747	7.92	11.7	9.7	7.8	1.1	1.6	7.0	6.3	5.1	3.7	2.9	2.4	III	–	–
	bu) *Morus alba*	Mulberry (MUL)	Uttar Pradesh	743	8.20	11.8	9.8	7.9	1.0	1.4	6.6	5.8	4.8	3.8	2.9	2.4	II	–	B
	bv) *Morus serrata*	Mulberry (MUL)	Himachal Pradesh	657	7.03	10.2	8.5	6.8	0.9	1.3	5.6	5.0	4.1	2.6	2.0	1.6	III	–	B
	bw) *Morus laevigata*	Bola (BOL)	Andaman	588	8.61	12.3	10.2	8.2	1.0	1.5	7.2	6.4	5.3	3.3	2.5	2.1	–	–	B
	by) *Ougeinia eejeinensis* (*Syn. O. delbergioides*)	Sandan (SAD)	Madhya Pradesh	784	8.54	13.3	11.1	8.9	1.2	1.7	8.5	7.5	6.2	5.1	3.9	3.2	I	–	B
	bz) *Phoebe hainesiana*	Bonsum (BOH)	Assam	566	9.50	13.2	11.0	8.8	0.8	1.2	8.8	7.8	6.4	2.8	2.1	1.8	II	c	B

Table 1 (*Continued*)

Sl No.	**Species**		**Locality from where Tested**	**Average Density at 12 Percent Moisture Content** Kg/m^3	**Modulus of Elasticity (All Grades and All Locations) × 10^3** N/mm^2	**Permissible Stress for Grade I** N/mm^2											**Preservative Characters**		**Refractoriness to Air Seasoning**3)
	Botanical Name	Trade Name				Bending-Tension Along Grain, Extreme Fibre Stress			Shear all Locations		Compression Parallel to Grain			Compression Perpendicular to Grain			Durability Class1)	Treat-ability Grade2)	
						Inside Location	Outside Location	Wet Location	Horizontal	Along Grain	Inside Location	Outside Location	Wet Location	Inside Location	Outside Location	Wet Location			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
	ca) *Pinus roxburghii* (*Syn. P. longifolia*)	Chir (CHR)	Uttar Pradesh	525	9.82	8.5	7.3	6.0	0.6	0.9	6.0	5.3	4.4	2.0	1.5	1.3	III	b	C
	cb) *Pinus wallichiana*	Kail (KAL)	–	515	6.80	6.6	5.6	5.0	0.6	0.8	5.2	4.6	3.8	1.7	1.3	1.0	II	c	C
	cc) *Phoebe goalperansis*	Bonsum (BOH)	Assam	511	7.65	9.7	8.1	6.5	0.7	1.0	6.6	5.9	4.8	2.2	1.7	1.4	II	c	B
	cd) *Parretiopsis jacquementiena*	Rohu Parrotia	Himachal Pradesh	761	5.77	12.5	10.4	8.3	1.2	1.7	6.8	6.1	5.0	4.0	3.1	2.5	III	–	B
	ce) *Pinus kesia* (*Syn. Pinus insularis*)	Khasi pine (KPI)	North East	513	7.38	8.9	7.4	5.9	0.6	0.7	5.8	5.2	4.3	1.5	1.2	1.0	III	a	B
	cf) *Pistacia integerrima*	Kikar singhi	Jammu and Kashmir	881	7.32	13.1	10.9	8.7	1.2	1.7	8.0	7.1	5.8	4.3	3.4	2.8	–	–	–
	cg) *Podocarpus nerrifolius*	Thitmin (THT)	Southern Andaman	533	9.41	12.5	10.4	8.3	6.1	0.9	8.0	7.1	5.8	2.6	2.0	1.6	II	–	–
	ch) *Polyalthia fragrances*	Debdaru (DEB) (Nedunar)	Maharashtra	752	9.15	11.9	9.9	7.9	0.8	1.2	6.7	6.0	4.9	3.0	2.3	1.9	III	–	B

Table 1 (*Continued*)

Sl No.	Species		Locality from where Tested	Average Density at 12 Percent Moisture Content Kg/m^3	Modulus of Elasticity (All Grades and All Locations) × 10^3 N/mm^2	Permissible Stress for Grade I N/mm^2											Preservative Characters		Refracteriness to Air Seasoning$^{3)}$
	Botanical Name	Trade Name				Bending-Tension Along Grain, Extreme Fibre Stress			Shear all Locations		Compression Parallel to Grain			Compression Perpendicular to Grain			Durability Class$^{1)}$	Treat-ability Grade$^{2)}$	
						Inside Location	Outside Location	Wet Location	Horizontal	Along Grain	Inside Location	Outside Location	Wet Location	Inside Location	Outside Location	Wet Location			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
	cj) *Polyalthia coreoides*	–	Madhya Pradesh	700	9.29	13.2	11.0	8.8	1.0	1.4	7.1	6.3	5.2	3.2	2.5	2.0	–	–	–
	ck) *Prunus napeulensis*	Arupati	West Bengal	548	9.41	104.4	8.7	69.6	0.9	1.2	6.7	6.0	4.9	2.4	1.9	1.6	–	–	–
	cm) *Pterespermum acerifolium*	Hattipaila (HAT)	West Bengal	607	9.55	13.5	11.3	9.0	0.9	1.2	8.7	7.7	6.3	3.2	2.5	2.0	III	c	B
	cn) *Qucrcus spp.*	Oak	North East	657	11.65	11.4	9.5	7.6	0.8	1.2	6.7	5.9	4.8	2.0	1.6	1.3	II	c	B
	cp) *Raderomachera xylocarpe* (*Syn. Sterosperam xylocarpum*)	Vedankonnai	Chennai	696	8.52	13.2	11.0	8.8	1.1	1.5	9.0	8.0	6.6	4.3	3.3	2.7	II	a	–
	cq) *Schleichera oleosa* (*Syn. S. trijuga*)	Kusum (KUS)	Bihar	1 032	12.12	15.5	13.0	10.4	1.5	2.1	10.9	9.7	7.9	6.1	4.2	3.9	II	a	A
	cr) *Schima wallichii*	Chilauni (CHL)	West Bengal	693	9.57	11.1	9.3	7.4	0.9	1.3	6.6	5.9	4.8	2.3	1.8	1.4	III	d	B
	cs) *Shotea assamica*	Makai (MAK)	Assam	548	9.27	11.1	9.2	7.4	0.9	1.3	7.1	6.3	5.2	2.9	2.2	1.8	III	c	B

Table 1 (*Continued*)

Sl No.	Species		Locality from where Tested	Average Density at 12 Percent Moisture Content Kg/m^3	Modulus of Elasticity (All Grades and All Locations) × 10^3 N/mm^2	Permissible Stress for Grade I N/mm^2											Preservative Characters		Refracteriness to Air Seasoning$^{3)}$
	Botanical Name	Trade Name				Bending-Tension Along Grain, Extreme Fibre Stress			Shear all Locations		Compression Parallel to Grain			Compression Perpendicular to Grain			Durability Class$^{1)}$	Treat-ability Grade$^{2)}$	
						Inside Location	Outside Location	Wet Location	Horizontal	Along Grain	Inside Location	Outside Location	Wet Location	Inside Location	Outside Location	Wet Location			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
	ct) *Sonneralia apetale*	Keora (KEO)	West Bengal	617	8.63	12.8	10.7	8.5	0.9	1.3	7.4	6.6	5.4	4.8	3.7	3.0	II	–	B
	cu) *Stereospermum suaveolans*	Padri (PAD)	Uttar Pradesh	721	8.86	13.3	11.1	8.9	0.9	1.3	7.3	7.0	5.7	3.5	2.7	2.2	III	–	B
	cv) *Tactona grandis*	Teak (TEA)	Madhya Pradesh	617	8.49	12.8	10.7	8.5	0.8	1.3	7.9	7.0	5.7	4.0	3.1	2.6	I	e	B
	cw) *Terminalia arjuna*	Arjun (ARJ)	Bihar	794	7.71	12.2	10.2	8.2	1.1	1.6	7.4	6.6	5.4	5.2	4.1	3.3	II	b	B
	cy) *Terminalia myriocarpa*	Hollock (HOC)	Assam	615	9.62	11.9	9.9	8.0	0.9	1.2	7.6	6.7	5.5	2.9	2.2	1.8	III	a	B
	cz) *Terminalia procera*	White bombwae (WBO)	Northern Andaman	626	8.99	11.8	9.8	7.9	0.9	1.3	7.2	6.4	5.3	3.0	2.3	1.9	III	b	B
	da) *Taxus buccata*	Yew (YEW)	West Bengal	705	7.79	14.3	11.9	9.5	1.2	1.7	8.7	7.8	6.4	4.7	3.7	3.0	–	–	–
	db) *Tamarindus indica*	Imli (IML)	Chennai	913	5.63	11.4	9.5	7.6	1.2	1.7	7.0	6.2	5.1	5.3	4.1	3.4	–	–	B

Table 1 (*Continued*)

Sl No.	**Species**		**Locality from where Tested**	**Average Density at 12 Percent Moisture Content** Kg/m^3	**Modulus of Elasticity (All Grades and All Locations) × 10^3** N/mm^2	**Permissible Stress for Grade I** N/mm^2											**Preservative Characters**		**Refracteriness to Air Seasoning**3)
	Botanical Name	Trade Name				Bending-Tension Along Grain, Extreme Fibre Stress			Shear all Locations		Compression Parallel to Grain			Compression Perpendicular to Grain			Durability Class1)	Treat-ability Grade2)	
						Inside Location	Outside Location	Wet Location	Horizontal	Along Grain	Inside Location	Outside Location	Wet Location	Inside Location	Outside Location	Wet Location			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
	dc) *Toena ciliata*	Toon (TOO)	Uttar Pradesh	487	6.40	8.7	7.3	5.8	0.7	1.0	5.4	4.8	3.9	2.4	1.8	1.5	II	c	B
	dd) *Vateria indica*	Vellapine (VEL)	Chennai	535	10.95	11.5	9.6	7.6	0.7	1.1	7.5	6.7	5.5	2.3	1.8	1.4	III	e	C
	de) *Aeculas indica*	Horse chestnut (HCH)	Uttar Pradesh	484	7.55	8.5	7.1	5.7	0.8	1.1	4.8	4.2	3.5	1.8	1.4	1.1	–	–	B
	df) *Borassus flabelsfer*	Tad (Palmyra) (TAD)	Arunachal Pradesh	838	8.79	10.5	8.8	7.0	0.7	1.0	10.0	8.8	7.2	4.7	3.6	2.7	–	–	–
	dg) *Eucalyptus cemaldulensis*	Eucalyptus	Karnataka	804	9.53	12.8	10.6	8.5	0.8	1.1	7.2	6.4	5.2	3.5	2.7	2.2	–	–	A
	dh) *Eucalyptus camaldulenis*	Eucalyptus	Uttar Pradesh	781	7.03	12.4	10.4	8.3	1.1	1.6	7.9	7.0	5.7	3.5	2.8	2.3	–	–	A
	dj) *Eucalyptus pilularia*	Eucalyptus	Tamil Nadu	713	9.22	14.8	12.3	11.1	1.0	1.4	8.5	7.6	6.2	2.8	2.2	1.8	–	–	A
	dk) *Eucalyptus propingus*	Eucalyptus	Tamil Nadu	584	7.93	12.8	10.7	8.5	0.8	1.2	8.0	5.4	4.4	2.5	1.9	1.6	–	–	A

Table 1 (*Concluded*)

Sl No.	Species		Locality from where Tested	Average Density at 12 Percent Moisture Content Kg/m^3	Modulus of Elasticity (All Grades and All Locations) × 10^3 N/mm^2	Permissible Stress for Grade I N/mm^2											Preservative Characters		Refracteriness to Air Seasoning[3]
	Botanical Name	Trade Name				Bending-Tension Along Grain, Extreme Fibre Stress			Shear all Locations		Compression Parallel to Grain			Compression Perpendicular to Grain			Durability Class[1]	Treat-ability Grade[2]	
						Inside Location	Outside Location	Wet Location	Horizontal	Along Grain	Inside Location	Outside Location	Wet Location	Inside Location	Outside Location	Wet Location			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
	dm) *Eucalyptus saligna*	Eucalyptus	Uttar Pradesh	819	8.24	11.5	9.6	7.6	1.5	2.1	8.2	7.3	6.0	6.2	4.8	4.0	–	–	A

NOTE — Any other species (including foreign species) of timber may be classified into Group A, B, or C based on their safe permissible stresses and other relevant properties, corresponding to the classification table provided for given Indian timber species. The assignment of a timber species to a specific group may be determined through standardized testing and evaluation of mechanical properties, including strength, durability and density, in accordance with the applicable test methods and criteria specified in accordance with accepted standards [C-3A(2)].

[1] Classification for preservation based on durability tests, etc.

Class:

I Average life more than 120 months;
II Average life 60 months and above but less than 120 months; and
III Average life less than 60 months.

[2] Treatability Grades:

a Heartwood easily treatable;
b Heartwood treatable, but complete penetration not always obtained; in case where the least dimension is more than 60 mm;
c Heartwood only partially treatable;
d Heartwood refractory to treatment; and
e Heartwood very refractory to treatment, penetration of preservative being practically nil even from the ends.

[3] Classifications based on seasoning behaviour of timber and refractoriness with respect to cracking, splitting and drying rate:

A Highly refractory (slow and difficulty to season free from surface and end cracking);
B Moderately refractory (may be seasoned free from surface and end cracking within reasonably short periods, given a little protection against rapid drying conditions); and
C Non-refractory may be rapidly seasoned free from surface and end-cracking even in the open air and sun. If not rapidly dried, they develop blue stain and mould on the surface.

[4] Species thus marked and tested from other localities show higher strength to enable their categorization in higher group.

For Example:

i) Sal tested from West Bengal, Bihar, Uttar Pradesh and Assam can be classified as Group `A' species.
ii) Haldu tested from Bihar can be classified as Group `B' species.
iii) Morus laevigate (Bole) of Assam can be classified in Group `B' species.

4.1.1 *Grouping*

Species of timber recommended for constructional purposes are classified in three groups on the basis of their strength properties, namely, modulus of elasticity (E) and extreme fibre stress in bending-tension (f_b).

The characteristics of these groups are as given below:

a) *Group A* — E above 12.6 kN/mm^2 and f_b above 18.0 N/mm^2.

b) *Group B* — E above 9.8 kN/mm^2 and up to 12.6 kN/mm^2 and f_b above 12.0 N/mm^2 and up to 18.0 N/mm^2.

c) *Group C* — E above 5.6 kN/mm^2 and up to 9.8 kN/mm^2 and f_b above 8.5 N/mm^2 and up to 12.0 N/mm^2.

NOTE — Modulus of elasticity given above is applicable for all locations and extreme fibre stress in bending is for inside location.

4.1.2 Timber species may be identified in accordance with good practice [C-3A(3)].

4.2 The general characteristics like durability, treatability and seasoning of the species are also given in Table 1. Species of timber other than those recommended in Table 1 may be used, provided the basic strength properties are determined and found in accordance with **4.1.1**.

NOTE — For obtaining basic stress figures of the unlisted species, reference may be made to the Forest Research Institute, Dehradun.

4.3 The permissible lateral strength (in double shear) of mild steel common wire nail shall be as given in Table 2 and Table 3 for different species of timber.

4.4 Moisture Content in Timber

The permissible moisture content of timber for various positions in buildings shall be as given in Table 4.

Table 2 Permissible Lateral Strengths (in Double Shear) of Nails 3.55 mm Dia (9 SWG), 80 mm Long

(*Clauses* 4.3, 7.8.2 *and* 8.3.2)

Sl No.	**Species of Wood**		**For Permanent Construction Strength per Nail**		**For Temporary Structures Strength per Nail (for Both Lengthening Joints and Node Joints)**
	Botanical Name	Trade Name	Lengthening Joints	Node Joints	
			N × 10^2	N × 10^2	N × 10^2
(1)	(2)	(3)	(4)	(5)	(6)
i)	*Albies pirdrow*	Fir	8	2	12
ii)	*Acacia catecha*	Khair	20	17.5	37.0
iii)	*Acacia nilotica*	Babul	15	11	32.5
iv)	*Acrocarpus fraxinifolius*	Mundani	18	9.5	19.5
v)	*Adina cordifolia*	Haldu	23.5	10	22
vi)	*Albizia lebbeck*	Kokko	20	7	24
vii)	*Albizia odoratissima*	Kala siris	14	5	22
viii)	*Anogeissus latifolia*	Axlewood	20	10	29
ix)	*Aphanamixis polystachya*	Pithraj	19	9	19

Table 2 (*Continued*)

Sl No.	Species of Wood		For Permanent Construction Strength per Nail		For Temporary Structures Strength per Nail (for Both Lengthening Joints and Node Joints)
	Botanical Name	Trade Name	Lengthening Joints	Node Joints	
			N × 10^2	N × 10^2	N × 10^2
(1)	(2)	(3)	(4)	(5)	(6)
x)	*Azadiratchta indica*	Neem	22	11.5	19
xi)	*Balanocarpus utilis*	Karung	17.5	21	32
xii)	*Bischofia javnica*	Uriam	13	6.5	18
xiii)	*Betula alnoides*	Birch	13	12	22.5
xiv)	*Boswellia serrata*	Salai	12	5	14.5
xv)	*Calophyllum spp.*	Poon	16	9	21
xvi)	*Canarium euphyllum*	White dhup	9	8	10.5
xvii)	*Castanopsis hystrix*	Indian chestnut	18	10.5	23.5
xviii)	*Cedrus deodara*	Deodar	9	4	15
xix)	*Chukrasia tabularis*	Chikrassy	24	8	27
xx)	*Cinnamomum spp.*	Cinnomon	12	9	13
xxi)	*Cullenia rosaana* (*Syn. Cullenia excalsa*)	Karani	11.5	5	19
xxii)	*Cupressus torulosa*	Cypress	6	5	18
xxiii)	*Dalbergia latifohia*	Rosewood	19	8.5	23
xxiv)	*Dalberia sissoo*	Sissoo	14.5	7.5	19
xxv)	*Dipterocarpus macrocarpus*	Hollong	17	7	20
xxvi)	*Dipterocarpus spp.*	Gurjan	19	9	19.5
xxvii)	*Dillenia pertagyna*	Dillenia	16.5	12	16
xxviii)	*Diospyros melanoxylon*	Ebony	26.5	10	30.5
xxix)	*Duabanga grandiflora*	Lampati	15	5	12
xxx)	*Dysoxylum binectariferum*	White Cedar	7.5	5	14.5
xxxi)	*Eucalyptus eugenioides*	Eucalyptus	17	10	30
xxxii)	*Garuga pinnata*	Garuga	11.0	7.5	21.0
xxxiii)	*Gmelina arborea*	Gaman	8	4	9.5
xxxiv)	*Grerillea robusta*	Silver oak	12.0	7.0	10.5
xxxv)	*Grewia tilifolia*	Dhaman	13	5	24
xxxvi)	*Lagerstroemia spp.*	Jarul	24.5	21.5	22.5

Table 2 (*Continued*)

Sl No.	**Species of Wood**		**For Permanent Construction Strength per Nail**		**For Temporary Structures Strength per Nail (for Both Lengthening Joints and Node Joints)**
	Botanical Name	Trade Name	Lengthening Joints	Node Joints	
			N × 10^2	N × 10^2	N × 10^2
(1)	(2)	(3)	(4)	(5)	(6)
xxxvii)	*Holoptelea integrifolia*	Kanju	12.5	9.5	20.5
xxxviii)	*Hopea parviflora*	Hopea	31.5	13	28.5
xxxix)	*Lagerstroemia spp.*	Lendi	19	5	26
xl)	*Madhuka Logifera* (*Syn. Barfia Latifolia*)	Mahua	23	7.5	26
xli)	*Mangifera indica*	Mango	11	9	16
xlii)	*Maniltoa polyandra*	Ping	26	23.5	32
xliii)	*Mesua ferrea*	Mesua	26	8	41
xliv)	*Michelia spp.*	Champ	13	9	20
xlv)	*Millingtonia spp.*	Phulsopa	10.5	6	17
xlvi)	*Morus alba*	Mulberry	13	10.5	22.5
xlvii)	*Melia azedarach*	Persian lilac (bakain)	10.5	2.5	10.5
xlviii)	*Morus alba*	Mulberry	13	10.5	22.5
xlix)	*Ougeinia oojeinensis*	Sandan	17	11	18
l)	*Phoebe spp.*	Bonsum	12	6	13
li)	*Pinus roxburghii*	Chir	11	10	16
lii)	*Pinus wallichiana*	Kail	7	3	9
liii)	*Planchonia andamanica*	Red bombwe	14	13	29
liv)	*Planchonia valida* (*Syn. P. andamonica*)	Red bombwe	14.5	13	29.5
lv)	*Poeciloneuron indicum*	Ballagi	16	7	15.5
lvi)	*Populus deltoides*	Poplar	16	11.5	17.5
lvii)	*Protium serratum* (*Syn. Burserra Serrata*) A. P.	–	25.5	7.0	22.5
lviii)	*Pterocarpus marsupium*	Bijasal	15	12	27
lix)	*Pterocarpus dalbergiodes*	Pauduak	19	14	23
lx)	*Quercus spp.*	Oak (Assam)	21	10	37.5

Table 2 (*Concluded*)

Sl No.	Species of Wood		For Permanent Construction Strength per Nail		For Temporary Structures Strength per Nail (for Both Lengthening Joints and Node Joints)
	Botanical Name	Trade Name	Lengthening Joints	Node Joints	
			N × 10^2	N × 10^2	N × 10^2
(1)	(2)	(3)	(4)	(5)	(6)
lxi)	*Quercus spp.*	Oak (Uttar Pradesh)	11	10.5	26.5
lxii)	*Scheichera cleosa*	Kusum	23	16	39.5
lxiii)	*Schima wallachi*	Chillauni	19.5	9.5	25.5
lxiv)	*Shorea assamica*	Makai	12.5	7.5	15.0
lxv)	*Shorea robusta*	Sal (Madhya Pradesh)	23	15.5	19.5
lxvi)	*Shorea robusta*	Sal (Uttar Pradesh)	10	5	19
lxvii)	*Stereospenmum chelonoides*	Padriwood	16	8	19.5
lxviii)	*Syzygium spp.*	Jamum	15	12	25
lxix)	*Tectona grandis*	Teak	14	8	13
lxx)	*Terminalia alata*	Sain	16	16	29
lxxi)	*Terminalia arjuna*	Arjun	8.5	7	16.5
lxxii)	*Terminalia bellirica*	Bahera	10	10	14
lxxiii)	*Terminalia biolata*	White chuglam	18	9	21
lxxiv)	*Terminalia chebula*	Myrobalan	16.5	5.5	22.5
lxxv)	*Terminalia procera*	Badam	18	10.5	20
lxxvi)	*Terminalia manii*	Black chuglam	23	10	33
lxxvii)	*Terminalia myriocarpa*	Hollock	13	10	19.5
lxxviii)	*Toona spp.*	Toona	10	8	21
lxxix)	*Xylia xylacarpa*	Irul	23	6	33
lxxx)	*Toona ciliata*	Toon	16	9	21

NOTES

1 Nails of 3.55 mm (9 SWG) diameter are most commonly used. The above values can also be used for 4 mm (8 SWG) diameter 100 mm long nails.

2 The values in Newton (N) are approximate converted values from kgf. For exact conversion the value is 1 kgf = 9.806 65 N.

3 Preboring of nail-jointed timber construction is desirable and shall be done in accordance with good practice as in, **6.2.2** and Table 3 of [C-3A(7)].

Table 3 Permissible Lateral Strengths (In Double Shear) of Nails 5.00 mm Dia (6 SWG), 125 mm and 150 mm Long

(*Clauses* 4.3, 7.8.2 *and* 8.3.2)

Sl No.	**Species of Wood**		**For Permanent Construction Strength per Nail**		**For Temporary Structures Strength per Nail (for Both Lengthening Joints and Node Joints)**
	Botanical Name	Trade Name	Lengthening Joints $N \times 10^2$	Node Joints $N \times 10^2$	$N \times 10^2$
(1)	(2)	(3)	(4)	(5)	(6)
i)	*Abies pindrow*	Fir	16.5	4.5	21
ii)	*Acacia catechu*	Khair	42	25	71.5
iii)	*Acacia nilotica*	Babul	27	13.5	53
iv)	*Alibizia procera*	Safed siris	35	18	-
v)	*Alibizia odoratissima*	Kala siris	27.5	17.5	45
vi)	*Alstonia scholaris*	Chatian	9.5	5.5	27
vii)	*Anogeissus latifolia*	Axlewood	22.5	13	46.5
viii)	*Azadirachata indica*	Neem	23.5	16	47
ix)	*Cupressus torulosa*	Cypress	20	7	27
x)	*Cullenia rosayroana*	Karani	11	9.5	30
xi)	*Dalbergia sissoo*	Sissoo	17	15	43
xii)	*Diptrocarous spp.*	Gurjan	19.5	9.5	33
xiii)	*Eucalyptus Prob. E. Tereticornis*	–	37.5	28.5	47
xiv)	*Hardwickia binata*	Anjan	32	19	59
xv)	*Hopea perviflora*	Hopea	60.5	25	61.5
xvi)	*Holoptelea integrifolia*	kanju	18	12.5	37.5
xvii)	*Mangifera indica*	Mango	22.5	15	32
xviii)	*Mesua ferrea*	Mesua	24	15.5	57.5
xix)	*Michelia champaca*	Champ	26	12.5	39
xx)	*Pterocarpus marsupium*	Bijasal	20.5	15	43
xxi)	*Pinus roxburghii*	Chir	9	6	24
xxii)	*Shorea robusta* (Uttar Pradesh)	Sal	19.5	17	37
xxiii)	*Shorea robusta*	Sal	30.5	20	41
xxiv)	*Schleichera cleosa*	Kusum	15	14	55
xxv)	*Stereospimum personatum*	Padriwood	22	8	34
xxvi)	*Syzygium cumini*	Jamum	18	14.5	38.5
xxvii)	*Terminalia myriocarpa*	Hollock	27.5	9	41
xxviii)	*Tectona grandis*	Teak	28	13	30
xxix)	*Toona ciliata*	Toon	19	7	32.5
xxx)	*Hopea utilis*	Karung kangoo	31	10	58
xxxi)	*Phoebe spp.*	Bonsum	20	7.5	30
xxxii)	*Pterocarpus dalbergiodes*	Padauk	27.4	13.4	37.7
xxxiii)	*Populus deltoides*	Poplar	21	15	38.5

NOTES

1 Nails of 5.00 mm diameter are most commonly used.

2 The values in Newton (N) are approximate converted values from kgf. For exact conversion the value is 1 kgf = 9.806 65 N.

3 Preboring of nail-jointed timber construction is desirable and shall be done in accordance with good practice as in, **6.2.2** and Table 3 of [C-3A(7)].

Table 4 Permissible Percentage Moisture Content Values

(*Clause* 4.4)

Sl No.	Use	Zones (*see* Note)			
		I	II	III	IV
(1)	(2)	(3)	(4)	(5)	(6)
i)	Structural elements	12	14	17	20
ii)	Doors and windows:				
	a) 50 mm and above in thickness	10	12	14	16
	b) Thinner than 50 mm	8	10	12	14
iii)	Flooring strips for general purposes	8	10	10	12
iv)	Flooring strips for tea gardens	12	12	14	16

NOTE — The country has been broadly divided into the following four zones based on the humidity variations in the country:

a) Zone I — Average annual relative humidity less than 40 percent;

b) Zone II — Average annual relative humidity 40 percent to 50 percent;

c) Zone III — Average annual relative humidity 50 percent to 67 percent; and

d) Zone IV — Average annual relative humidity more than 67 percent.

For detailed zonal classification in the country, tolerances, etc, reference may be made to good practice [C-3A(4)].

4.5 Sawn Timber

4.5.1 *Sizes*

Preferred cut sizes of timber for use in structural components shall be as given in Table 5, Table 6 and Table 7.

Table 5 Preferred Cut Sizes of Structural Timber for Roof Trusses (Span from 3 m to 20 m)

(*Clause* 4.5.1)

Sl No.	Thickness mm	Width mm							
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
i)	20	40	50	60	80	100	–	–	–
ii)	25	40	50	60	80	100	120	140	160
iii)	30	40	50	60	80	100	120	140	160
iv)	35	–	–	60	80	100	120	140	160
v)	40	–	–	60	80	100	120	140	160
vi)	50	–	–	60	80	100	120	140	160
vii)	60	–	–	–	80	100	120	140	160
viii)	80	–	–	–	–	100	120	140	160

NOTES

1 For truss spans marginally above 20 m, preferred cut sizes of structural timber may be allowed.

2 Preferred lengths of timber — 1 m, 1.5 m, 2 m, 2.5 m and 3 m.

Table 6 Preferred Cut Sizes of Structural Timber for Roof Purlins, Rafters, Floor Beams, etc

(*Clause* 4.5.1)

Sl No.	**Thickness** mm	**Width** mm						
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
i)	50	80	100	120	140	–	–	–
ii)	60	80	100	120	140	160	–	–
iii)	80	–	100	120	140	160	–	–
iv)	100	–	–	–	140	160	180	200

NOTE — Preferred lengths of timber — 1.5 m, 2 m, 2.5 m and 3 m.

Table 7 Preferred Cut Sizes of Structural Timber for Partition Framing and Covering and for Centering

(*Clause* 4.5.1)

Sl No.	**Thickness** mm	**Width** mm								
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
i)	10	40	50	60	80	–	–	–	–	–
ii)	15	40	50	60	80	100	–	–	–	–
iii)	20	40	50	60	80	100	120	160	200	–
iv)	25	40	50	60	80	100	120	160	200	240
v)	30	40	50	60	80	100	120	160	200	240
vi)	40	40	–	60	80	100	120	160	200	240
vii)	50	–	50	–	80	100	120	160	200	240
viii)	60	–	–	60	80	100	120	160	200	240
ix)	80	–	–	–	80	100	120	160	200	240

NOTE — Preferred lengths of timber: 0.5 m, 1 m, 1.5 m, 2 m, 2.5 m and 3 m.

4.5.2 *Tolerances*

Permissible tolerances in measurements of cut sizes of structural timber shall be as follows:

a) For width and thickness:
  1) Up to and including 100 mm : $+3\ -\ 0\ mm$
  2) Above 100 mm : $+6\ -\ 3\ mm$
b) For length : $+10\ -\ 0\ mm$

4.6 Grading of Structural Timber

4.6.1 Cut sizes of structural timber shall be graded, after seasoning, into three grades based on permissible defects given in Table 8:

a) Select grade;
b) Grade I; and
c) Grade II.

Table 8 Permissible Defects for Cut Sizes of Timber for Structural Use

(*Clauses* 4.6.1 *and* 4.6.2.2)

All dimensions in millimetres.

Sl No.	Defects	Select Grade	Grade I	Grade II
(1)	(2)	(3)	(4)	(5)
i)	Wane	Shall be permissible at its deepest portion up to a limit of 1/8 of the width of the surface on which it occurs	Shall be permissible at its deepest portion up to a limit of 1/6 of the width of the surface on which it occurs	Shall be permissible at its deepest portion up to a limit of 1/4 of the width of the surface on which it occurs
ii)	Worm holes	Other than those due to powder post beetles are permissible	Other than those due to powder post beetles are permissible	Other than those due to powder post beetles are permissible
iii)	Slope of grain	Shall not be more than 1 in 20	Shall not be more than 1 in 15	Shall not be more than 1 in 12
iv)	Live knots:			

Sl No.	*Width of Wide Faces of Cut Sizes of Timber, Max*	*Permissible Maximum Size of Live Knot on*		*Permissible Maximum Size of Live Knot on*		*Permissible Maximum Size of Live Knot on*	
		Narrow Faces and ¼ of the Width Face Close to Edges of Cut Size of Timber	Remaining Central Half of the Width of the Wide Faces	Narrow Faces and ¼ of the Width Face Close to Edges of Cut Size of Timber	The Remaining Central Half of the Width of the Wide Faces	Narrow Faces and ¼ of the Width Face Close to Edges of Cut Size of Timber	Remaining Central Half of the Width of the Wide Faces
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	75	10	10	19	19	29	30
ii)	100	13	13	25	25	38	39
iii)	150	19	19	38	38	57	57
iv)	200	22	25	44	50	66	75
v)	250	25	29	50	57	66	87
vi)	300	27	38	54	75	81	114
vii)	350	29	41	57	81	87	123
viii)	400	32	44	63	87	96	132
ix)	450	33	47	66	93	99	141
x)	500	35	50	69	100	105	150
xi)	550	36	52	72	103	108	156
xii)	600	38	53	75	106	114	159

Table 8 (*Concluded*)

v) Checks and shakes:

Sl No. (1)	*Width of the Face of the Timber Max* (2)	*Permissible Depth Max* (3)	*Permissible Depth Max* (4)	*Permissible Depth Max* (5)
i)	75	12	25	36
ii)	100	18	35	54
iii)	150	25	50	75
iv)	200	33	65	99
v)	250	40	81	120
vi)	300	50	100	150
vii)	350	57	115	171
viii)	400	66	131	198
ix)	450	76	150	225
x)	500	83	165	249
xi)	550	90	181	270
xii)	600	100	200	300

4.6.2 The prohibited defects given in **4.6.2.1** and permissible defects given in **4.6.2.2** shall apply to structural timber.

4.6.2.1 *Prohibited defects*

Loose grains, splits, compression wood in coniferous species, heartwood rot, sap rot, crookedness, worm holes made by powder post beetles and pitch pockets shall not be permitted in all the three grades.

4.6.2.2 *Permissible defects*

Defects to the extent specified in Table 8 shall be permissible.

NOTE — Wanes are permitted provided they are not combined with knots and the reduction in strength on account of the wanes is not more than the reduction with maximum allowable knots.

4.6.3 *Location of Defects*

The influence of defects in timber is different for different locations in the structural element. Therefore, these should be placed during construction in such a way so that they do not have any adverse effect on the members, in accordance with the accepted standard [C-3A(5)].

4.7 Suitability

4.7.1 *Suitability in Respect of Durability and Treatability for Permanent Structures*

There are two choices as given in **4.7.1.1** and **4.7.1.2**.

4.7.1.1 *First choice*

The species shall be any one of the following:

a) Untreated heartwood of high durability. Heartwood if containing more than 15 percent sap wood, may need chemical treatment for protection;

b) Treated heartwood of moderate and low durability and Class ‘a’ and Class ‘b’ treatability;

c) Heartwood of moderate durability and Class ‘c’ treatability after pressure impregnation; and

d) Sapwood of all classes of durability after thorough treatment with preservative.

4.7.1.2 *Second choice*

The species of timber shall be heartwood of moderate durability and Class ‘d’ treatability.

4.7.2 *Choice of Species for Load-Bearing Temporary Structures or Semi-Structural Components at Construction Site*

The species shall be any one of the following:

a) Heartwood of low durability and Class ‘e’ treatability; or

b) The species whose durability and/or treatability is yet to be established, as listed in Table 1.

4.8 Fastenings

All structural members shall be framed, anchored, tied and braced to develop the strength and rigidity necessary for the purposes for which they are used. Allowable stresses or loads on joints and fasteners shall be determined in accordance with recognized principles. Common mechanical fastenings are of bar type such as nails and spikes, wood screws and bolts, and timber connectors including metallic rings or wooden disc-dowels. Chemical fastenings include synthetic adhesives for structural applications.

NOTE — Synthetic adhesives are able to achieve for timber what welding has achieved for steel.

4.9 Requirements of Structural Timber

The various other requirements of structural timber for use in building shall be in accordance with the accepted standard [C-3A(5)].

5 PERMISSIBLE STRESSES

5.1 Fundamental stress values of different groups of timber are determined on small clear specimen according to good practices [C-3A(2)]. These values are then divided by the appropriate factors of safety to obtain the permissible stresses. Values of these factors of safety for different strength characteristics are as per the relevant table of the accepted standard [C-3A(5)].

5.2 The permissible stresses for Groups A, B and C for different locations applicable to Grade I structural timber shall be as given in Table 9 provided that the following conditions are satisfied:

a) The timbers should be of high or moderate durability and be given the suitable treatment where necessary;

b) Timber of low durability shall be used after proper preservative treatment to good practice [C-3A(6)]; and

c) The loads should be continuous and permanent and not of impact type.

5.3 The permissible stresses (excepting E) given in Table 9 shall be multiplied by the following factors to obtain the permissible stresses for other grades provided that the conditions laid down in **5.2** are satisfied:

a) For select grade timber : 1.16

b) For Grade II timber : 0.84

5.3.1 When low durability timbers are to be used [*see* **5.2(b)**] on outside locations, the permissible stresses for all grades of timber, arrived at by **5.2** and **5.3** shall be multiplied by 0.80.

5.4 Modification Factors for Permissible Stresses

5.4.1 *Due to Change in Slope of Grain*

When the timber has not been graded and has major defects like slope of grain, knots and checks or shakes but not beyond permissible value, the permissible stress given in Table 1 shall be multiplied by modification factor K_1 for different slopes of grain as given in Table 10.

Table 9 Minimum Permissible Stress Limits (in N/mm^2) in Three Groups of Structural Timbers (For Grade I Material)

(*Clauses* 5.2 *and* 5.3)

Sl No. (1)	Strength Character (2)	Location of Use (3)	Group A (4)	Group B (5)	Group C (6)
i)	Bending and tension along grain	Inside[1]	18.0	12.0	8.5
ii)	Shear[2]:				
	a) Horizontal	All locations	1.05	0.64	0.49
	b) Along grain	All locations	1.5	0.91	0.70
iii)	Compression parallel to grain	Inside[1]	11.7	7.8	4.9
iv)	Compression perpendicular to grain	Inside[1]	4.0	2.5	1.1
v)	Modulus of elasticity ($\times 10^3$ N/mm^2)	All locations and grade	12.6	9.8	5.6

Table 10 Modifications Factor K_1 to Allow for Change in Slope of Grain

(*Clause* 5.4.1)

Sl No.	Slope	Modification Factor K_1	
		Strength of Beams, Joists and Ties	Strength of Posts or Columns
(1)	(2)	(3)	(4)
i)	1 in 10	0.80	0.74
ii)	1 in 12	0.90	0.82
iii)	1 in 14	0.98	0.87
iv)	1 in 15 and flatter	1.00	1.00

NOTE — For intermediary slopes of grains, values of modification factor may be obtained by interpolation.

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[1] For working stresses for other locations of use, that is, outside and wet, generally factors of 5/6 and 2/3 are applied.

[2] The values of horizontal shear to be used only for beams. In all other cases shear along grain to be used.

5.4.2 *Due to Duration of Load*

For different durations of design load, the permissible stresses given in Table 1 shall be multiplied by the modification factor K_2 given in Table 11.

NOTE — The strength properties of timber under load are time-dependent.

Table 11 Modification Factor K_2, for Change in Duration of Loading

(*Clause* 5.4.2)

Sl No. (1)	**Duration of Loading** (2)	**Modification Factor K_2** (3)
i)	Continuous (normal)	1.0
ii)	Two months	1.15
iii)	Seven days	1.25
iv)	Wind and earthquake	1.33
v)	Instantaneous or impact	2.00

5.4.2.1 The factor K_2 is applicable to modulus of elasticity when used to design timber columns, otherwise they do not apply thereto.

5.4.2.2 If there are several duration of loads (in addition to the continuous) to be considered, the modification factor shall be based on the shortest duration load in the combination, that is, the one yielding the largest increase in the permissible stresses, provided the designed section is found adequate for a combination of other larger duration loads.

NOTE — In any structural timber design for dead loads, snow loads and wind or earthquake loads, members may be designed on the basis of total of stresses due to dead, snow and wind loads using modification factor $K_2 = 1.33$ for the permissible stresses (*see* Table 1) to accommodate the wind load, that is, the shortest of duration and giving the largest increase in the permissible stresses. The section thus found is checked to meet the requirements based on dead loads alone with modification factor $K_2 = 1.00$.

5.4.2.3 Modification factor K_2 shall also be applied to allowable loads for mechanical fasteners in design of joints, when the wood and not the strength of metal determines the load capacity.

6 DESIGN CONSIDERATIONS

6.1 All structural members, assemblies or framework in a building, in combination with the floors, walls and other structural parts of the building shall be capable of sustaining, with due stability and stiffness the whole dead and imposed loadings as per Part C 'Structural Design, Section 1 Loads and Load Effects' of this NBCS, without exceeding the limits of relevant stresses specified in this Subsection.

6.2 Buildings shall be designed for all dead and imposed loads or forces assumed to come upon them during construction or use, including uplifts or horizontal forces from wind and forces from earthquakes or other loadings. Structural members and their connections shall be proportioned to provide a sound and stable structure with adequate strength and stiffness. Wooden components in construction generally include panels for sheathing and diaphragms, siding, beams, girder, columns, light framings, masonry wall and joist construction, heavy-frames, glued laminated structural members, structural sandwiches, prefabricated panels, lamella arches, portal frames and other auxiliary constructions.

6.3 Net Section

6.3.1 The net section is obtained by deducting from the gross sectional area of timber the projected area of all material removed by boring, grooving or other means at critical plane. In case of nailing, the area of the prebored hole shall not be taken into account for this purpose.

6.3.2 The net section used in calculating load carrying capacity of a member shall be at least net section determined as above by passing an imaginary plane or a series of connected planes transversely through the members.

6.3.3 Notches shall be in no case remove more than one quarter of the section.

6.3.4 In the design of an intermediate or a long column, gross section shall be used in calculating load carrying capacity of the column.

6.4 Loads

6.4.1 The loads shall conform to those given in Part C ‘Structural Design, Section 1 Loads and Load Effects’ of this NBCS.

6.4.2 The worst combination and location of loads shall be considered for design. Wind and seismic forces shall not be considered to act simultaneously.

6.5 Flexural Members

6.5.1 Such structural members shall be investigated for the following:

a) Bending strength;
b) Maximum horizontal shear;
c) Stress at the bearings; and
d) Deflection.

6.5.2 *Effective Span*

The effective span of beams and other flexural members shall be taken as the distance from face of supports plus one-half of the required length of bearing at each end except that for continuous beams and joists the span may be measured from centre of bearing at those supports over which the beam is continuous.

6.5.3 Usual formula for flexural strength shall apply in design:

$$f_{ab} = \frac{M}{Z} \leq f_b$$

6.5.4 *Form Factors for Flexural Members*

The following form factors shall be applied to the bending stress:

a) *Rectangular section* — For rectangular sections, for different depths of beams, the form factor K_3 shall be taken as:

$$K_3 = 0.81\left(\frac{D^2 + 89\,400}{D^2 + 55\,000}\right)$$

NOTE — Form factor (K_3) shall not be applied for beams having depth less than or equal to 300 mm.

b) *Box beams and I-beams* — For box beams and I-beams the form factor K_4 shall be obtained by using the formula:

$$K_4 = 0.8 + 0.8y\left(\frac{D^2 + 89\,400}{D^2 + 55\,000} - 1\right)$$

where

$$y = {p_1}^2\,(6 - 8p_1 + 3{p_1}^2)(1 - q_1) + q_1$$

c) *Solid circular cross sections* — For solid circular cross sections the form factor K_5 shall be taken as 1.18; and

d) *Square cross sections* — For square cross sections where the load is in the direction of diagonal, the form factor K_6 shall be taken as 1.414.

6.5.5 *Width*

The minimum width of the beam or any flexural member shall not be less than 50 mm or 1/50 of the span, whichever is greater.

6.5.6 *Depth*

The depth of beam or any flexural member shall not be taken more than three times of its width without lateral stiffening.

6.5.6.1 *Stiffening*

All flexural members having a depth exceeding three times its width or a span exceeding 50 times its width or both shall be laterally restrained from twisting or buckling and the distance between such restraints shall not exceed 50 times its width.

6.5.7 *Shear*

6.5.7.1 The following formulae shall apply:

a) The maximum horizontal shear, when the load on a beam moves from the support towards the centre of the span, and the load is at a distance of three to four times the depth of the beam from the support, shall be calculated from the following general formula:

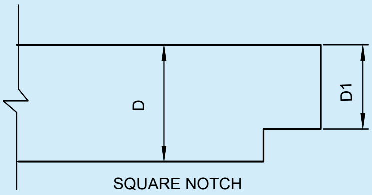
$$H = \frac{VQ}{Ib}$$

b) For rectangular beams:

$$H = \frac{3V}{2bD}$$

c) For notched beams, with tension notch at supports (*see* 6.5.7.3):

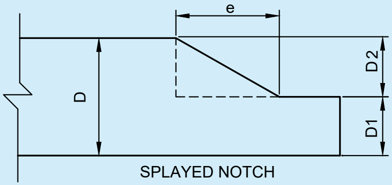
$$H = \frac{3VD}{2b{D_1}^2}$$



SQUARE NOTCH
(BOTTOM SIDE
NOTCHED)

d) For notched at upper (compression) face, where e > D:

$$H = \frac{3VD}{2bD_1}$$



SPLAYED NOTCH
(UPPER SIDE
NOTCHED)

e) For notched at upper (compression) face, where e < D:

$$H = \frac{3V}{2b\left[D - \left(\frac{D_2}{D}\right)e\right]}$$

6.5.7.2 For concentrated loads:

$$V = \frac{10C(l-x)(x/D)^2}{9l[2+(x/D)^2]} \quad and$$

For uniformly distributed loads:

$$V = \frac{W}{2}\left(1 - \frac{2D}{l}\right)$$

After arriving at the value of *V*, its value shall be substituted in the formula:

$$H = \frac{VQ}{Ib}$$

6.5.7.3 In determining the vertical reaction *V*, the following deductions in loads may be made:

a) Consideration shall be given to the possible distribution of load to adjacent parallel beams, if any;

b) All uniformly distributed loads within a distance equal to the depth of the beam from the edge of the nearest support may be neglected except in case of beam hanging downwards from a particular support; and

c) All concentrated loads in the vicinity of the supports may be reduced by the reduction factor applicable according to Table 12.

Table 12 Reduction Factor for Concentrated Loads in the Vicinity of Supports

[*Clause* 6.5.7.3(c)]

Sl No. (1)	**Distance of Load from the Nearest Support** (2)	**1.5 D or Less** (3)	**2 D** (4)	**2.5 D** (5)	**3 D or More** (6)
i)	Reduction factor	0.60	0.40	0.20	No reduction

NOTE — For intermediate distances, factor may be obtained by linear interpolation.

6.5.7.4 Unless the local stress is calculated and found to be within the permissible stress, flexural member shall not be cut, notched or bored except as follows:

a) Notches may be cut in the top or bottom neither deeper than one-fifth of the depth of the beam nor farther from the edge of the support than one-sixth of the span;

b) Holes not larger in diameter than one quarter of the depth may be bored in the middle third of the depth and length; and

c) If holes or notches occur at a distance greater than three times the depth of the member from the edge of the nearest support, the net remaining depth shall be used in determining the bending strength (*see* Fig. 1):

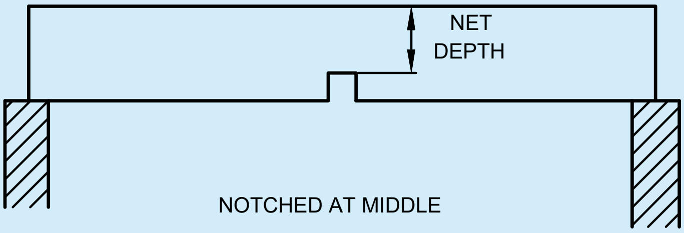


FIG. 1 NOTCHED BEAMS

6.5.8 *Bearing*

6.5.8.1 The ends of flexural members shall be supported in recesses which provide adequate ventilation to prevent dry rot and shall not be enclosed. Flexural members except roof timbers which are supported directly on masonry or concrete shall have a length of bearing of not less than 75 mm. Members supported on corbels, offsets and roof timbers on a wall shall bear immediately on and be fixed to wall-plate not less than 75 mm × 40 mm.

6.5.8.2 Timber joists or floor planks shall not be supported on the top flange of steel beams unless the bearing stress, calculated on the net bearing as shaped to fit the beam, is less than the permissible compressive stress perpendicular to the grain.

6.5.8.3 *Bearing stress*

6.5.8.3.1 *Length and position of bearing*

a) At any bearing on the side grain of timber, the permissible stress in compression perpendicular to the grain, f_{cn}, is dependent on the length and position of the bearing.

b) The permissible stresses given in Table 1 for compression perpendicular to the grain are also the permissible stresses for any length at the ends of a member and for bearings 150 mm or more in length at any other position.

c) For bearings less than 150 mm in length located 75 mm or more from the end of a member as shown in Fig. 2, the permissible stress may be multiplied by the modification factor K_7 given in Table 13.

d) No allowance need be made for the difference in intensity of the bearing stress due to bending of a beam.

e) The bearing area should be calculated as the net area after allowance for the amount of wane.

f) For bearings stress under a washer or a small plate, the same coefficient specified in Table 13 may be taken for a bearing with a length equal to the diameter of the washer or the width of the small plate.

g) When the direction of stress is at angle to the direction of the grain in any structural member, then the permissible bearing stress in that member shall be calculated by the following formula:

$$f_{c\theta} = \frac{f_{cp} \times f_{cn}}{f_{cp}\theta \ + f_{cn}\theta}$$

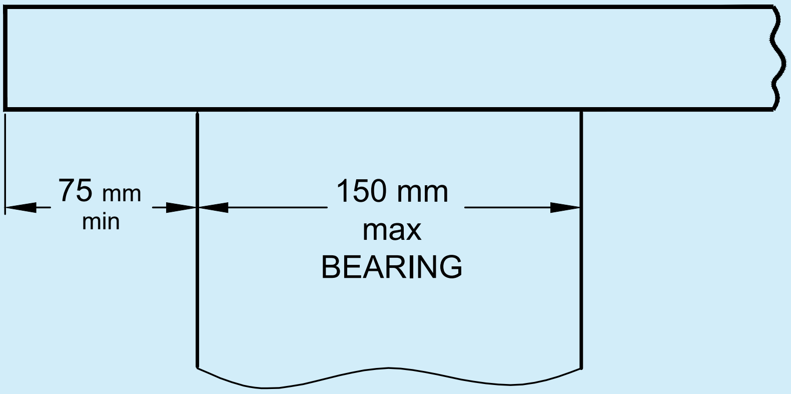


FIG 2. POSITION OF END BEARINGS

Table 13 Modification Factor K_7 for Bearing Stresses

[*Clauses* 6.5.8.3.1(c) *and* (f)]

Sl No.	Length of Bearing mm	15	25	40	50	75	100	150 or More
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
i)	Modification factor, K_7	1.67	1.40	1.25	1.20	1.13	1.10	1.00

6.5.9 Purlin is a structural member, essentially a beam subjected to transverse loads and rests on the top chord of roof truss. Being under bi-axial bending, vertical loads are resolved into two components, that is, perpendicular to and parallel to roof slopes (*see* Fig. 3). The effect of normal and tangential components of the vertical load is worked out separately and the in fibre stress in bending, shall be the algebraic sum of both.

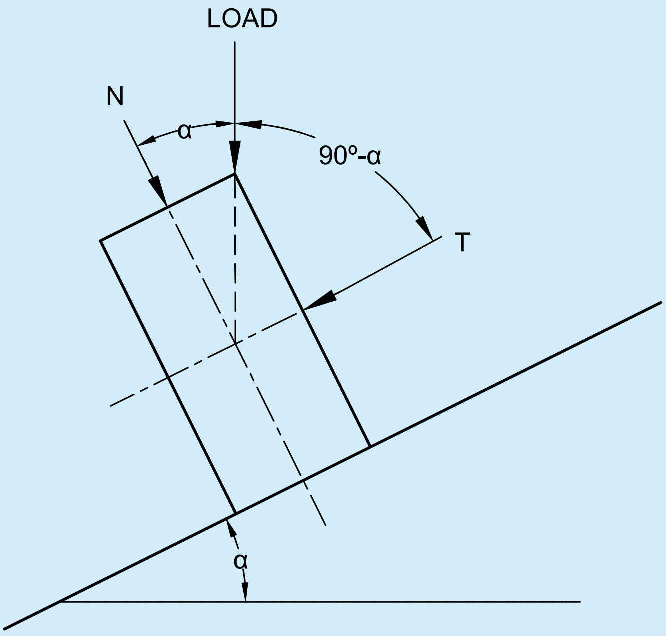


FIG. 3 PURLIN

6.5.10 *Deflection*

The deflection in the case of all flexural members supporting brittle materials like gypsum ceilings, slates, tiles and asbestos sheets shall not exceed 1/360 of the span. The deflection in the case of other flexural members shall not exceed 1/240 of the span and 1/150 of the freely hanging length in the case of cantilevers.

6.5.10.1 Usual formula for deflection shall apply*:*

$$\delta = \frac{KWL^3}{EI} \quad \text{(ignoring deflection due to shear strain)}$$

K-value = 1/3 for cantilevers with load at free end;
= 1/8 for cantilevers with uniformly distributed load;
= 1/48 for beams supported at both ends with point load at centre; and
= 5/384 for beams supported at both ends with uniformly distributed load.

6.5.10.2 In order to allow the effect of long duration loading on *E*, for checking deflection in case of beams and joists the effective loads shall be twice the dead load if timber is initially dry.

NOTE — The tendency of flexural members to acquire larger permanent deflections under long continued loadings has to be taken care of either by considering double the dead load in calculations of deflection or by giving a factor of safety to MOE.

6.5.10.3 Self weight of beam shall be considered in design.

6.6 Columns

NOTE — The formulae given are for columns with pin end conditions and the length shall be modified suitably with other end conditions.

6.6.1 *Solid Columns*

Solid columns shall be classified into short, intermediate and long columns depending upon their slenderness ratio (*S/d*) as follows:

a) *Short columns* — where *S/d* does not exceed 11;

b) *Intermediate columns* — where *S/d* is between 11 and K_8; and

c) *Long columns* — where *S/d* is greater than K_8.

6.6.1.1 For short columns, the permissible compressive stress shall be calculated as follows:

$$f_c = f_{cp}$$

6.6.1.2 For intermediate columns, the permissible compressive stress is calculated by using the following formula:

$$f_c = f_{cp}\left[1 - \frac{1}{3}\left(\frac{S}{K_8 d}\right)^4\right]$$

6.6.1.3 For long columns, the permissible compressive stress shall be calculated by using the following formula:

$$f_c = \frac{0.329E}{\left(\frac{S}{d}\right)^2}$$

6.6.1.4 In case of solid columns of timber, *S/d* ratio shall not exceed 50.

6.6.1.5 The permissible load on a column of circular cross section shall not exceed that permitted for a square column of an equivalent cross sectional area, where side of square is equal to 0.886 times the diameter.

6.6.1.6 For determining *S*/*d* ratio of a tapered column, such as for wooden poles, its least dimension shall be taken as the sum of the corresponding least dimensions at the small end of the column and one-third of the difference between this least dimension at the small end and the corresponding least dimension at the large end, but in no case shall the least dimension for the column be taken as more than one and a half times the least dimension at the small end. The induced stress at the small end of the tapered column shall not exceed the permissible compressive stress in the direction of grain.

6.6.2 *Built-up Columns*

6.6.2.1 *Box column*

Box columns shall be classified into short, intermediate and long columns as follows:

a) *Short columns* — where $\frac{S}{\sqrt{{d_1}^2+{d_2}^2}}$ is less than 8;

b) *Intermediate columns* — where $\frac{S}{\sqrt{{d_1}^2+{d_2}^2}}$ is between 8 and K_9; and

c) *Long columns* — where $\frac{S}{\sqrt{{d_1}^2+{d_2}^2}}$ is greater than K_9;

6.6.2.2 For short columns, the permissible compressive stress shall be calculated as follows:

$$f_c = q f_{cp}$$

6.6.2.3 For intermediate columns, the permissible compressive stress shall be obtained using the following formula:

$$f_c = q f_{cp}\left[1 - \frac{1}{3}\left(\frac{S}{K_9\sqrt{{d_1}^2 + {d_2}^2}}\right)^4\right]$$

6.6.2.4 For long columns, the permissible compressive stress shall be calculated by using the following formula:

$$f_c = \frac{0.329UE}{\left(\frac{S}{\sqrt{{d_1}^2 + {d_2}^2}}\right)^2}$$

6.6.2.5 The following values of *U* and *q*, depending upon plank thickness (*t*) in 6.6.2.3 and 6.6.2.4, shall be used for width of plank not greater than 5 times the plank thickness:

Sl No.	*t* mm	*U*	*q*
(1)	(2)	(3)	(4)
i)	25	0.80	1.00
ii)	50	0.60	1.00

6.6.3 *Spaced Columns*

6.6.3.1 The formulae for solid columns as specified in 6.6.1 are applicable to spaced columns with a restraint factor of 2.5 or 3, depending upon distances of end connectors in the column.

NOTE — A restrained factor of 2.5 for location of centroid group of fasteners at *S*/20 from end and 3 for location at *S*/10 to *S*/20 from end shall be taken.

6.6.3.2 For intermediate spaced column, the permissible compressive stress shall be:

$$f_c = f_{cp}\left[1 - \frac{1}{3}\left(\frac{S}{K_{10}d}\right)^4\right]$$

6.6.3.3 For long spaced columns, the permissible compressive stress shall be:

$$f_c = \frac{0.329E \times 2.5}{(S/d)^2}$$

6.6.3.4 For individual members of spaced columns, *S*/*d* ratio shall not exceed 80.

6.6.4 Compression members shall not be notched. When it is necessary to pass services through such a member, this shall be effected by means of a bored hole provided that the local stress is calculated and found to be within the permissible stress specified. The distance from the edge of the hole to the edge of the member shall not be less than one quarter of width of the face.

6.7 Tension Member (Ties)

The stress is axial tension parallel to grain of wood shall be calculated on the basis of net-section area which shall not exceed the safe permissible value in tension parallel to grain:

$$f_{at} = \frac{Maximum\ force\ prevailing}{Area\ of\ cross\ section} \leq f_t$$

6.8 Structural Members Subject to Bending and Axial Stresses

6.8.1 Structural members subjected both to bending and axial compression shall be designed to comply with the following:

$$\frac{f_{ac}}{f_c} + \frac{f_{ab}}{f_b} \text{ is not greater than 1}$$

6.8.2 Structural members subjected both to bending and axial tension shall be designed to comply with the following:

$$\frac{f_{at}}{f_t} + \frac{f_{ab}}{f_b} \text{ is not greater than 1}$$

6.9 Timber Roof Truss

Trusses are framed structures in which separate straight members are so arranged and connected at their ends that members form triangles. The external loads cause direct stresses in the members. Essentially a plane structure which is very stiff in the plane of the members but very flexible in every other direction. For members subjected to reversal of stresses, design has to be for one stress and tested for the other applied at the panel points. Eccentricity of meeting members at joint may result in the increased stresses in design.

7 DESIGN OF COMMON STEEL WIRE NAIL JOINTS

7.1 General

Nail jointed timber construction is suitable for light and medium timber framings (trusses, etc) up to 15 m spans. With the facilities of readily available materials and simpler workmanship in mono-chord and split-chord constructions, this type of fabrication has a large scope. Preboring of nail-jointed timber construction is desirable and shall be done in accordance with good practice as in, **6.2.2** and Table 3 of good practice [C-3A(7)].

7.2 Dimensions of Members

The dimension of an individual piece of timber (that is any single member) shall be within the range given below:

a) The minimum thickness of the main members in mono-chord construction shall be 30 mm;

b) The minimum thickness of an individual piece of members in split-chord construction shall be 20 mm for web members and 25 mm for chord members; and

c) The space between two adjacent pieces of timber shall be restricted to a maximum of 3 times the thickness of the individual piece of timber of the chord member. In case of web members, it may be greater for joining facilities.

7.3 No lengthening joint shall preferably be located at a panel point. Generally, not more than two, but preferably one, lengthening joint shall be permitted between the two panel points of the members.

7.4 Specification and Diameter of Nails

7.4.1 The nails used for timber joints shall conform to Part B 'Building Materials' of this NBCS. The nails shall be diamond pointed.

7.4.2 The diameter of nail shall be within the limits of one-eleventh to one-sixth of the least thickness of members being connected.

7.4.3 Where the nails are exposed to be saline conditions, common wire nails shall be galvanized.

7.5 Arrangement of Nails in the Joints

The end distances, edge distances and spacing of nails in a nailed joint should be such as to avoid undue splitting of the wood and shall not be less than those given in **7.5.1** and **7.5.2**.

7.5.1 *Lengthening Joints*

The requirement of spacing of nails in a lengthening joint shall be as given in Table 14 (*see also* Fig. 4):

Table 14 Spacing of Nails

(*Clause* 7.5.1)

Sl No.	Spacing of Nails	Type of Stress in the Joint	Requirement *Min*
(1)	(2)	(3)	(4)
i)	End distance	Tension compression	12 *n* 10 *n*
ii)	In direction of grain	Tension compression	10 *n* 5 *n*
iii)	Edge distance	–	5 *n*
iv)	Between row of nails perpendicular to the grain	–	5 *n*

NOTES

1 *n* is shank diameter of nails.

2 The 5*n* distance between rows perpendicular to the grain may be increased subject to the availability of width of the member keeping edge distance constant.

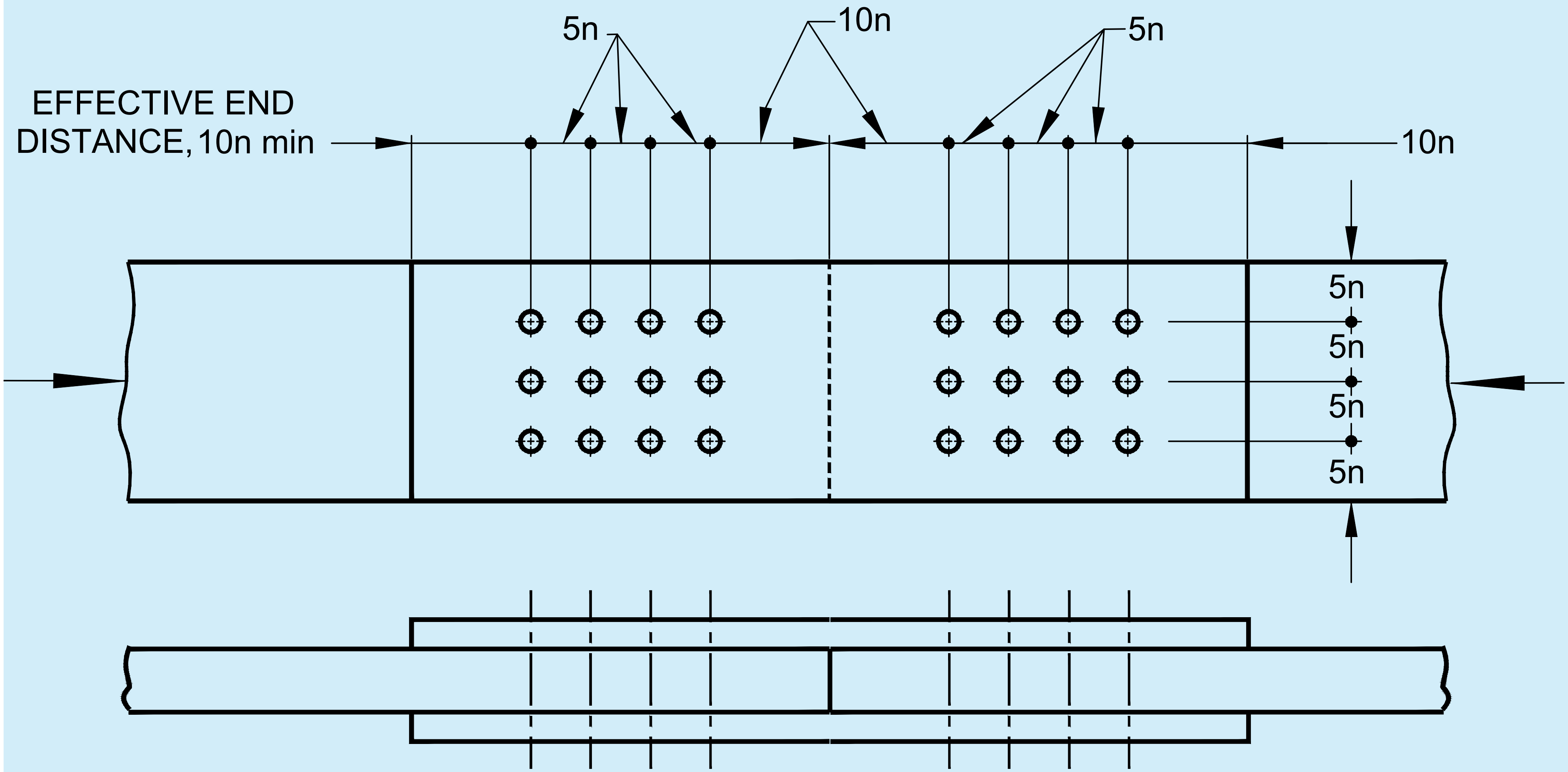
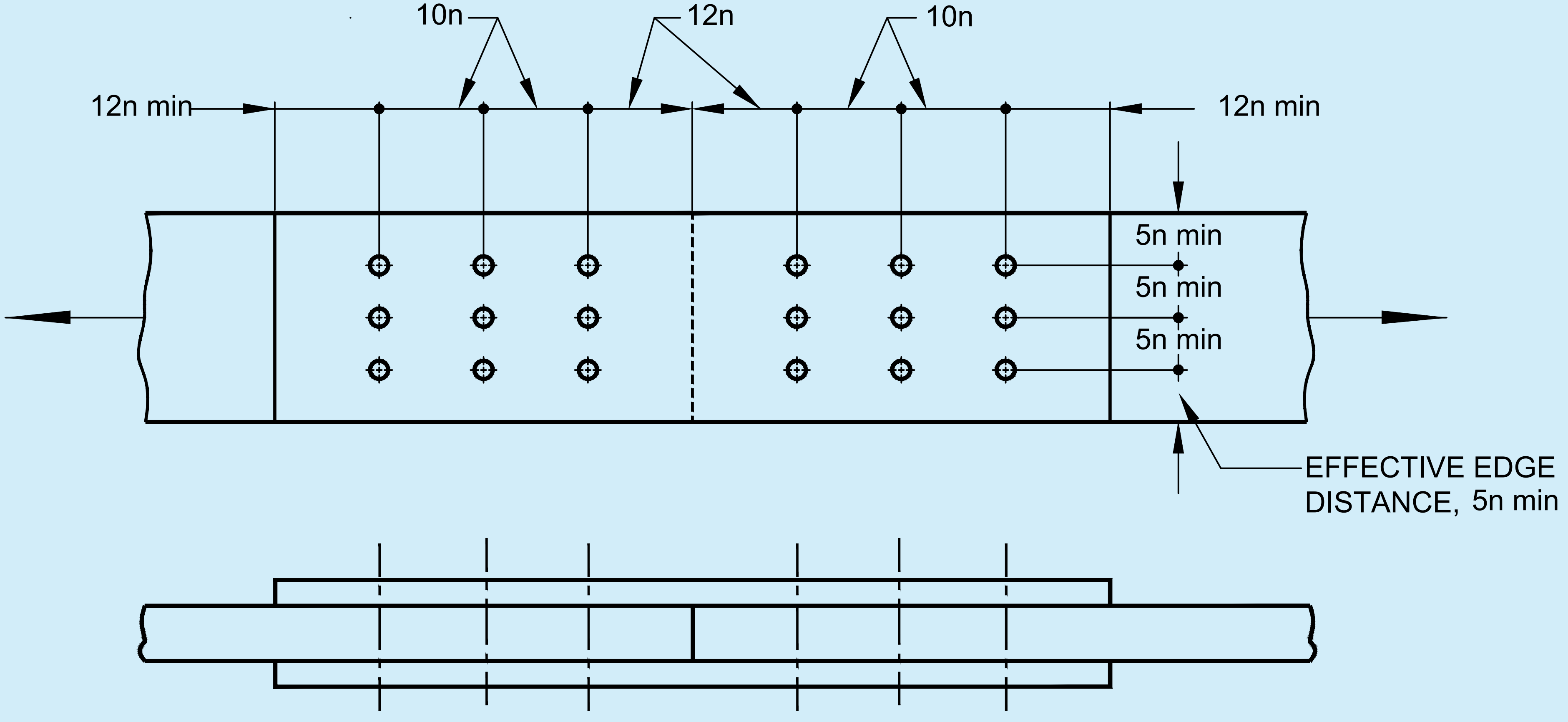

5n
10n
5n
EFFECTIVE END DISTANCE, 10n min
10n
5n
5n
5n
5n

FIG. 4A MONOCHORD TYPE BUTT JOINT SUBJECT TO COMPRESSION


10n
12n
10n
12n min
12n min
5n min
5n min
5n min
EFFECTIVE EDGE
DISTANCE, 5n min

n = SHANK DIAMETER OF NAIL

FIG. 4B MONOCHORD TYPE BUTT JOINT SUBJECT TO TENSION

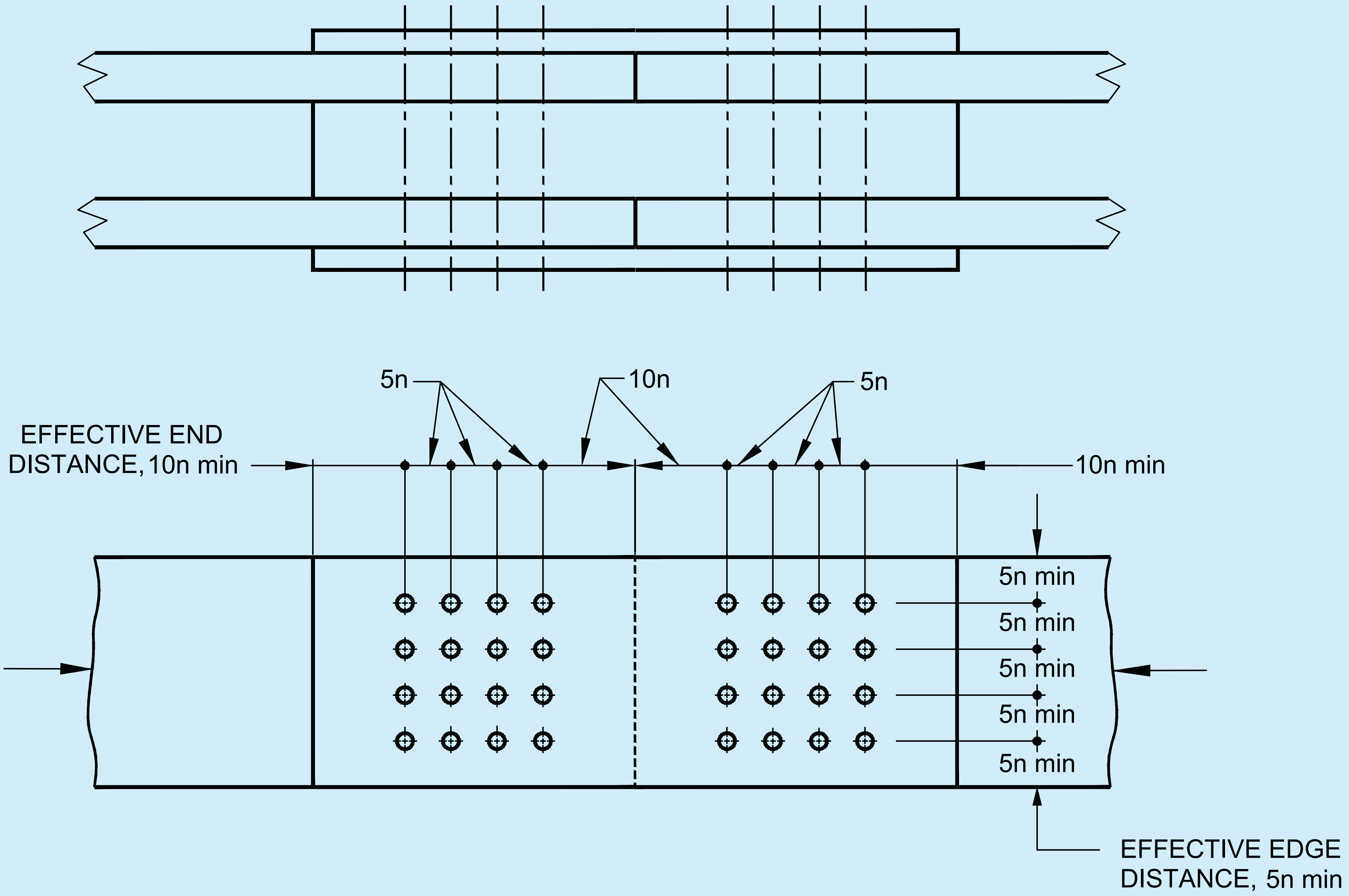

5n
10n
5n
EFFECTIVE END DISTANCE, 10n min
10n min
5n min
5n min
5n min
5n min
5n min
EFFECTIVE EDGE DISTANCE, 5n min

FIG. 4C SPLIT - CHORD TYPE BUTT JOINT SUBJECT TO COMPRESSION

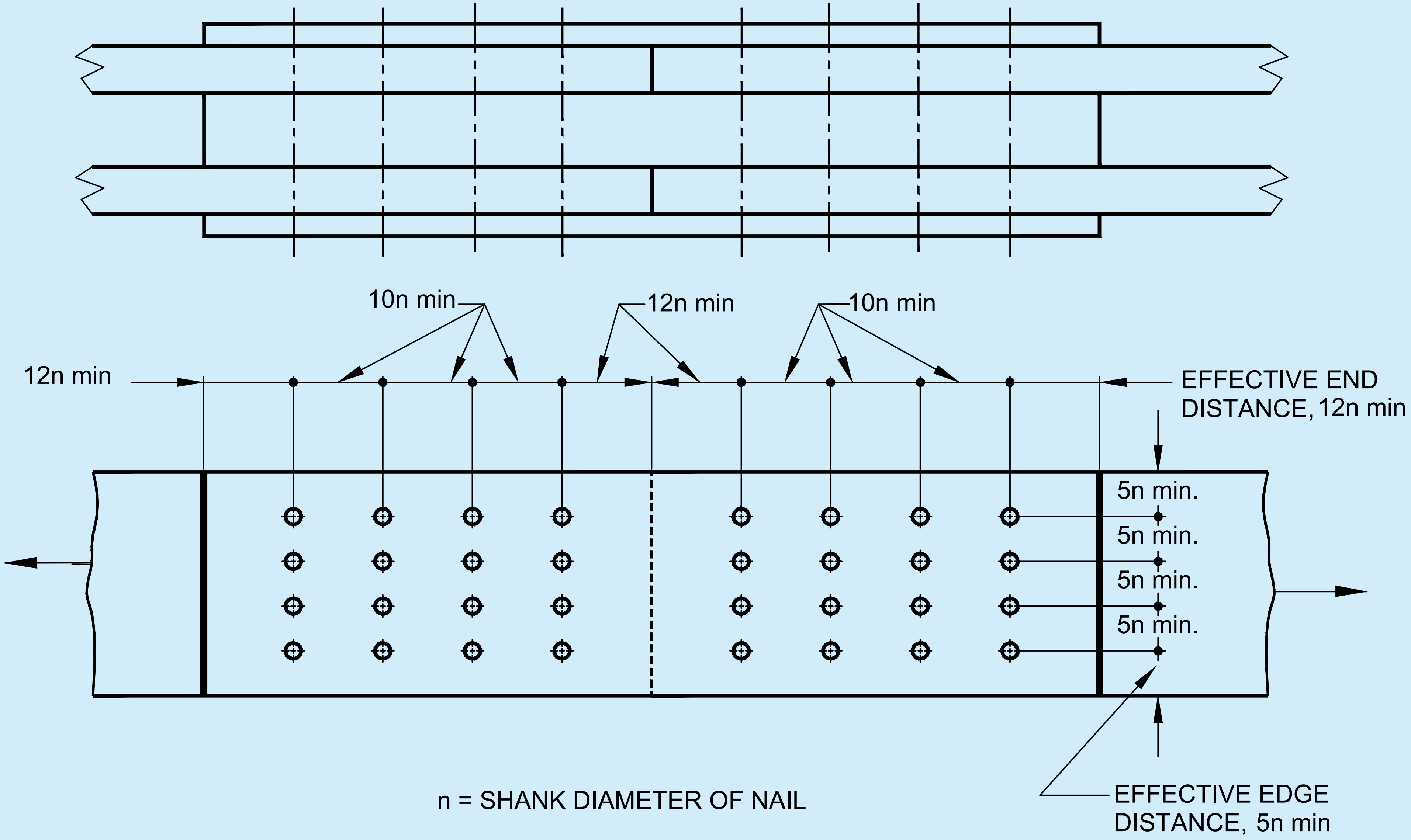
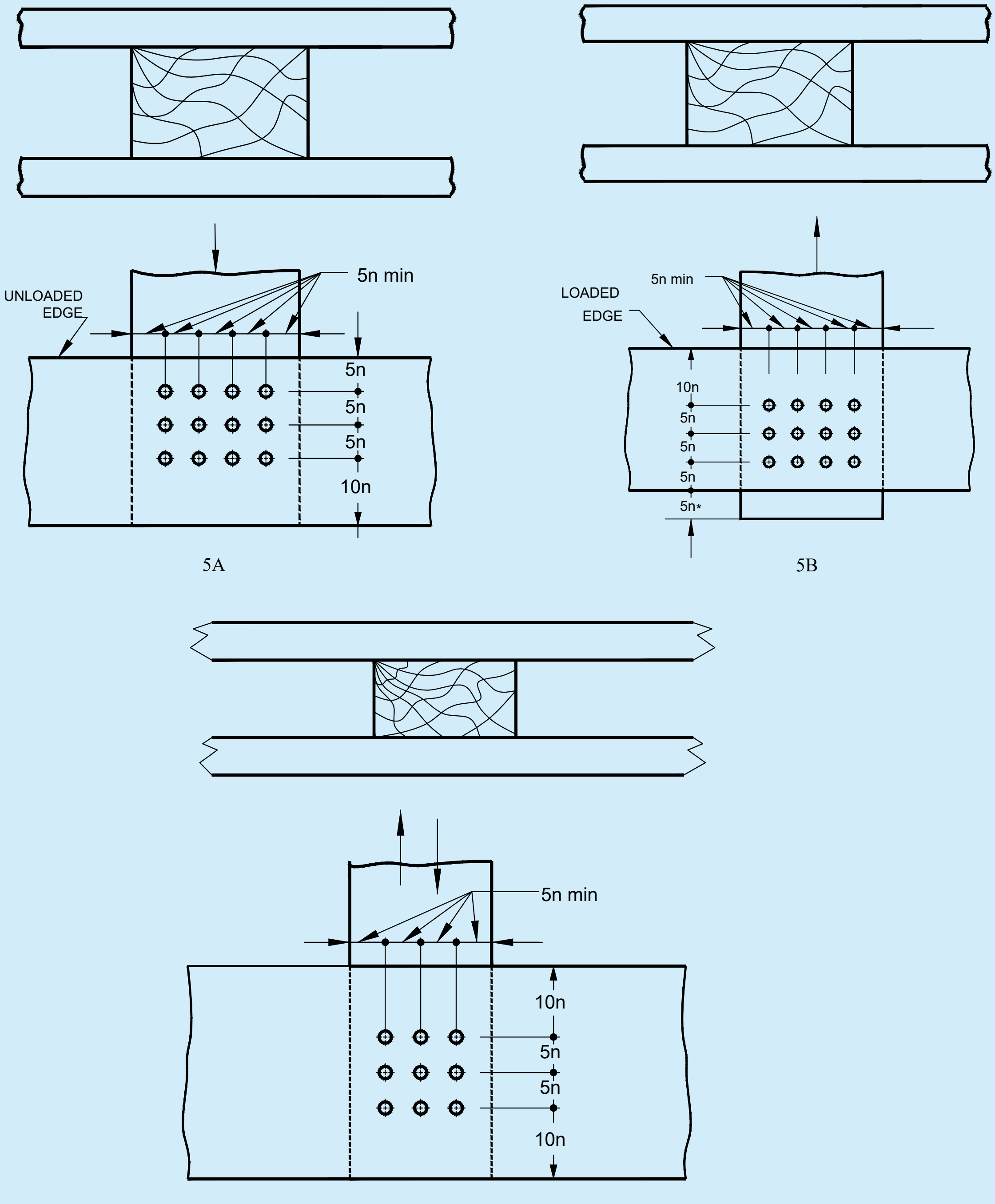

10n min
12n min
10n min
12n min
EFFECTIVE END DISTANCE, 12n min
5n min.
5n min.
5n min.
5n min.
n = SHANK DIAMETER OF NAIL
EFFECTIVE EDGE DISTANCE, 5n min

FIG. 4D SPLIT - CHORD TYPE BUTT JOINT SUBJECT TO TENSION

FIG. 4 SPACING OF NAILS IN A LENGHTHENING JOINT

7.5.2 *Node Joints*

The requirement for spacing of nails in node joints shall be as specified in Fig. 5 where the members are at right angle and as in Fig. 6 where the members are inclined to one another at angles other than 90° and subjected to either pure compression or pure tension.


UNLOADED EDGE
5n min
5n
5n
5n
10n
LOADED EDGE
5n min
10n
5n
5n
5n
5n*
5n min
10n
5n
5n
10n

5A

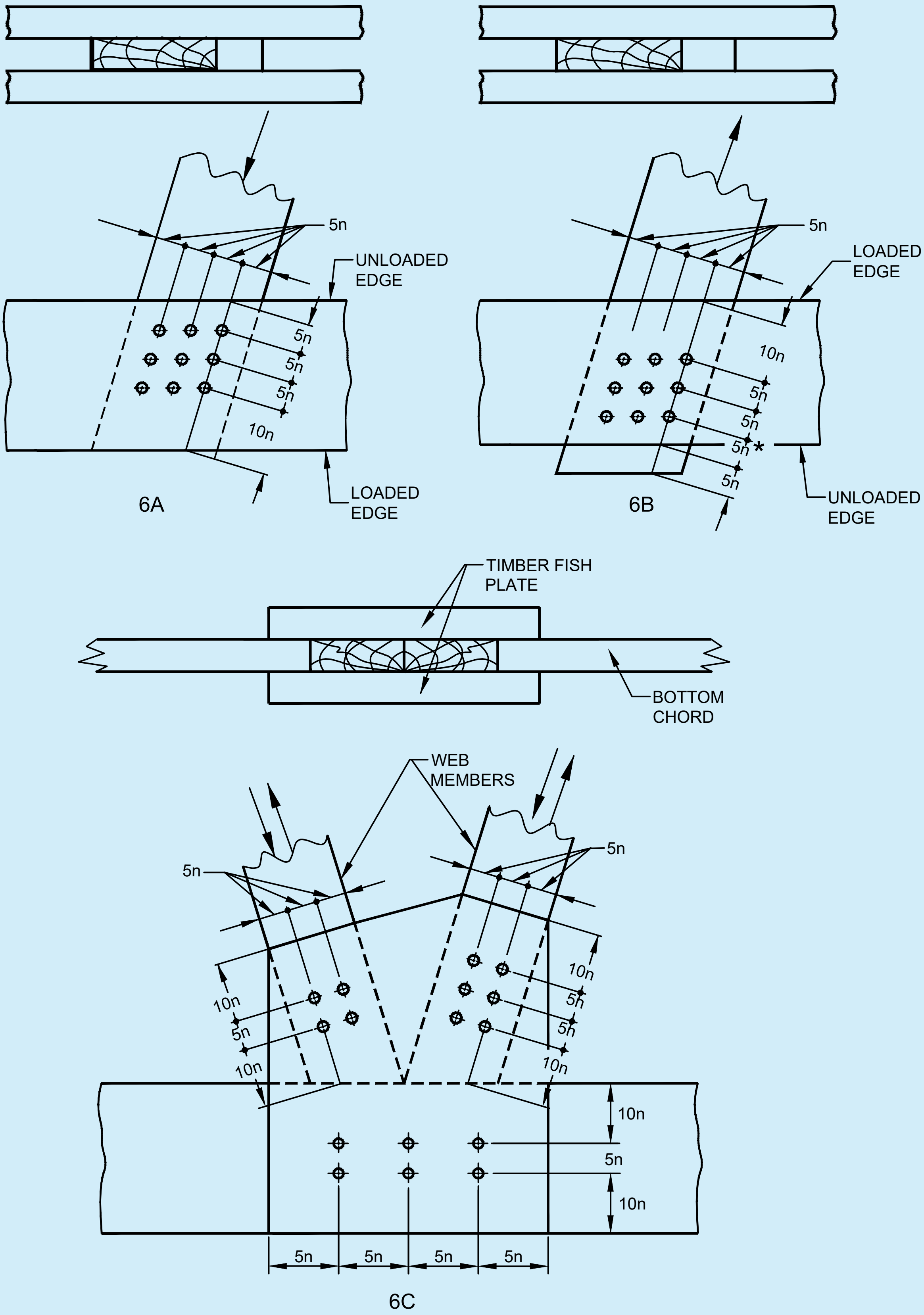
5B

n = SHANK DIAMETER OF NAIL

5C

* 5n MAY BE INCREASED TO 10n, IF THE DESIGNED WIDTH OF CHORD MEMBER PERMITS. OTHERWISE THE END OF THE LOADED WEB MEMBER MAY BE EXTENDED BY 5n min

FIG. 5 SPACING OF NAILS WHERE MEMBERS ARE AT RIGHT ANGLES TO ONE ANOTHER



5n
UNLOADED EDGE
5n
5n
5n
10n
LOADED EDGE
5n
LOADED EDGE
10n
5n
5n
5n *
5n
UNLOADED EDGE
TIMBER FISH PLATE
BOTTOM CHORD
WEB MEMBERS
5n
5n
10n
5n
10n
10n
5n
5n
10n
10n
5n
10n
5n
5n
5n
5n

6A

6B

6C

*5n MAY BE INCREASED TO 10n, IF THE DESIGNED WIDTH OF CHORD MEMBER PERMITS. OTHERWISE THE END OF THE LOADED WEB MEMBER MAY BE EXTENDED BY 5n min

n = SHANK DIAMETER OF NAIL

Fig. 6 Spacing of Nails at Node Joints where Members are Inclined to One Another

7.6 Penetration of Nails

7.6.1 For a lap joint when the nails are driven from the side of the thinner member, the length of penetration of nails in the thicker member shall be one and a half times the thickness of the thinner member subject to maximum of the thickness of the thicker member.

7.6.2 For butt joints the nails shall be driven through the entire thickness of the joint.

7.7 Design Considerations

7.7.1 Where a number of nails are used in a joint, the allowable load in lateral resistance shall be the sum of the allowable loads for the individual nails, provided that the centroid of the group of these nails lies on the axis of the member and the spacings conform to **7.5**. Where a large number of nails are to be provided at a joint, they should be so arranged that there are more of rows rather than more number of nails in a row.

7.7.2 Nails shall, as far as practicable, be arranged so that the line of force in a member passes through the centroid of the group of nails. Where this is not practicable, allowance shall be made for any eccentricity in computing the maximum load on the fixing nails as well as the loads and bending moment in the member.

7.7.3 Adjacent nails shall preferably be driven from opposite faces, that is, the nails are driven alternatively from either face of joint.

7.7.4 For a rigid joint, a minimum of 2 nails for nodal joints and 4 nails for lengthening joint shall be driven.

7.7.5 Two nails in a horizontal row are better than using the same number of nails in a vertical row.

7.7.6 The permissible lateral strength (in double shear) of mild steel common wire for different species of timber shall be as per **4.3**.

7.8 Special Consideration in Nail-Jointed Truss Construction

7.8.1 The initial upward camber provided at the centre of the lower chord of nail-jointed timber trusses shall be not less than 1/200 of the effective span for timber structures using seasoned wood and 1/100 for unseasoned or partially seasoned wood.

7.8.2 The total combined thickness of the gusset or splice plates on either side of the joint in a mono-chord type construction shall not be less than one and a half times the thickness of the main members subject to a minimum thickness of 25 mm of individual gusset plate.

NOTES

1 The allowable load or lateral strength values of nails shall be those as given in Table 2 and Table 3.

2 The strength data for joints given in the Subsection apply to gusset or splice or fish plates of solid wood; however, materials other than solid wood may be used for gusset when field tests are made and their strength requirements have been established.

7.8.3 The total combined thickness of all spacer blocks or plates or both including outer splice plates, at any joint in a split-chord type construction shall not be less than one and a half times the total thickness of all the main members at that joint.

7.9 Fabrication

The fabrication of nail-jointed timber construction shall be done in accordance with good practice [C-3A(7)].

8 DESIGN OF NAIL LAMINATED TIMBER BEAMS

8.1 Method of Arrangement

8.1.1 The beam shall be made up of 20 mm to 30 mm thick planks placed vertically with joints staggered in the adjoining planks with a minimum distance of 300 mm. The planks are laminated with the help of wire nails at regular intervals to take up horizontal shear developed in the beam besides keeping the planks in position (*see* Fig. 7).

8.1.2 The advantage in laminations lies in dimensional stability, possible dispersal of defects and better structural performance.

8.2 Sizes of Planks and Beams

8.2.1 The plank thickness for fabrication of nailed laminated beams recommended are 20 mm, 25 mm and 30 mm.

8.2.2 In case of nailed laminated timber beam the maximum depth and length of planks shall be limited to 250 mm and 2 000 mm, respectively.

8.2.3 In order to obtain the overall width of the beam, the number and thickness of planks to form vertical nailed laminated beams, and also type and size of wire nail shall be as mentioned in Table 15. The protruding portion of the nail shall be cut off or clenched across the grains.

8.3 Design Considerations

8.3.1 Nail laminated beams shall be designed in accordance with **6** and provisions in the good practice [C-3A(8)].

8.3.1.1 The deflection in the case of nailed laminated timber beams, joists, purlins, battens and other flexural members supporting brittle materials like gypsum, ceiling slates, tiles and asbestos sheets shall not exceed 1/480 of the span. The deflection in case of other flexural members shall not exceed 1/360 of the span in the case of beams and joists and 1/225 of the freely hanging length in case of cantilevers.

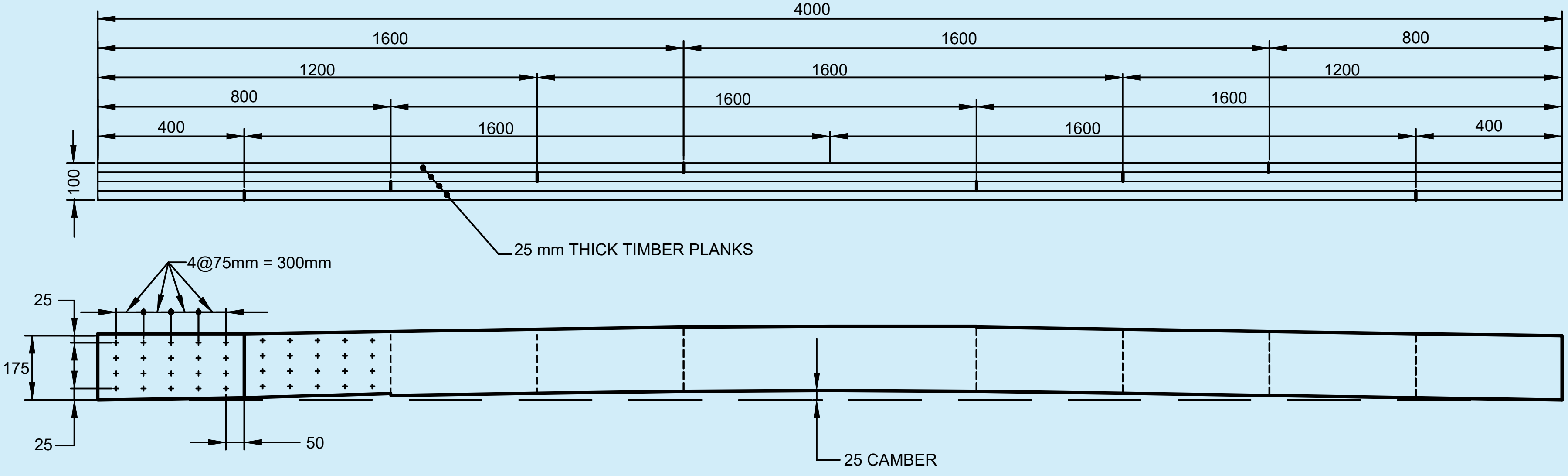
8.3.2 Permissible lateral strength of diamond pointed mild steel wire nails shall be as given in Table 2 and Table 3 for Indian species of timber, which shall apply to nails that have their points cut flush with the faces. For nails clenched across the grains the strength may be increased by 20 percent over the values for nails with points cut flush.

Table 15 Number and Size of Planks and Nails for Nailed Laminated Beams

(*Clause* 8.2.3)

Sl No. (1)	Overall Width of Beam mm (2)	No. of Planks (3)	Thickness of Each Plank mm (4)	Type and Size of Nail to be Used mm (5)
i)	50	2	25	80 long 3.55 dia
ii)	60	3	20	- do -
iii)	70	3	(2 × 25) (1 × 20)	- do -
iv)	80	4	20	100 long 4.0 dia
v)	90	3	30	- do -
vi)	100	4	25	125 long 5.0 dia
vii)	110	4	(3 × 30) (1 × 20)	- do -
viii)	120	4	30	- do -
ix)	150	5	30	150 long 5.0 dia

NOTE — A number of combinations of the different thickness of planks may be adopted as long as the minimum and maximum thickness of the planks are adhered to.


4000
1600
1600
800
1200
1600
1200
800
1600
1600
400
1600
1600
400
100
25 mm THICK TIMBER PLANKS
4@75mm = 300mm
25
175
25
50
25 CAMBER

All dimensions in millimetres.

FIG. 7 PLAN AND ELEVATION OF A TYPICAL NAILED LAMINATED TIMBER BEAM

8.3.3 *Arrangement of Nails*

8.3.3.1 A minimum number of four nails in a vertical row at regular interval not exceeding 75 mm to take up horizontal shear as well as to keep the planks in position shall be used. Near the lengthening joints of the planks this distance may, however, be limited to 50 mm instead of 75 mm.

8.3.3.2 Shear shall be calculated at various points of the beam and the number of nails required shall be accommodated within the distance equal to the depth of the beam, with a minimum of 4 nails in a row at a standard spacing as shown in Fig. 8.

8.3.3.3 If the depth of the beam is more, then the vertical intermediate spacing of nails may be increased proportionately.

8.3.3.4 If the nails required at a point are more than that can be accommodated in a row, then these shall be provided lengthwise of the beam within the distance equal to the depth of the beam at standard lengthwise spacing.

8.3.3.5 For nailed laminated beam minimum depth of 100 mm for 3.55 mm and 4 mm diameter nails and 125 mm for 5 mm diameter nails shall be provided.

8.4 Fabrication

The fabrication of nailed laminated timber beams shall be done in accordance with good practice [C-3A(8)].

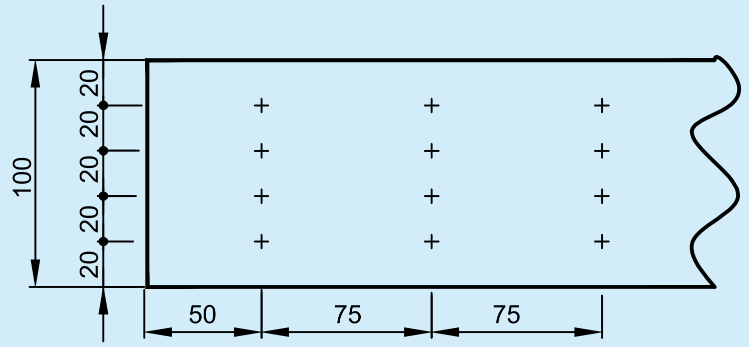


FIG. 8A FOR 3.55 mm AND 4 mm DIAMETER NAILS

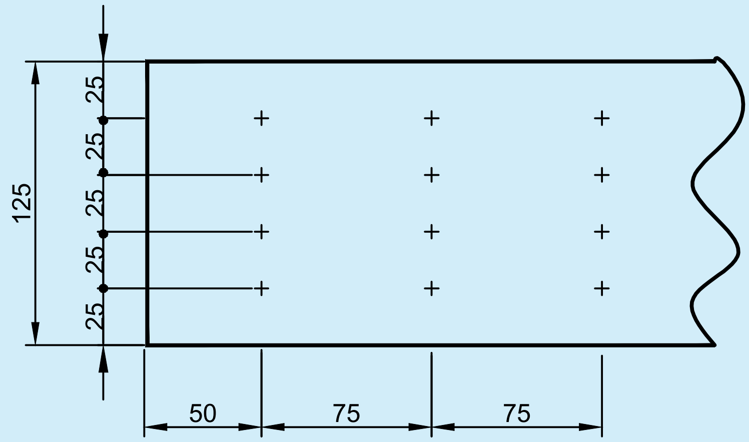


FIG. 8B FOR 5 mm DIAMETER NAILS

All dimensions in millimetres.

FIG. 8 STANDARD LENGTHWISE SPACING IN NAILED LAMINATED BEAM

9 DESIGN OF BOLTED CONSTRUCTION JOINTS

9.1 General

Bolted joints suit the requirements of prefabrication in small and medium span timber structures for speed and economy in construction. Bolt jointed construction units offer better facilities as regards to workshop ease, mass production of components, transport convenience and re-assembly at site of work particularly in defence sector for high altitudes and far off situations. Designing is mainly influenced by the species, size of bolts, moisture conditions and the inclination of loadings to the grains. In principle, bolted joints follow the pattern of riveted joints in steel structures.

9.2 Design Considerations

9.2.1 Bolted timber construction shall be designed in accordance with **6**. The concept of critical section, that is, the net section obtained by deducting the projected area of bolt-holes from the cross-sectional area of member is very important for the successful design and economy in timber.

9.2.2 *Bolt Bearing Strength of Wood*

The allowable load for a bolt in a joint consisting of two members (single shear) shall be taken as one half the allowable loads calculated for a three member joint (double shear) for the same t'/d_3 ratio. The percentage of safe working compressive stress of timber on bolted joints for different t'/d_3 ratios shall be as given in Table 16.

Table 16 Percentage of Safe Working Compressive Stress of Timber for Bolted Joints in Double Shear

(*Clause* 9.2.2)

Sl No.	**t'/d_3 Ratio**	**Stress Percentage**	
		Parallel to Grain λ_1	Perpendicular to Grain λ_2
(1)	(2)	(3)	(4)
i)	1.0	100	100
ii)	1.5	100	96
iii)	2.0	100	88
iv)	2.5	100	80
v)	3.0	100	72
vi)	3.5	100	66
vii)	4.0	96	60
viii)	4.5	90	56
ix)	5.0	80	52
x)	5.5	72	49
xi)	6.0	65	46
xii)	6.5	58	43
xiii)	7.0	52	40
xiv)	7.5	46	39
xv)	8.0	40	38
xvi)	8.5	36	36
xvii)	9.0	34	34
xviii)	9.5	32	33

Table 16 (*Concluded*)

Sl No.	t'/d_3 Ratio	Stress Percentage	
		Parallel to Grain λ_1	Perpendicular to Grain λ_2
(1)	(2)	(3)	(4)
xix)	10.0	30	31
xx)	10.5	–	31
xxi)	11.0	–	30
xii)	11.5	–	30
xiii)	12.0	–	28

9.2.2.1 Where a number of bolts are used in a joint, the allowable loads shall be the sum of the allowable loads for the individual bolts.

9.2.2.2 The factors for different bolt diameter used in calculating safe bearing stress perpendicular to grain in the joint shall be as given in Table 17.

9.2.3 *Dimensions of Members*

a) The minimum thickness of the main member in mono-chord construction shall be 40 mm;

b) The minimum thickness of side members shall be 20 mm and shall be half the thickness of main members; and

c) The minimum individual thickness of spaced member in split-chord construction shall be 20 mm and 25 mm for webs and chord members, respectively.

9.2.4 *Bolts and Bolting*

a) The diameter of bolt in the main member shall be so chosen to give larger slenderness (t'/d_3) ratio of bolt;

b) There shall be more number of small diameter bolts rather than small number of large diameter bolts in a joint;

c) A minimum of two bolts for nodal joints and four bolts for lengthening joints shall be provided;

d) There shall be more number of rows rather than more bolts in a row;

e) The bolt holes shall be of such diameter that the bolt can be driven easily; and

f) Washers shall be used between the head of bolt and wood surface as also between the nut and wood.

Table 17 Bolt Diameter Factor

(*Clause* 9.2.2.2)

Sl No.	Diameter of Bolt mm	Diameter Factor (d_f)
(1)	(2)	(3)
i)	6	5.70
ii)	10	3.60
iii)	12	3.35
iv)	16	3.15
v)	20	3.05
vi)	22	3.00
vii)	25	2.90

9.3 Arrangement of Bolts

9.3.1 The following spacings in bolted joints shall be followed (*see* Fig. 9):

a) *Spacing of bolts in a row* — For parallel and perpendicular to grain loading = 4 d_3;

b) *Spacing between rows of bolts*:

   1) *For perpendicular to grain loading* — 2.5 d_3 to 5 d_3 (2.5 d_3 for t'/d_3 ratio of 2 and 5 d_3 for t'/d_3 ratio of 6 or more. For ratios between 2 and 6 the spacing shall be obtained by interpolation.

   2) *For parallel to grain loading* — At least (N - 4) d_3 with a minimum of 2.5 d_3. Also governed by net area at critical section which should be 80 percent of the total area in bearing under all bolts.

c) *End distance* — 7d_3 for softwoods in tension, 5 d_3 for hardwoods in tension and 4 d_3 for all species in compression; and

d) *Edge distance*:

   1) For parallel to grain loading 1.5 d_3 or half the distance between rows of bolts, whichever is greater.

   2) For perpendicular to grain loading, the loaded edge distance shall be at least 4 d_3.

9.3.2 For inclined members, the spacing given above for perpendicular and parallel to grain of wood may be used as a guide and bolts arranged at the joint with respect to loading direction.

9.3.3 The bolts shall be arranged in such a manner so as to pass the centre of resistance of bolts through the intersection of the gravity axis of the members.

9.3.4 Staggering of bolts shall be avoided as far as possible in case of members loaded parallel to grain of wood. For loads acting perpendicular to grain of wood, staggering is preferable to avoid splitting due to weather effects.

9.3.5 *Bolting*

The bolt holes shall be bored or drilled perpendicular to the surface involved. Forcible driving of the bolts shall be avoided which may cause cracking or splitting of members. A bolt hole of 1.0 mm oversize may be used as a guide for preboring.

9.3.5.1 Bolts shall be tightened after one year of completion of structure and subsequently at an interval of two to three years.

9.4 Outline for Design of Bolted Joints

Allowable load on one bolt (unit bearing stress) in a joint with wooden splice plates shall not be greater than value of P, R, F as determined by one of the following equations:

a) *For loads parallel to grain*:

$$P = f_{cp}\ a\ \lambda_1$$

b) *For loads perpendicular to grain*:

$$R = f_{cn}\ a\ \lambda_2\ d_f$$

c) *For loads at an angle to grain*:

$$F = \frac{PR}{P\sin^2\theta + R\cos^2\theta}$$

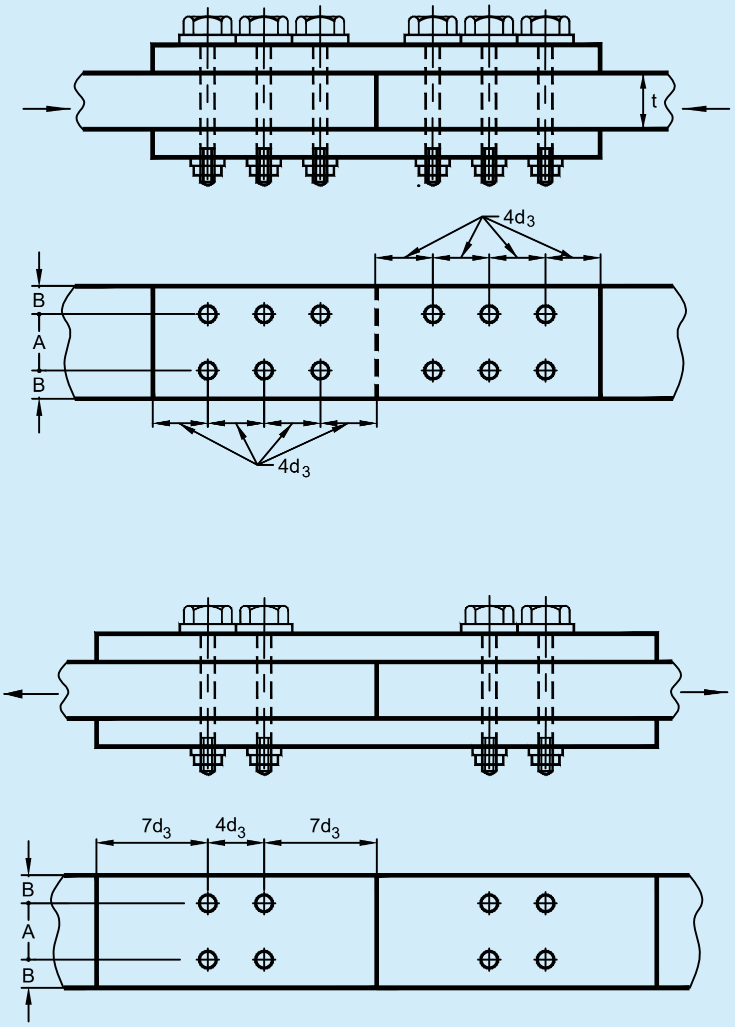
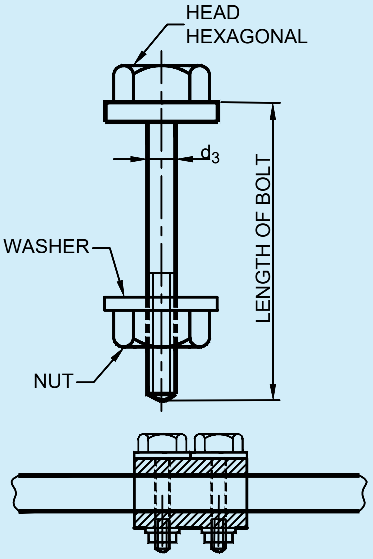

t
4d3
B
A
B
4d3
7d3
4d3
7d3
B
A
B

FIG. 9A SPACING OF BOLTS IN LENTHENING JOINTS (JOINTS LOADED PARALLEL TO GRAIN)


HEAD HEXAGONAL
d3
LENGTH OF BOLT
WASHER
NUT

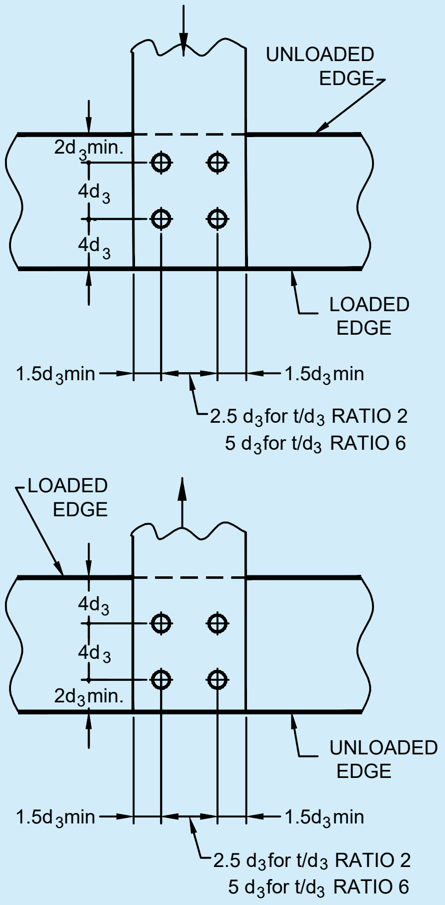

UNLOADED EDGE
2d3min.
4d3
4d3
LOADED EDGE
1.5d3min
1.5d3min
2.5 d3for t/d3 RATIO 2
5 d3for t/d3 RATIO 6
LOADED EDGE
4d3
4d3
2d3min.
UNLOADED EDGE
1.5d3min
1.5d3min
2.5 d3for t/d3 RATIO 2
5 d3for t/d3 RATIO 6

FIG. 9B SPACING OF BOLTS AT NODE JOINTS

FIG. 9 TYPICAL SPACING OF BOLTS IN STRUCTURAL JOINTS

9.5 Fabrication

The fabrication of bolt jointed construction shall be in accordance with good practice [C-3A(9)].

To meet the specific requirements of ‘all-timber construction’ for structures where chemical corrosion of steel elements is a problem, and in order to erect anti-magnetic laboratories, sheds, etc, design should be made on the basis of mild steel bolt joints with the following reductions for timber bolts and bamboo pins:

Allowable safe working load per hardwood timber bolt = 66 percent of the safe working load per mild steel bolt

Safe working load per solid bamboo pin = 56 percent of the working load per mild bamboo per steel bolt

10 DESIGN OF TIMBER CONNECTOR JOINTS

10.1 In large span structures, the members have to transmit very heavy stresses requiring stronger jointing techniques with metallic rings or wooden disc-dowels. Improvised metallic ring connector is a split circular band of steel made from mild steel pipes. This is placed in the grooves cut into the contact faces of the timber members to be joined, the assembly being held together by means of a connecting bolt (*see* Fig. 10).

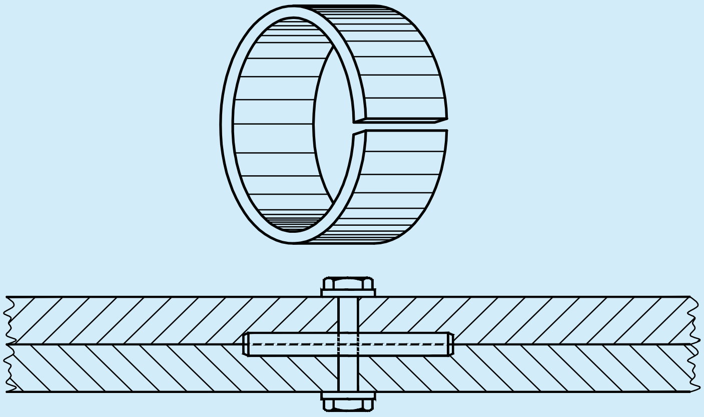


FIG. 10 SPLIT RING CONNECTOR

10.1.1 *Dimensions of Members*

Variation of thickness of central (main) and side members affect the load carrying capacity of the joint. The thickness of main member shall be at least 57 mm and that of side member 38 mm with length and width of members governed by placement of connector at joint.

The metallic connector shall be so placed that the loaded edge distance is not less than the diameter of the connector and the end distance not less than 1.75 times the diameter on the loaded side.

10.1.2 *Design Considerations*

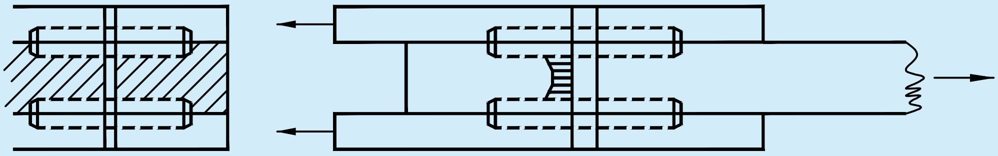
The primary stresses in a split ring connector joint under tension are illustrated in Fig. 11. The shaded areas represent the part of wood in shear, compression and tension. Related formulae for the same are given in **10.1.2.1**.

For fabrication of structural members, a hole of the required size of the bolt is drilled into the member and a groove is made on the contact faces of the joint.

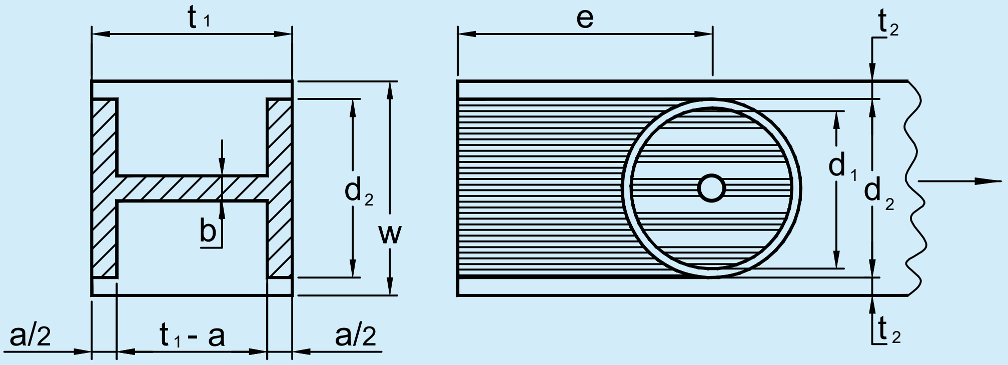
Theoretical safe loads in design shall be corroborated with sample tests done in accordance with a [C-3A(10)].

NOTE — A pilot study on determination of strength of improvised split ring connector joint in a compression test for a specific design problem conducted using *Mesua ferrea* (Mesua), yielded the data which is given below, for guidance:

Sl No.	*No. and Diameter of Ring Used in a Joint*		*No. and Size of Bolt Used in a Joint*		*Side Member*		*Central Member*		*Load Direction with respect to Grains of Wood*	*End Distance*	*Inter-mediate Distance*	*Load Per Pair of Connector*
	No.	Size mm	No.	Size mm	Thickness mm	Width mm	Thickness mm	Width mm		mm	mm	kgf
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
i)	2	63	1	12 × 125	31	92	38	92	Parallel	63	–	3 930
ii)	2	63	1	12×125	31	92	38	92	Parallel	75	–	4 185
iii)	2	63	1	12 × 150	38	92	63	92	Parallel	75	–	4 010
iv)	2	63	1	12 × 150	38	117	63	117	Parallel	75	–	4 450
v)	2	63	1	12 × 125	31	138	38	92	Perpendicular	69	–	2 520
vi)	2	63	1	12 × 125	38	138	38	92	Perpendicular	69	–	3 515
vii)	2	100	1	19 × 175	38	138	66	138	Parallel	100	–	7 075
viii)	2	100	1	19 × 175	38	138	66	138	Parallel	125	–	7 370
ix)	2	100	1	19 × 175	41	138	75	138	Parallel	100	–	7 220
x)	2	100	1	19 × 175	41	138	75	138	Parallel	125	–	7 645
xi)	4	100	2	19 × 200	38	138	66	138	Parallel	100	150	5 655
xii)	4	100	2	19 × 200	41	138	75	138	Parallel	100	150	5 925
xiii)	4	100	2	19 × 200	41	138	75	138	Parallel	125	200	7 135



11A VERTICAL STRESS DITRBUTION



11B HORIZONTAL STRESS DITRBUTION

NOTE — Symbols are exclusive to this figure.

FIG. 11 STRESS DISTRIBUTION IN A SPLIT RING CONNECTOR

10.1.2.1 Strength of joint is controlled by one or another or combination of three properties:

a) Tension area (*see* Fig. 11A):

$$t_1 w - \left[2\left(\frac{a d_2}{2}\right) + b(t_1 - a)\right]$$

b) Compression area (*see* Fig. 11B):

$$2\left(\frac{a d_2}{2}\right) + b(t_1 - a)$$

c) Shear area (*see* Fig. 11B):

1) *Within core* : $2\left(\frac{\pi {d_1}^2}{4}\right)$

2) *Below core* : $2\left[d_2 e - \frac{1}{2}\left(\frac{\pi {d_2}^2}{4}\right) + 2\left(\frac{ae}{2}\right)\right]$

where

d_1 = inside diameter of connector;
t_1 = thickness of member;
w = width of member;
a = depth of connector;
d_2 = outside diameter of connector;
b = diameter of bolt;
e = end distance from centre of connector to end of member; and
t_2 = thickness of metal.

10.2 Wooden Disc-Dowel

10.2.1 It is a circular hardwood disc generally tapered each way from the middle so as to form a double conical frustum. Such a disc is made to fit into preformed holes (recesses), half in one member and the other half in another, the assembly being held by one mild steel bolt through the centre of the disc to act as a coupling for keeping the jointed wooden members from spreading apart.

As timber always fails by shearing or crushing in front of bolts, the function of disc-dowel incorporated in the joint is to distribute the shearing stresses on a larger area of wood so as to transmit the full amount of stresses.

10.2.2 *Dimensions of Members*

The thickness of dowel may vary from 25 mm to 35 mm and diameter from 50 mm to 150 mm. The diameter of dowel shall be 3.25 to 3.50 times the thickness.

The edge clearance shall range from 12 mm to 20 mm as per the size of the dowel. The end clearance shall be at least equal to the diameter of dowel for joints subjected to tension and three-fourth the diameter for compression joints. Disc dowel shall be turned from radial (quarter sawn) planks of seasoned material.

10.2.3 *Choice of Species*

Wood used for making dowels shall be fairly straight grained, free from excessive liability to shrink and warp, and retain shape well after seasoning and having high shear strength. Species recommended include:

a) Babul;
b) Dhaman;
c) Irul;
d) Sissoo;
e) Rose wood;
f) Sandal;
g) Axle-wood;
h) Padauk; and
j) Yon.

NOTE – Data on the above species are as per Table 1.

10.2.4 *Design Considerations*

The forces on dowel in a lap joint and butt joint are illustrated in Fig. 12. Dowel is subjected to shearing at the mid-section, and compression along the grain at the bearing surfaces. For equal strength in both the forces, formula equations are given in the Fig. 12 to determine the size of dowel.

The making of wooden discs may present some problems in the field, but they may be made in small workshop to the specifications of the designer. This is also economically important. Once the wood fittings are shop tailored and made, the construction process in the field is greatly simplified.

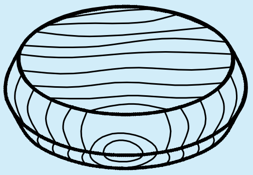
Theoretical safe loads in design shall be confirmed through sample tests.

NOTE — Some experimental studies have indicated the following safe loads, in kN, for dowels bearing parallel to the grain, which are given here for guidance only.

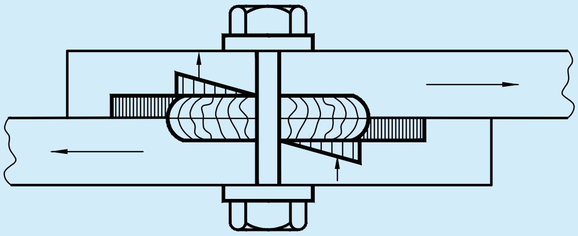
Sl No.	*Species*		*Safe Loads for Dowels Bearing Parallel to the Grain, in kN* *Size of Dowel* (mm)					
	Members	Dowels	62 × 25	75 × 25	87 × 25	100 × 31	112 × 37	125 × 37
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
i)	Sal	Babul	6.671	9.810	13.342	17.805	22.269	27.566
ii)	Sal	Sissoo	5.346	7.554	10.251	13.342	16.922	20.895

10.2.4.1 Rigid specifications regarding use of particular planks for fabrication of wooden disc-dowels, and the specific alignment of grains to be in line with grains of members forming the joint, can be relaxed. Application of appropriate factors in design of such joints whatever be the angle of load and members, etc, would eliminate risks involved by providing 60 percent more number of dowels at a joint. Thus, decrease the calculated load per dowel to 60 percent.

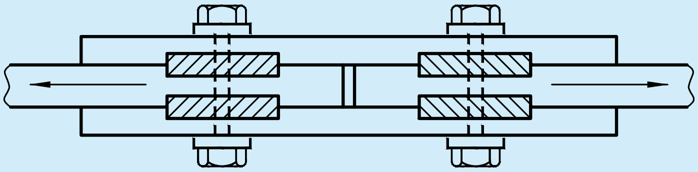
10.2.4.2 Analysis of variance for safe load in case of dowel joints made with MS bolt, timber bolt, bamboo pin as joiners showed no significant difference. Thus, the concept of 'all-timber construction' hold good for chemical industries where corrosion due to acid fumes is a recurring problem.



DOWEL



LAP JOINT



BUTT JOINT

Lap joint — Bolt in simple tension due to clockwise turning moment on dowel.

Butt joint — No tilting moment in dowel due to balancing effect [dowels are in shear (no bending, shearing and tensile stress on bolts)]

Size of dowel for equal strength in both shearing and bearing.

$$\frac{\pi d^2}{4} \times S = d \times \frac{t}{2} \times c$$

where

d = mid diameter of the dowel;

t = thickness of dowel;

s = safe working stress in shear along grain; and

c = safe compressive stress along grain.

NOTE — Symbols are exclusive to this figure.

FIG. 12 DISTRIBUTION OF FORCES IN DOWEL JOINT

11 GLUED LAMINATED CONSTRUCTION

11.1 Developments in the field of synthetic adhesive have brought gluing techniques within the range of engineering practice. Timber members of larger cross-sections and long lengths can be fabricated from small sized planks by the process of glulam. The term glued laminated timber construction as applied to structural members refers to various laminations glued together, either in straight or curved form, having grain of all laminations essentially parallel to the length of the member.

11.1.1 *Choice of Glue*

The adhesive used for glued laminated assembly are ‘gap filling’ type. A ‘filler’ in powder form is introduced in the adhesive. Structural adhesives are supplied either in powder form to which water is added or in resin form to which a hardener or catalyst is added. For choice of glues, reference may be made to good practice [C-3A(11)]. However, it is important that only boiling water proof (BWP) grade adhesives shall be used for fabrication of glulam in tropical, high humid climates like India.

11.1.2 *Manufacturing Schedule*

In absence of a systematic flow-line in a factory, provisions of intermediate technology shall be created for manufacturing structural elements. The schedule involves the following steps:

a) Drying of planks;
b) Planning;
c) End-jointing by scarfs or fingers;
d) Machining of laminations;
e) Setting up dry assembly of structural unit;
f) Application of glue;
g) Assembly and pressing the laminations;
h) Curing the glue lines, as specified; and
j) Finishing, protection and storage.

11.1.3 The information with regard to block shear test results on glued timber joints is given in Table 18.

Table 18 Block Shear Test Results on Glued Timber Joints

(*Clause* 11.1.3)

Sl No.	Timber Species	Ultimate Shear Stress (Inside Location) N/mm^2		
		Solid Timber Along the Grain (Un-Jointed)	With Urea Formaldehyde	With Phenol Formaldehyde
(1)	(2)	(3)	(4)	(5)
i)	*Abies pindrow* (Fir)	5.984	7.652	9.614
ii)	*Acacia catechu* (Khair)	15.107	7.456	–
iii)	*Acacia milotica* (Babul)	14.126	5.199	3.237
iv)	*Albizia odoratissima* (Karasiris)	15.009	14.126	5.984
v)	*Azadirachta indica* (Neem)	12.557	7.259	8.240
vi)	*Casteanopsis hystrix* (Chestnut)	8.044	1.668	–
vii)	*Cedrus deodar* (Deodar)	6.867	4.218	3.237

Table 18 (*Concluded*)

Sl No.	Timber Species	Ultimate Shear Stress (Inside Location) N/mm^2		
		Solid Timber Along the Grain (Un-Jointed)	With Urea Formaldehyde	With Phenol Formaldehyde
(1)	(2)	(3)	(4)	(5)
viii)	*Dalbergia sissoo* (Sissoo)	10.595	15.107	9.320
ix)	*Eucalyptus eugenioides* (Eucalyptus)	12.164	10.987	5.101
x)	*Grewia tiliefolia* (Dhawan)	8.927	10.889	6.475
xi)	*Hopea utilis* (Karunkangoo)	14.813	9.320	–
xii)	*Hopea glabra &* *H. parviflora* (Hopea)	15.009	13.832	0.491
xiii)	*Mangifera Indica* (Mango)	9.418	9.418	3.826
xiv)	*Madhuca longifolia* (Mahua)	9.810	0.883	7.456
xv)	*Mesua ferrea* (Mesua)	12.164	1.079	2.256
xvi)	*Morus alba* (Mulberry)	9.810	13.734	8.142
xvii)	*Pinus wallichiana* (Kail)	5.494	6.377	7.259
xviii)	*Pinus roxburghii* (Chir)	6.082	6.769	7.750
xix)	*Poecilone indicum* (Ballagi)	14.911	5.297	5.984
xx)	*Pterocarpus mersupium* (Bijasal)	9.221	5.003	6.671
xxi)	*Quercus spp.* (Oak)	8.142	10.791	5.396
xxii)	*Ougeinia oojeinensis* (Sanetan)	13.440	5.396	9.516
xxiii)	*Shorea robusta* (Sal) M.P	9.123	5.003	–
xxiv)	*Shorea robusta* (Sal) UP	12.361	5.396	1.472
xxv)	*Sterospermum chelonoides* (Padriwood)	11.674	9.221	8.829
xxvi)	*Syzygium cuzainii* (Jaman)	10.791	9.418	10.301
xxvii)	*Terminalia alata* (Sain)	9.320	13.538	8.142
xxviii)	*Tectona grandis* (Teak)	10.987	5.984	6.377
xxix)	*Terminalia myriocarpa* (Hollock)	8.339	9.221	9.810
xxx)	*Toona ciliata* (Toon)	6.867	4.905	6.180

NOTE — The information given in the above table is based on the block shear test results on glued timber joints conducted on the basis of BS 4169 : 1970 'Specification for manufacture of glued-laminated timber structural members' (since revised and subsequently superseded by BS EN 392 : 1995, BS EN 391 : 1995, BS EN 386 : 1995) and the failures observed with regard to glue line and the wood. Ultimate shear stresses for 29 species were studied keeping design glue shear strength at least one-third of ultimate. Glue mixing, spreading, pressing and curing was done as per the instructions of adhesive manufacturers under improvised techniques locally developed. Sustainable period before delamination of glue bond (urea formaldehyde) in weathering tests was recorded for over a year. Limited number of species survived with most of them failed within a period of six months.

11.2 Design of Glued Laminated Beams

11.2.1 *General*

Glued laminated structural members shall be fabricated only where there are adequate facilities for accurate sizing and surfacing of planks, uniform application of glue, prompt assembly, and application of adequate pressure and prescribed temperature for setting and curing of the glue. Design and fabrication shall be in accordance with established engineering principles and good practice. A glued laminated beam is a straight member made from a number of laminations assembled both ways either horizontally or vertically (*see* Fig. 13). While vertical laminations have limitations in restricting the cross section of a beam by width of the plank, horizontally laminated section offers wider scope to the designer in creating even the curved members. Simple straight beams and joists are used for many structures from small domestic rafters or ridges to the light industrial structures.

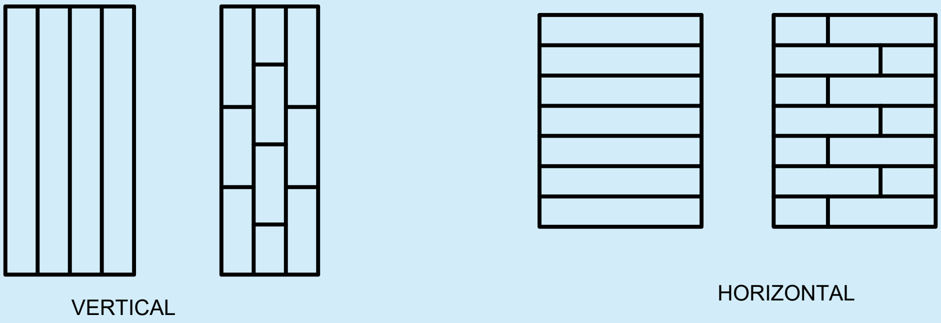


FIG. 13 POSSIBLE ORIENTATION OF PLANKS IN GLULAM

11.2.2 *Design*

The design of glue laminated wood elements shall be in accordance with good engineering practice and shall take into consideration the species and grade of timber used, presence of defects, location of end joints in laminations, depth of beams and moisture contents expected while in service. Beams of large spans shall be designed with a suitable camber to assist in achieving the most cost effective section where deflection governs the design. The strength and stiffness of laminated beams is often governed by the quality of outer laminations. Glued laminated beams can be tapered to follow specific roof slopes across a building and/or to commensurate with the varying bending moments. Glulam allows the engineers to mix grades within a beam. Obviously, the lower tensile portion should be of high grade material. However, it is possible to incorporate a considerable volume of lower grade material near the neutral axis taking care of the horizontal shear stress. Similarly, species can also be mixed depending upon the modulus of elasticity.

Straight beams that will be simply supported should be cambered during fabrication to allow for deflection due to dead loads over a period of time. The usual camber is $\frac{span}{400}$, unless otherwise specified.

11.2.2.1 *Design outline for horizontally laminated beams*

A design outline for horizontal laminated beams, specifying data required and a possible solution is given below.

a) *Data required:*

  1) Span (L), loads including self weight of beam (W), species of timber, thickness of lamination proposed; and
  2) Mechanical properties of timber species (permissible extreme fibre stress in bending-tension, permissible compressive stress perpendicular to grain, modulus of elasticity, permissible shear stress parallel to grain).

  The permissible shear stress at the glue line is at least the same as the permissible shear stress parallel to grain of the species in design, unless otherwise tested.

b) *Solution:*

1) Let, b = width of beam, and d = depth of beam, for lateral stability, $b : d = 1 : 4$ (*say*).
2) Determine bending moment on the basis of span, loading and support conditions (say, $WL/8$ for beams with both ends fixed).
3) Also, bending moment (M) = Bending stress (f_b) × Section modulus (Z):

$$\text{Therefore, } M = f_b \times \frac{bd^2}{6} = \frac{WL}{8}$$

$$\text{or } bd^2 = \frac{WL}{8} \times \frac{6}{f_b}$$

4) From bd^2 obtained at (c) and $b : d$ assumed at (a), arrive at appropriate values of b and d.
5) Check for deflection of beam. Since dead load is for long term, double this for deflection check, that is:

$$W = (2 \times \textit{Dead load}) + \textit{Imposed load}$$

Deflection is to be limited to the specified requirement, say 0.003 of span.

Substituting values of b and d from (d) and $I (= bd^3/12)$ in the formula for deflection, perform check against the limit for deflection.

6) Decide the number and thickness of laminations for the required depth of section.

11.2.3 *Material*

Laminating boards shall not contain decay, knots or other strength reducing characteristics in excess of those sizes or amounts permitted by specifications. The moisture content shall approach that expected in service and shall in no case exceed 15 percent at the time of gluing. The moisture content of individual laminations in a structural member shall not differ by more than 3 percent at the time of gluing. Glue shall be of type suitable for the intended service of a structural member.

11.2.4 *Fabrication/Manufacture*

In order to assure a well-bonded and well-finished member of true shape and size, all equipment, end-jointing, glue spread, assembly, pressing, curing or any other operation in connection with the manufacture of glued structural members shall be in accordance with the available good practices and as per glue manufacturers' instructions as applicable.

11.2.4.1 End joints shall be scattered in adjacent laminations, which shall not be located in very highly stressed outer laminations.

11.2.5 *Testing*

Quality control, inspection and testing during production is essential to structural glulam. Special attention needs to be given to members exposed to weather.

For examining the quality of glue and its relative strength namely species of timber in glued laminated construction, it is necessary to conduct block shear and other related tests in accordance with accepted standard [C-3A(11)]. Structural loading tests on prototype sizes provide information on the strength properties, stiffness or rigidity against deflection of a beam. Information on different strength functions as obtained from such indigenous tests carried out on laminated timber beams are given in Table 19, for guidance in design.

Table 19 Laminated Timber Beams — Structural Bending Test Under Three Point Loading

(*Clause* 11.2.5)

Species — *Pinus wallichiana* (Kail);
Effective span — 2.3 m, Cross section: 100 × 240 mm; and
Adhesive — Urea formaldehyde.

Sl No.	Strength Functions	Nail Laminated Vertical Laminates with Four Full Size Planks Using 8 SWG, 100 mm Long Nails	Glue Laminated		Solid (Control) Specimen
			Vertical Laminates Four Planks, Each 25 mm Thick	Horizontal Laminates Eight Planks, Each 30 mm Thick	
(1)	(2)	(3)	(4)	(5)	(6)
i)	Modulus of rupture, N/mm^2	27.439	31.363	21.568	30.509
ii)	Modulus of elasticity (× 10^3 N/mm^2)	8.167	8.903	8.210	7.554
iii)	Fibre stress at limit of proportionality, N/mm^2	18.136	14.166	13.259	18.276
iv)	Maximum horizontal shear stress, N/mm^2	1.723	1.967	1.319	1.906

12 LAMINATED VENEER LUMBER

12.1 Certain reconstituted lignocellulosic products with fibre oriented along a specific direction have been developed and are being adopted for load bearing applications. Laminated veneer lumber is one such product developed as a result of researches in plantation grown species of wood. Density of laminated veneer lumber ranges from 600 kg/m^3 to 750 kg/m^3 which is manufactured in accordance with accepted standard [C-3A(12)].

12.1.1 *Dimensions*

Sizes of laminated veneer lumber composite shall be inclusive of margin for dressing and finishing unless manufactured to order. The margin for dressing and finishing shall not exceed 3 mm in the width and thickness and 12 mm in the length.

12.1.2 *Permissible Defects*

a) Jointing gaps	:	Not more than 3 mm wide, provided they are well staggered in their spacing and position between the successive plies;
b) Slope of grain	:	Not exceeding 1 in 10 in the face layers;
c) Tight knot	:	Three numbers up to 25 mm diameter in 1 m^2 provided they are spaced 300 mm or more apart; and
d) Warp	:	Not exceeding 1.5 mm per metre length.

12.1.3 *Strength Requirements*

The strength requirements for laminated veneer lumber shall be as per Table 20.

Table 20 Requirements of Laminated Veneer Lumber

(*Clause* 12.1.3)

Sl No. (1)	Properties (2)	Requirement (3)
i)	Modulus of rupture, N/mm^2, *Min*	50
ii)	Modulus of elasticity, N/mm^2, *Min*	7 500
iii)	Compressive strength parallel to grain, N/mm^2, *Min*	35
iv)	Horizontal shear:	
	a) Parallel to laminae, N/mm^2, *Min*	6
	b) Perpendicular to laminae, N/mm^2, *Min*	8
v)	Tensile strength parallel to grain, N/mm^2, *Min*	55
vi)	Screw holding power:	
	a) Edge (N), *Min*	2 300
	b) Face (N), *Min*	2 700
vii)	Thickness swelling in 2 h water soaking (percent), *Max*	3

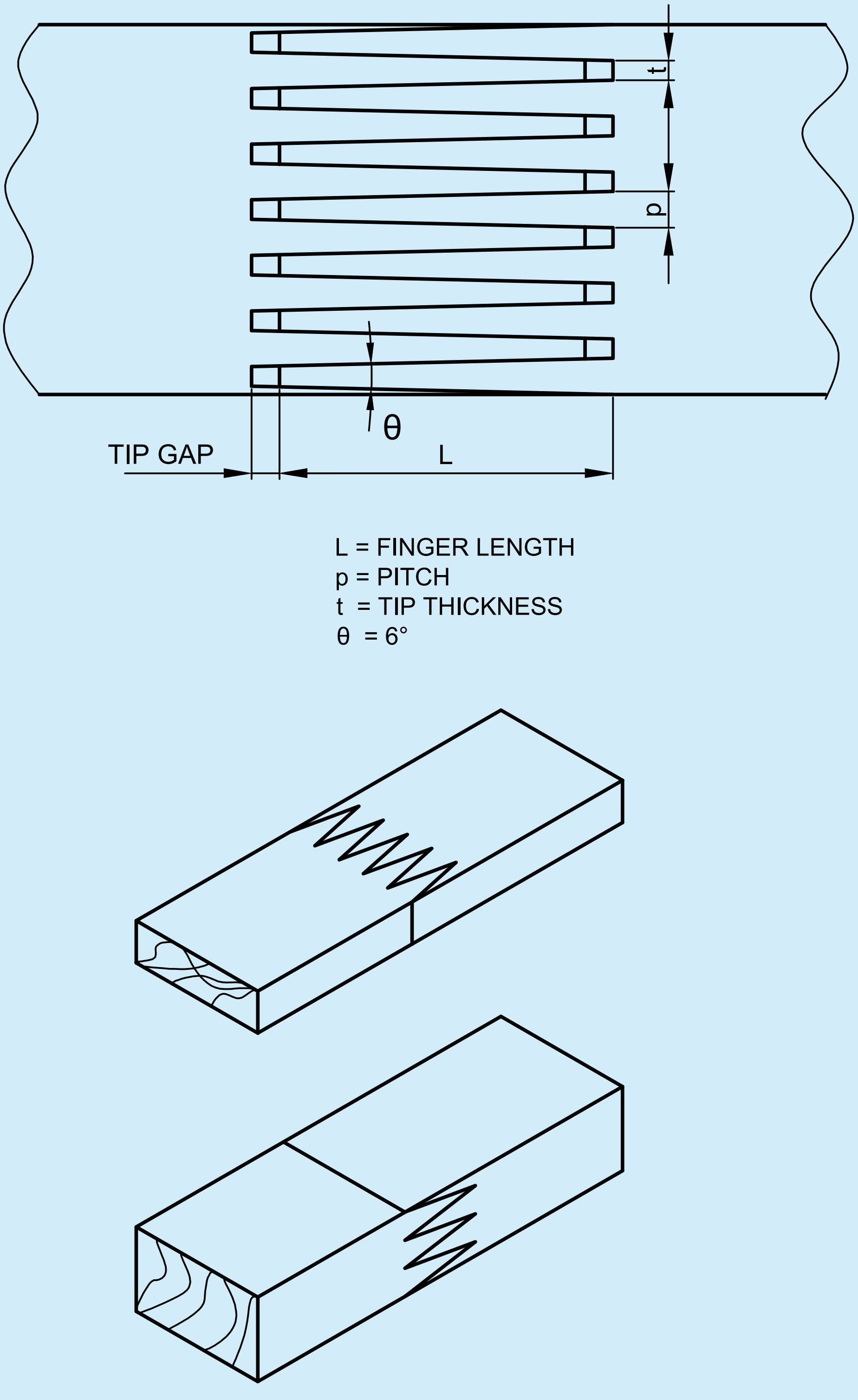
13 GLUED FINGER JOINTS

13.1 Finger joints are glued joints connecting timber members end-to-end (*see* Fig. 14). Such joints shall be produced by cutting profiles (tapered projections) in the form of v-shaped grooves to the ends of timber planks or scantling to be joined, gluing the interfaces and then mating the two ends together under pressure. Finger joints provide long lengths of timber, ideal for upgrading timber by permitting removal of defects, minimizing warping and reducing wastage by avoiding short off-cuts. To improve the long-term durability and performance of glued finger joints, the timber used should be well-seasoned to maintain dimensional stability. Additional protective treatments may be required for finger-jointed timber used in outdoor or high-moisture environments to prevent decay and degradation of the adhesive bonds.

13.1.1 In finger joints the glued surfaces are on the side grain rather than on the end grain and the glue line is stressed in shear rather in tension.

13.1.1.1 The fingers can be cut from edge-to-edge or from face-to-face. The difference is mainly in appearance, although bending strength increases if several fingers share the load. A joist is slightly stronger with edge-to-edge finger joints and a plank is stronger with face-to-face finger joint. The choice of adhesive should consider the wood species being used, as different timber species may exhibit varying adhesive compatibility. For example, denser species may require stronger bonding adhesives, while lower-density woods may work well with more flexible adhesives. Testing of specific adhesives with the wood species used is recommended to ensure optimal joint strength and performance.

13.1.1.2 For structural finger jointed members for interior dry locations, adhesives based on melamine formaldehyde cross linked polyvinyl acetate (PVA) are suited. For high humid and exterior conditions, phenol formaldehyde and resorcinol formaldehyde type adhesives are recommended. Proper adhesives should be selected in consultation with the designer and adhesive manufacturers and assessed in accordance with accepted standard [C-3A(11)]. The environmental impact of adhesives used in finger-jointed construction should also be considered. Where possible, the use of low- volatile organic compounds (VOC) or environmentally friendly adhesives should be promoted, particularly in indoor applications, to reduce emissions and promote healthier indoor air quality.



L = FINGER LENGTH
p = PITCH
t = TIP THICKNESS
θ = 6°

ORIENTATION OF FINGER JOINTS

FIG. 14 TYPICAL FINGER JOINT GEOMETRY

13.1.2 *Manufacturing Process*

In the absence of sophisticated machinery, the finger joints shall be manufactured through intermediate technology with the following steps:

a) Drying of wood;

b) Removal of knots and other defects;

c) Squaring the ends of the laminating planks;

d) Cutting the profile of finger joint in the end grain;

e) Applying adhesives on the finger interfaces;

f) Pressing the joint together at specified pressure;

g) Curing of adhesive line at specified temperature; and

h) Planing of finger-jointed planks for smooth surface.

For higher precision and productivity, modern manufacturing facilities could implement computer numerical control (CNC) machines for cutting finger joints. Automation helps achieve consistent profile geometry, improves the quality of adhesive application, and reduces the margin for human error during production.

13.1.3 *Strength*

Strength of finger joints depends upon the geometry of the profile for structural purpose; this is generally 50 mm long, 12 mm pitch.

13.1.3.1 The strength properties of glued finger joints are given in Table 21 for information and guidance in design.

13.1.3.2 Tip thickness shall be as small as practically possible.

14 STRUCTURAL USE OF PLYWOOD

Unlike sawn timber, plywood is a layered panel product comprising veneers of wood bonded together with adjacent layers usually at right angles. As wood is strongest when stressed parallel to grain, and weak perpendicular to grain, the lay up or arrangement of veneers in the panel determines its properties. When the face grain of the plywood is parallel to the direction of stress, veneers parallel to the face grain carry almost all the load. Some information/guidelines for structural use of plywood which should be manufactured in accordance with accepted standards [C-3A(13)] are given in **14.1** to **14.3**.

14.1 The plywood has a high strength to weight ratio and is dimensionally stable material available in sheets of a number of thicknesses and construction. Plywood can be sawn, drilled and nailed with ordinary wood working tools. The glues used to bond these veneers together are derived from synthetic resins which are set and cured by heating. The properties of adhesives can determine the durability of plywood.

14.2 In glued plywood construction, structural plywood is glued to timber resulting in highly efficient and light structural components like web beams (I and box sections) (*see* Fig. 15 and Fig. 16) stressed skin panels (*see* Fig. 17) used for flooring and walling and pre-fabricated houses, cabins, etc. Gluing can be carried out by nail gluing techniques with special clamps. High shear strength of plywood in combination with high flexural strength and stiffness of wood result in structures characterized by high stiffness for even medium spans. Plywood can act as web transmitting shear stress in web bearing or stressed skin or sandwich construction. The effective moment of inertia of web beam and stressed skin construction depends on modular ratio that is, *E* of wood to *E* of plywood.

Table 21 Strength Characteristics of Glued Finger Joints

(*Clause* 13.1.3.1)

Timber species – *Pinus wallichiana* (Kail)

(Averaged test results)

Sl No.	Character → Treatment ↓	Compressive Parallel to Grain Tests			Tension Parallel to Grain Tests			Static Bending Tests											
								Central Point Loading						Two Point Loading					
								Edge-wise			Flat-wise			Edge-wise			Flat-wise		
		Maximum Compressive Stress (N/mm^2)	Fibre Stress at EL (N/mm^2)	MOE (×10^3 N/mm^2)	Maximum Tensile Stress (N/mm^2)	Tensile Stress at EL (N/mm^2)	MOE (×10^3 N/mm^2)	Fibre Stress at EL (N/mm^2)	MOR (N/mm^2)	MOE (×10^3 N/mm^2)	Fibre Stress at EL (N/mm^2)	MOR (N/mm^2)	MOE (×10^3 N/mm^2)	Fibre Stress at EL (N/mm^2)	MOR (N/mm^2)	MOE (×10^3 N/mm^2)	Fibre Stress at EL (N/mm^2)	MOR (N/mm^2)	MOE (x10^3 N/mm^2)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
i)	UL$_1$	31.196	16.971	10.202	30.019	23.446	10.202	20.993	29.136	6.769	39.142	46.401	8.142	25.114	28.743	8.044	32.471	38.553	9.516
ii)	UL$_2$	37.474	17.462	11.282	30.607	23.642	10.301	20.209	31.686	6.671	35.120	46.205	7.161	23.446	42.085	7.652	41.202	51.306	9.712
iii)	UL$_3$	35.905	19.914	10.595	32.667	23.838	10.006	22.171	35.022	6.867	38.750	47.480	8.437	25.898	29.234	7.848	29.626	38.357	8.633
iv)	PL$_1$	28.743	21.484	9.908	20.895	17.560	10.497	20.699	23.446	8.142	22.955	27.076	9.123	18.443	21.876	7.848	25.506	27.174	8.927
v)	PL$_2$	28.743	19.424	10.006	18.149	17.069	9.614	16.285	18.639	5.984	24.133	26.095	8.731	16.579	17.854	7.259	26.389	28.547	8.535
vi)	PL$_3$	27.860	20.111	9.908	24.721	19.326	10.497	15.009	17.069	7.652	21.680	26.193	8.829	10.301	11.183	6.867	26.487	30.313	11.183
vii)	C	35.512	27.959	10.301	31.490	23.152	10.104	25.506	45.518	7.063	36.788	57.192	7.063	31.883	44.537	7.946	38.161	52.582	9.221

MOE – Modulus of elasticity (values rounded off for decimals)
MOR – Modulus of rupture
EL – Elastic limit
U – Urea formaldehyde with liquid hardener
P – Cold setting phenolic glue with hardener
L$_1$ – Finger length 38 mm
L$_2$ – Finger length 50 mm
L$_3$ – Finger length 62 mm
C – Control (unjointed specimen)

NOTE — The information given in the above table is based on the tests conducted on glued finger joints of varying lengths/pitch with two types of adhesives.

14.3 Structural plywood is also very efficient as cladding material in wood frame construction such as houses. This type of sheathing is capable of resisting racking due to wind and earthquake forces. Structural plywood has been widely used as diaphragm (horizontal) as in roofing and flooring in timber frame construction. It has been established that 6 mm thick plywood can be used for sheathing and even for web and stressed skin construction, 9 mm to 12 mm thick plywood is suitable for beams, flooring diaphragms, etc. Phenol formaldehyde (PF) and PRF adhesive are suitable for fabrication of glued plywood components. 6 mm to 12 mm thick structural plywood can be very well used as nailed or bolted gussets in fixing members of trusses or lattice girders or trussed rafters.

Normally, scarf joints are used for fixing plywood to required length and timber can be joined by using either finger or scarf joints. Arch panels, folded plates, shelves are other possibilities with this technique.

15 TRUSSED RAFTER

15.1 General

A roof truss is essentially a plane structure which is very stiff in the plane of the members, that is the plane in which it is expected to carry loads, but very flexible in every other direction. Thus, it can virtually be seen as a deep, narrow girder liable to buckling and twisting under loads. In order, therefore, to reduce this effect, eccentricity of loading and promote prefabrication for economy, low-pitched trussed rafters are designed with bolt ply/nail ply joints. Plywood as gussets, besides being simple have inherent constructional advantage of grain over solid wood for joints and a better balance is achievable between the joint strength and the member strength.

Trussed rafters are light weight truss units spaced at close centres for limited spans to carry different types of roof loads. They are made from timber members of uniform thickness fastened together in one plane. The plywood gussets may be nailed or glued to the timber to form the joints. Conceptually a trussed rafter is a triangular pin jointed system, traditionally meant to carry the combined roof weight, cladding services and wind loads. There is considerable scope for saving timber by minimizing the sections through proper design without affecting structural and functional requirements.

Trussed rafters are required to be supported only at their ends so that there is no need to provide load bearing internal walls, purlins, etc. In comparison with traditional methods of construction they use less timber and considerably reduce on-site labour and mass production of reliable units can be carried out under workshop controls.

Additional consideration may include:

a) *Climatic Suitability* — Trussed rafters should be designed with consideration for India's diverse climatic zones. Timber species suitable for humid, dry and coastal regions should be preferred to prevent issues related to swelling, shrinkage, or decay due to moisture variations;

b) *Use of Local Timber Species* — Indian species such as Teak (*Tectona grandis*), Sal (*Shorea robusta*), Neem (*Azadirachta indica*), and other durable hardwoods should be prioritized. The use of locally available plantation-grown timber helps reduce transportation costs and supports sustainability; and

c) *Fire and Termite Resistance* — Due to the prevalence of termites in many regions of India, timber rafters should be treated with appropriate termite-resistant chemicals. Similarly, the risk of fire in construction should be mitigated through the application of fire-retardant coatings.

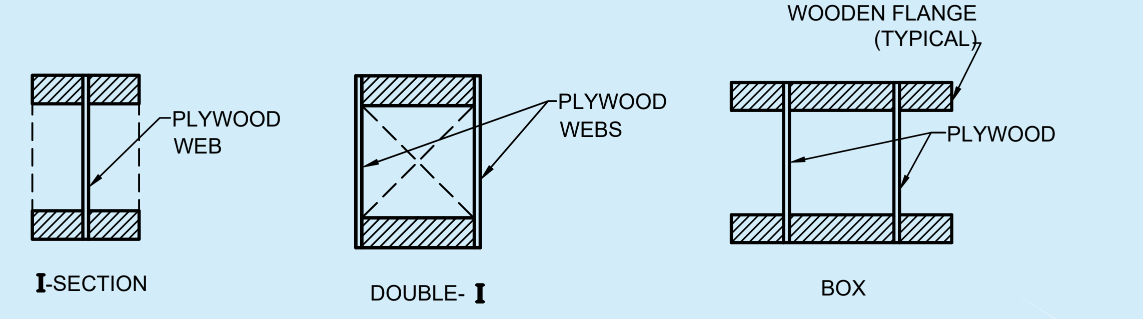
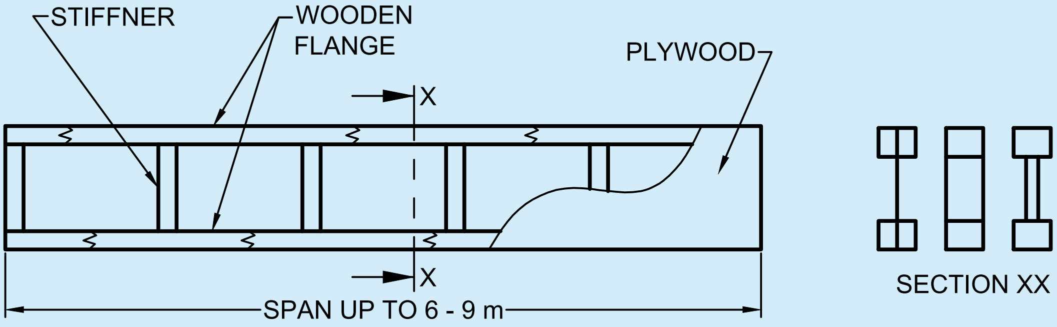
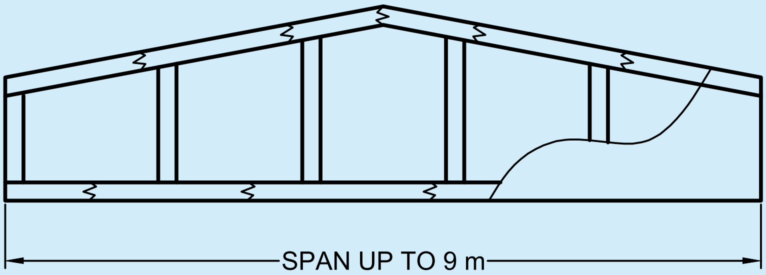


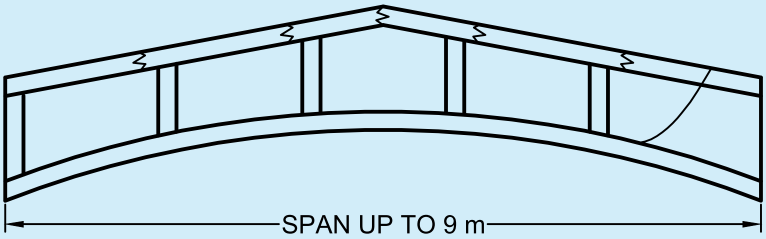
FIG. 15 TYPICAL CROSS SECTION OF WEB BEAMS


STIFFNER
WOODEN FLANGE
PLYWOOD
X
X
SPAN UP TO 6 - 9 m
SECTION XX

STRAIGHT


SPAN UP TO 9 m

DOUBLE TAPERED


SPAN UP TO 9 m

HAUNCHED

FIG. 16 WEB BEAM CONFIGRATIONS

FIG. 16 WEB BEAM CONFIGURATIONS

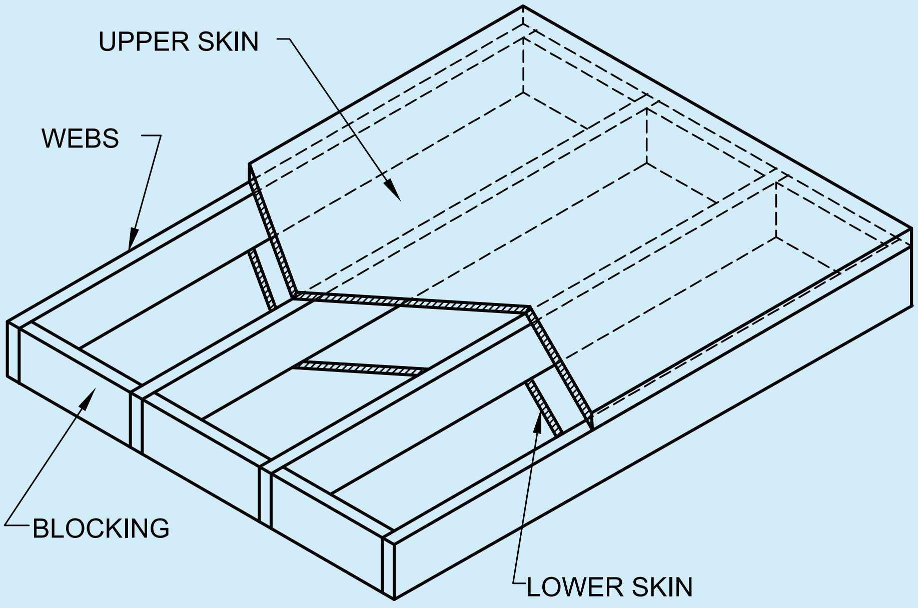


FIG. 17 STRESSED SKIN PANEL CONSTRUCTION (SINGLE SKIN OR DOUBLE SKIN)

15.2 Design

15.2.1 The design may be based on the use of Group ‘C’ species of standard grade timber in accordance with good practice [C-3A(7)] for nail jointed timber construction. As the strength and stiffness of any framing depends upon efficiency of joints, design calls for proper size and number of fasteners, their spacings and thickness of gusset plates for transfer of stress from one member to the other.

Trussed rafter shall be designed to sustain the dead and imposed loads specified in Part C ‘Structural Design, Section 1 Loads and Load Effects’ of this NBCS and the combinations expected to occur. Extra stresses/deflections during handling, transportation and erection shall be taken care of. Structural analysis, use of load-slip and moment, rotation characteristics of the individual joints may be used if feasible. Alternatively, the maximum direct force in a member may be assessed to be given by an idealized pin-jointed framework, fully loaded with maximum dead and imposed load in the combination in which they may reasonably be expected to occur.

NOTE — Some trussed rafters with plywood gusseted joint, span 6 m, designed in *Pinus roxburghii* (Chir) were tested in prototypes at Forest Research Institute, Dehradun for structural adequacy as under, in accordance with accepted standards [C-3A(14)]:

a) Destructive test (short-term); and

b) Proof test (long-term).

Results demonstrated an apparent factor at safety of 4 and actual factor of safety of 3. Deflection was well within the allowable deflection at design load. A pre-camber of 1/240 of span at the bottom chord was recommended.

15.3 Timber

The species of timber including plantation grown species which can be used for trussed rafter construction and permissible stresses thereof shall be in accordance with Table 1. Moisture contents shall be as per zonal requirements in accordance with **4.4**.

15.4 Plywood

Boiling water proof (BWP) grade preservative treated plywood shall be used in accordance with accepted standards [C-3A(13)]. Introduction of a plywood gusset simplifies the jointing and in addition provides rigidity to the joint. Preservation of plywood and other panel products shall be done in accordance with good practice [C-3A(15)].

15.5 Some design data on the lateral load bearing strength of common wire nails in plywood-to-wood joints are presented for timber species, Sal and Chir in Table 22, for guidance in design.

16 STRUCTURAL SANDWICHES

16.1 General

Sandwich constructions are composites of different materials including wood based materials formed by bonding two thin facings of high strength material to a light weight core which provides a combination of desirable properties that are not attainable with the individual constituent materials (*see* Fig. 18). The thin facings are usually of strong dense material since that are the principal load carrying members of the construction. The core should be stiff enough to ensure the faces remain at the correct distance apart. The sandwiches used as structural elements in building construction shall be adequately designed for their intended services and shall be fabricated only where there are adequate facilities for gluing or otherwise bonding cores to facings to ensure a strong and durable product. The entire assembly provides a structural element of high strength and stiffness in proportion to its mass.

Non-structural advantages can also be derived by proper selection of facing and core material, for example, an impermeable facings can be used to serve as a moisture barrier for walls and roof panels and core may also be selected to provide thermal and/or acoustic insulation, fire resistance, etc, besides the dimensional stability.

16.2 Cores

Sandwich cores shall be of such characteristics as to give to the required lateral support to the stressed facings to sustain or transmit the assumed loads or stresses. Core generally carries shearing loads and to support the thin facings due to compressive loads. Core shall maintain the strength and durability under the conditions of service for which their use is recommended. A material with low *E* and small shear modulus may be suitable.

16.3 Facings

Facings shall have sufficient strength and rigidity to resist stresses that may come upon them when fabricated into a sandwich construction. They shall be thick enough to carry compressive and tensile stresses and to resist puncture or denting that may be expected in normal usages.

16.4 Designing

Structural designing may be comparable to the design of I-beams, the facings of the sandwich represent the flanges of the I-beam and the sandwich core I-beam web.

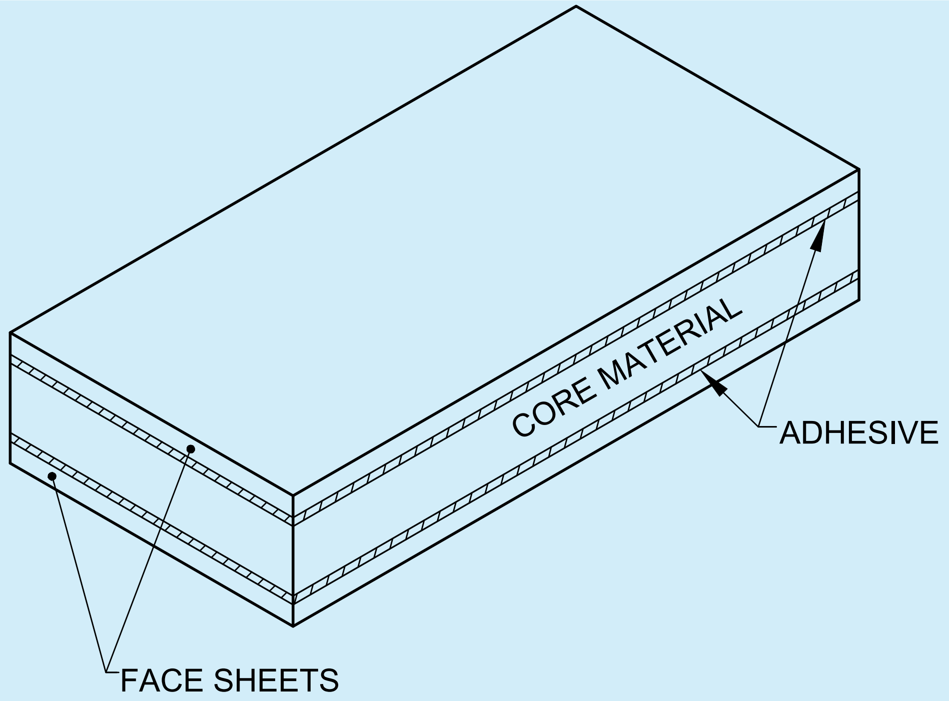


FIG. 18 SANDWICH CONSTRUCTION IN STRUCTURAL APPLICATIONS

Table 22 Lateral Load Bearing Strength of Wire Nails in Plywood-to-Wood Composite Joints Permissible Lateral Strength of 9 SWG (3.55 mm diameter) Nail in Double Shear (kg) Safe Load per Nail

(*Clause* 15.5)

Sl No.	**Thickness of Members** mm		**Facing Veneer of Plywood Along the Loading Direction**								**Across Loading Direction**	
			(Loading Direction in the Main Member of the Joint)								(Loading Direction in the Main Member of the Joint)	
	Main Member Timber	Side Members Plywood	Parallel to Grain		Perpendicular to Grain		At 60° Inclination to Grain		At 30° Inclination to Grain		Loaded Parallel to Grain	
			Permanent Structures	Temporary Structures	Permanent Structures	Temporary Structures	Permanent Structures	Temporary Structures	Permanent Structures	Temporary Structures	Permanent Structures	Temporary Structures
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
i)	Species — *Shorea robusta* (Sal):											
	a) 30	9	109	121	135	156	151	168	140	164	142	151
	b) 40		123	124	121	166	142	181	145	158		
	c) 50		89	123	157	167	162	170	99	139		
	d) 30	12	157	177	150	154	164	179	111	171	135	180
	e) 40		179	191	145	193	154	194	132	192		
	f) 50		151	183	149	191	155	202	128	182		
	g) 30	19	245	283	Larger thickness of plywood is generally not recommended to be used in structures unless heavily stressed						150	209
	h) 40		259	264								
	j) 50		231	316								
ii)	Species — *Pinus roxburghii* (Chir):											
	a) 30	9	102	127	112	141	60	125	92	124	107	148
	b) 40		103	148	100	153	98	142	101	141		
	c) 50		87	133	119	150	50	168	50	114		
	d) 30	12	133	163	116	111	80	132	127	150	118	174
	e) 40		114	173	112	136	64	157	137	174		
	f) 50		99	194	117	138	90	170	119	161		

Table 22 (*Concluded*)

Sl No.	**Thickness of Members** mm		**Facing Veneer of Plywood Along the Loading Direction**								**Across Loading Direction**	
			(Loading Direction in the Main Member of the Joint)								(Loading Direction in the Main Member of the Joint)	
	Main Member Timber	Side Members Plywood	Parallel to Grain		Perpendicular to Grain		At 60° Inclination to Grain		At 30° Inclination to Grain		Loaded Parallel to Grain	
			Permanent Structures	Temporary Structures	Permanent Structures	Temporary Structures	Permanent Structures	Temporary Structures	Permanent Structures	Temporary Structures	Permanent Structures	Temporary Structures
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	g) 30	19	219	309	Larger thickness of plywood generally not used in structures unless heavily stressed						158	249
	h) 40		238	306								
	j) 50		236	333								

NOTES

1 Plywood shall be of shuttering grade as per the accepted standard [C-3A(16)].

2 Subject to satisfying all the design requirements in structures:

a) For denser species, timber thickness of 30 mm may be used by means of a plywood of 9 mm thickness for all practical purposes. For species like Chir, plywood thickness of 12 mm may be used with 30 mm or 40 mm timber thickness.

b) Regarding aligning the veneers of plywood plate; nail strength data may be used as design function irrespective of alignment of face veneer to overcome practical difficulties.

c) While prebore is essential to drive nail in structural timber as per the good pratice [C-3A(7)], plywood plates need not be prebored for nailing.

16.5 Tests

Panels of sandwich construction shall be subject to testing in accordance with accepted standards [C-3A(17)]. Tests shall include, as applicable, one or more of the following:

a) Flexural strength/stiffness;

b) Edge-wise compressions;

c) Flat-wise compression;

d) Shear in flat-wise plane;

e) Flat-wise tensions;

f) Flexural creep (creep behaviour of adhesive);

g) Cantilever vibrations (dynamic property); and

h) Weathering for dimensional stability.

17 LAMELLA ROOFING

17.1 General

The lamella roofing offers an excellent architectural edifice in timber, amenable to prefabrication, light weight structure with high central clearance. It is essentially an arched structure formed by a system of intersecting skewed arches built-up of relatively short timber planks of uniform length and cross section. Roof is designed as a two hinged arch with a depth equal to the depth of an individual lamella and width equal to the span of the building. The curved lamellas (planks) are bevelled and bored at the ends and bolted together at an angle, forming a network (grid) pattern of mutually braced and stiffened members (*see* Fig. 19 and Fig. 20).

The design shall be based on the balanced or unbalanced assumed load distribution used for roof arches. Effect of deformation or slip of joints under load on the induced stresses shall be considered in design. Thrust components in both transverse and longitudinal directions of the building due to skewness of the lamella arch shall be adequately resisted. Thrust at lamella joints shall be resisted by the moment of inertia in the continuous lamella and roof sheathing (decking) of lamella roofing. The interaction of arches in two directions adds to the strength and stability against horizontal forces. For design calculations several assumption tested and observed derivations, long-duration loading factors, seasoning advantages and effects of defects should be taken into account.

17.2 Lamellas

Planking shall be of a grade of timber that is adequate in strength and stiffness to sustain the assumed loads, forces, thrust and bending moments generated in lamella roofing. Lamella planks shall be seasoned to a moisture content approximating that they will attain in service. Lamella joints shall be proportioned so that allowable stresses at bearings of the non-continuous lamellas on the continuous lamellas or bearings under the head or washer of bolts are not exceeded.

17.2.1 *Design Sequence and Methods*

A lamella roof is essentially an arch (segmental, parabolic or elliptical) formed by a system of intersecting skewed arches, built up of relatively short members of small dimensional planks called ‘lamellas’. The arch is designed as a two hinged arch with a depth equal to the depth of the individual lamella and a width equal to the span of the building of certain length. For design purposes, a unit length of the given span forming a single arch is considered loaded with the given loads. For the particular arch, curvature offers resultant outward suction on the roof to be less than its self weight to facilitate design and construction for economy (this is possible only when the semi-angle of arch is less than 42°).

Some design assumptions that should be considered include:

a) Self weight of timber components (in particular species), namely lamella planks, roof boarding, wall plates, etc is assumed for the particular timber section;

b) Imposed loads as per Part C ‘Structural Design, Section 1 Loads and Load Effects’ of this NBCS for curved roofs where slope at springing point is greater than 10°. Take the reduced worked out values of imposed loads for actual design for timber components as per this Subsection;

c) Wind load is taken as per Part C ‘Structural Design, Section 1 Loads and Load Effects’ of this NBCS for structures with large openings, that is, openings larger than 20 percent of wall area (or as the case may be);

d) Stresses developed in curved lamella planks should not exceed the allowable safe stresses of timber species used;

e) Range of various sizes of timber planks for lamellas shall be as under:

   1) *Length* — 1.0 m to 2.5 m;

   2) *Section*:

      i) *Thickness* — 25 mm to 50 mm; and

      ii) *Width of uncurved plank* — 100 mm to 250 mm.

f) Limitations to be observed for spacing of lamellas over wall plate (or bressummer):

   1) i) For skew angle of 21° (diamond angle 42°);
      ii) For 2.5 m length of plank, spacing shall be 870 mm maximum; and
      iii) For 1.0 m length, spacing shall be 360 mm maximum.

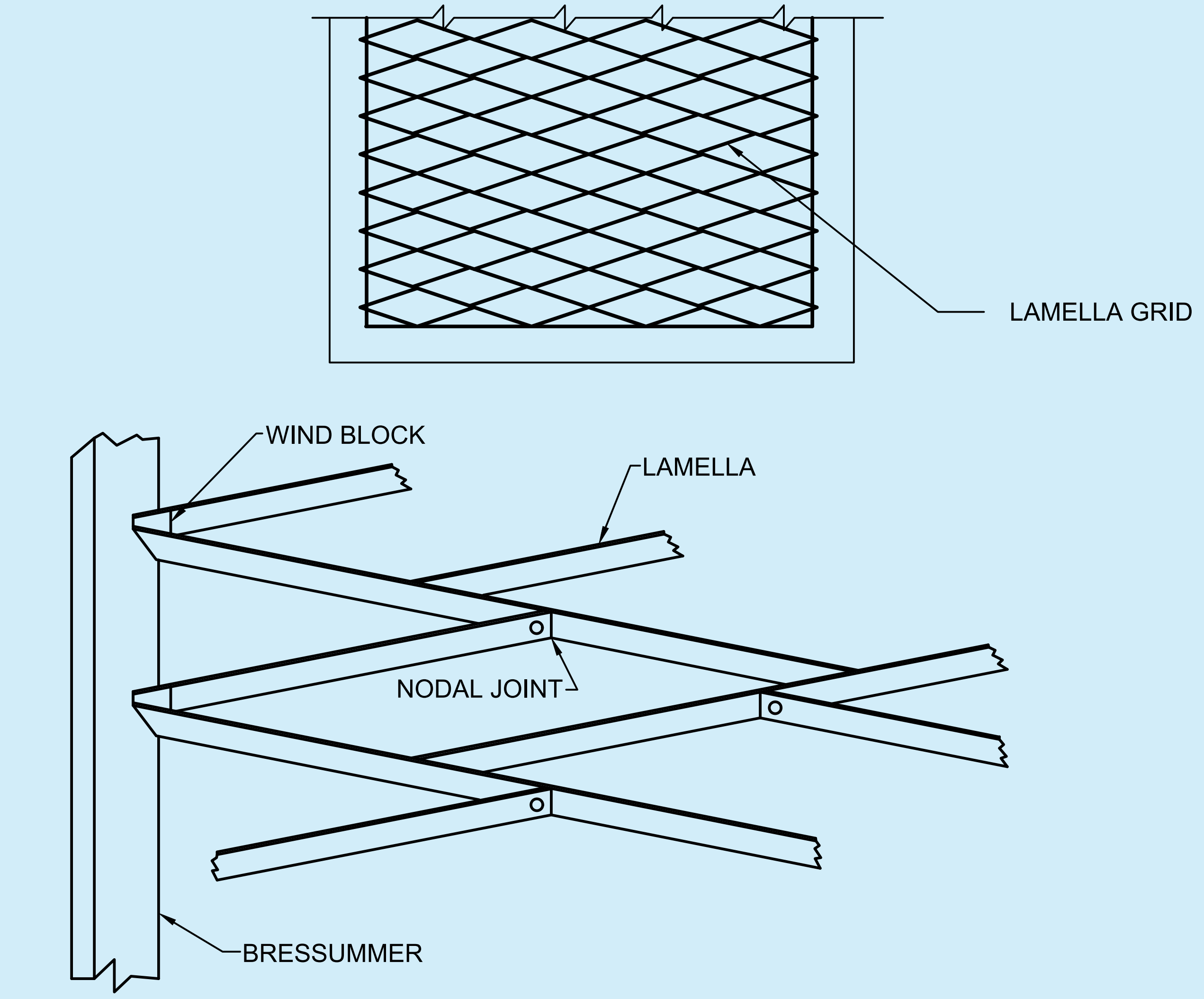
   2) i) For skew angle of 19° (diamond angle 38°);
      ii) For 2.5m length of plank, spacing shall be 800 mm maximum; and
      iii) For 1.0 m length of plank, spacing shall be 320 mm maximum.

g) Value of horizontal thrust, resultant thrust and maximum bending moment, are taken on per metre length of structure in case of transverse direction of arch;

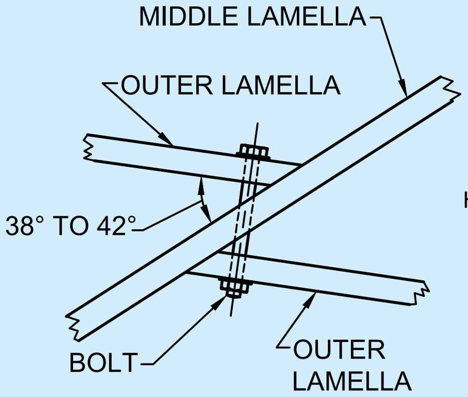
h) Bending moment may be suitably reduced, if so desired by the designer, by applying stability factor if the ratio of the length of structure to the curved length of arch so warrants (as this ratio increases, the stability of the structure decreases);

j) The thrust in the skewed direction of arch, within one spacing of lamellas is shared by two lamella-lines in skewed direction; and

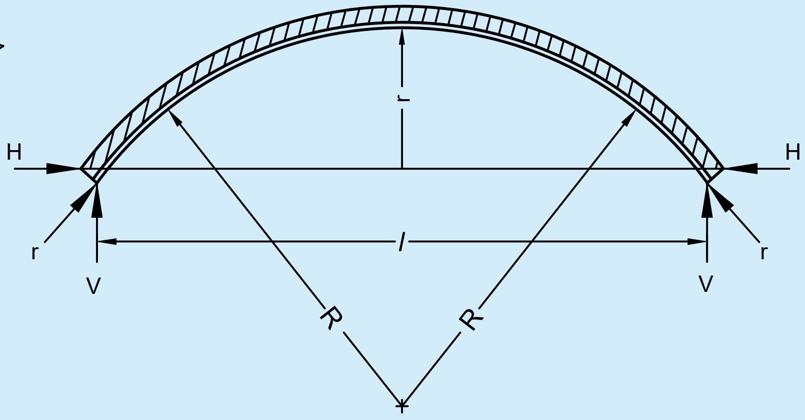
k) More than one bolt (MS) shall be used for nodal joint. For design check of bolt against tension, half the value of thrust in skewed direction will be considered for calculations purposes in light of (j) {in case of stiff roof covering material [that is, corrugated galvanized iron (CGI) sheet, close boarding, etc] all lamella planks will be held jointly behaving as a monolithic unit to a large extent and the actual stresses developed in bolt will be reduced resulting in lesser actual tension in bolts than the calculated design value}.


LAMELLA GRID
WIND BLOCK
LAMELLA
NODAL JOINT
BRESSUMMER

LAMELLA GRID


MIDDLE LAMELLA
OUTER LAMELLA
38° TO 42°
BOLT
OUTER LAMELLA

LAMELLA NODAL JOINT


r
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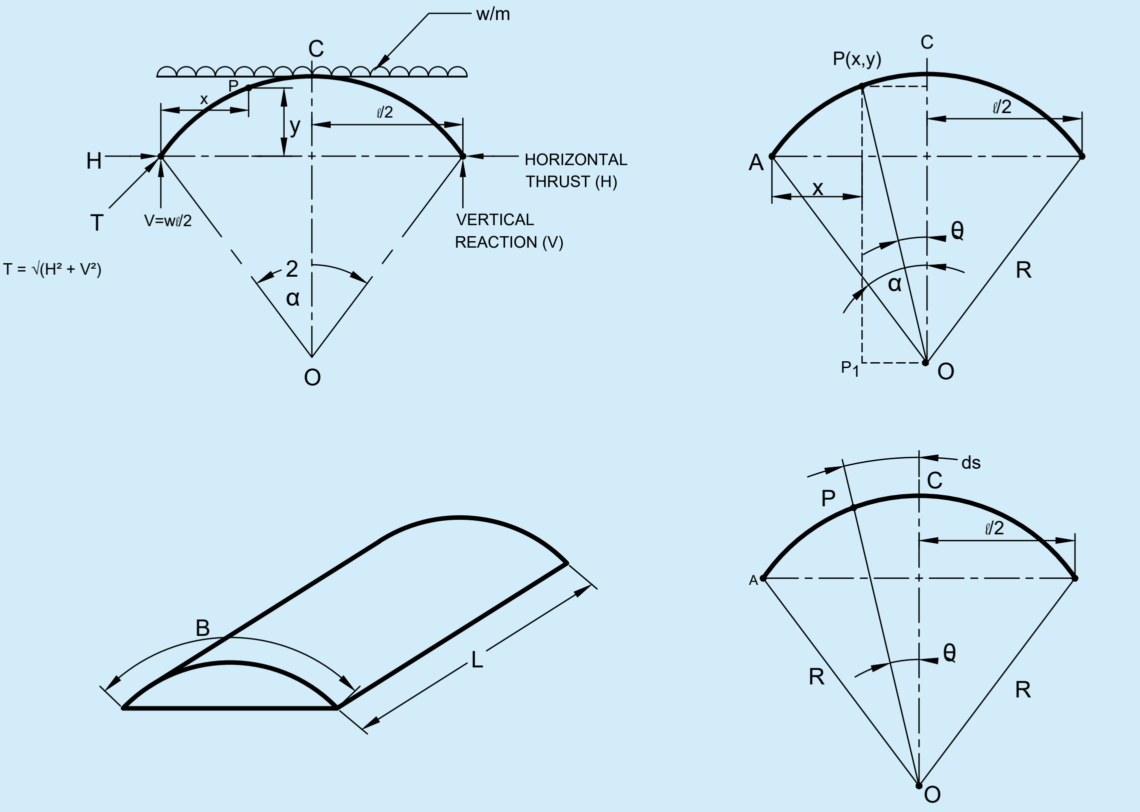
LOAD REACTION DIAGRAM

FIG. 19 TYPICAL ARRANGEMENT OF LAMELLA ROOFING



NOTES

1 When the ratio of length of the structure (*L*) to the circumference of the arch (*B*) increases, stability of the structure decreases. The roof should be designed as:

a) short roof (say, *L/B* = 1), or

b) long roof (say, *L/B* = 1.5).

Shorter roofs have an advantage over long roofs for economical design. However, there is no such advantage beyond *L/B* of 4.

2 Due to stiff roof covering material, stiffness is induced in an arch, which results in safer design.

FIG. 20 STABILITY OF LAMELLA ARCH ROOF

17.2.1.1 *Horizontal thrust*

Any of the known methods for solving a statically indeterminate structure is used to evaluate horizontal thrust, bending moment, etc, to which a segmental arch will be subjected under the given condition of loadings. For 60° segmental arch, the radius of an arch will be equal to the span of the arch. Horizontal thrust can be calculated by the following two methods:

a) *Method* 1

Horizontal thrust (H_B) per length of one bay (that is, distance between 'tie-rod spacing' or 'column centres'):

$$H_B = (DL + IL) \times \left[\frac{l^2 + {s_t}^2}{8r}\right]$$

where

H_B = horizontal thrust, in N;

DL = dead load, in N;

IL = imposed load, in N;

l = span of arch, in m;

s_t = tie-rod spacing, in m; and

r = rise of roof arch, in m.

b) *Method* 2

Horizontal thrust (H_1) per metre length of structure (in N):

$$H_1 = C \times w \times R$$

where

C = coefficient varying with the angle of arch and radius of arch;

w = equivalent distributed load per metre of span (in N/m); and

R = radius of circular arch (in m).

Horizontal thrust (H_1) is evaluated as:

$$H_1 = \frac{\int \mu y ds}{\int y^2 ds}$$

where

H_1 = horizontal thrust (per metre length of structure), in N;

μ = bending moment at any point 'P' distance 'x' metre from one end of springing point of arch and for vertical loads only (consider arch as a beam simply supported carrying the same load);

y = height of point 'P' above springing line of arch;

θ = angle which the point 'P' makes at the centre of arch with the vertical; and

ds = $Rd\theta$.

Now solution for numerator:

$$\mu = \frac{wl}{2}x - wx\frac{x}{2}$$

$$= \frac{wx}{2}\,(l - x)$$

where

$$x = \frac{l}{2} - R\sin\theta$$

$$x = \frac{R}{2} - R\sin\theta$$

$$x = R\left(\frac{1}{2} - \sin\theta\right)$$

and $y = R\cos\theta - R\cos\alpha$

$y = R(\cos\theta - \cos\alpha)$

and $ds = Rd\theta$

Substitute the values in expression:

$$\int \mu y ds = \int \frac{wx(l-x)}{2} R(cos\,\theta - cos\,\alpha)Rd\theta$$

Solve for limits of θ from $-\alpha$ to $+\alpha$ = $\int_0^{\alpha} wR^4(\frac{1}{4} - sin^2\,\theta)(cos\,\theta - cos\,\alpha)d\theta$

Again for denominator;

$$\int y^2\,ds = \int_{-\alpha}^{+\alpha} R^2(\cos\theta - \cos\alpha)^2 Rd\theta$$

$$= 2R^3 \int_0^{\alpha} (\cos\theta - \cos\alpha)^2\,d\theta$$

Therefore, $H_1 = \frac{\int \mu y ds}{\int y^2 ds}$

$$= \frac{wR^4 \int_0^{\alpha} \left[\frac{1}{4} - \sin^2\theta\right](\cos\theta - \cos\alpha)\,d\theta}{2R^3 \int_0^{\alpha}(\cos\theta - \cos\alpha)^2\,d\theta}$$

On simplification of the above equation for a particular arch, $\alpha = 30°$, $R = l$ (α in radian = 0.5 approx),
$\sin\alpha = 1/2$
$\cos\alpha = \sqrt{3}/2$

$H_1 = 0.923\,wR$

Vertical reaction, $V_1 = \frac{Total\ load \times span}{2}$ at each end of arch due to dead and live loads per metre length (curved strip) of arch roofing.

17.2.1.2 *Resultant thrust*, T_1

Due to horizontal thrust and the vertical reaction, resultant transverse thrust, in kg per metre length on the arch can be worked out:

$$T_1 = \sqrt{{H_1}^2 - {V_1}^2}$$

17.2.1.3 *Maximum bending moment*

Bending moment at any point 'P' on arch making an angle of θ with the vertical line OC is, $BM = \mu - (H \times y)$
$= \frac{wR^2}{2}\left(\frac{1}{4} - \sin^2\theta\right) - 0.923wR^2\left(\cos\theta - \frac{\sqrt{3}}{2}\right)$

Differentiating the above expression for BM, we get

$$\frac{dM}{d\theta} = (-\sin\theta\cos\theta + 0.923\sin\theta)wR^2$$

It is well known that $\frac{dM}{d\theta}$ = shear force

This shear is zero when BM is maximum, that is:

either θ = zero

or $\cos\theta = 0.923$

Therefore, $\theta = \cos^{-1}0.923 = 22.6°$

Substituting these values in the above equation of bending moment, we get maximum BM, that is, the maximum BM occurs at:

a) crown of arch; and

b) at 22.6° from the central line OC.

Thus when $\theta = 0$

$$BM = \frac{wR^2}{2} \times \frac{1}{4} - 0.923wR^2\left(1 - \frac{\sqrt{3}}{2}\right)$$

$$= wR^2(0.125 - 0.12368)$$

$$= 0.001\ 32wR^2$$

When $\theta = 22.6°$, $\sin\theta = 0.384$

$$BM = \frac{wR^2}{2}\left(\frac{1}{4} - 0.384\right)^2 - 0.923wR^2(0.923 - 0.866)$$

$$= wR^2(0.125 - 0.073\ 728) - 0.923 \times 0.057wR^2$$

$$= -0.001\ 339wR^2 \text{ or say } -0.001\ 34wR^2$$

The arch has to be designed for the greater of the two values (subject to the longitudinal stiffness coefficient on the basis of ratio *L*/*B* of length of the structure to the circumference of the arch) for economical design.

NOTE — Value of horizontal thrust, H_1, resultant thrust, T_1 and bending moment, M_1 shall be for 1 m length of building.

17.2.1.4 *Spacing of lamellas*

Lengthwise spacing of lamellas depends upon the angle of skew lamellas and the length of the planks used for lamellas (As a general guidance it may be stated that the angle enclosed between the intersecting skewed arches should not exceed 45°. An angle between 38° and 40° is always preferred).

17.2.1.5 *Design of lamella sizes*

Net section of each of lamellas is assumed in curved profile conforming to the curvature of the roof surface.

Maximum BM = M_s over 600 mm spacing of lamella in the direction of skew angle, for example:

$$= \frac{0.6M_1 \times 10}{\cos 19°} \text{ Nm}$$

where

M_1 = maximum bending moment per metre length of structure in transverse direction.

And maximum thrust *N* (in Newton) on this strip of 600 mm in skewed direction is:

$$N = \frac{0.6T_1}{\cos 19°} \times \frac{1}{2}$$

(as the force T_1 is shared by two lines of lamellas)

where

N = maximum thrust on 600 mm strip in skewed direction; and

T_1 = resultant thrust in transverse direction (in N) per metre length of structure.

Now total compressive and flexural stresses should not exceed the allowable safe stress of timber species used for lamella plank. For fulfilling this condition the following equation should be checked:

$$\frac{N/A}{f_{c\,\mathrm{II}}} + \frac{M_s/Z}{f_t} \leq 1$$

where

N = maximum thrust in skewed direction on strip of 600 mm (in N) corresponding to the maximum bending moment;

A = cross-sectional area of lamella plank, in mm^2;

Z = section modulus of lamella plank, in mm^3;

$f_{c\,\mathrm{II}}$ = safe compression strength of timber fibre parallel to grain, N/mm^2;

M_s = bending moment over 600 mm strip of arch in skewed direction, Nmm;

f_t = safe tensile strength of timber parallel to grain, N/mm^2; and

NOTE — In case the lamella plank is under stressed, the minimum section for practical reasons shall be 25 mm × 100 mm subject to satisfying minimum edge and intermediate distances for accommodating bolts at nodal joints.

17.2.1.6 *Design of bolts for nodal joint*

To avoid any possibility of hinge action with the use of bolts, it is imperative to adopt two or more bolts of smaller diameter and adequately spaced in accordance with the good practice [6-3A(9)].

Assume diameter of bolt 'd' in mm, and length of bolt in one plank 't' mm, that is, thickness of middle lamella plank.

Area of contact of bolt with timber plank = $d \times t$ mm^2

a) *Check against crushing of timber at contact point of bolt* — For the bolt to transmit load without crushing the timber fibres, the following condition shall be satisfied:

$$t \times d \times \text{compressive stress perpendicular to grain for the timber species} > P$$

where

P = total load to be transmitted through bolt, in N.

b) *Check against tension in bolt* — Arrangement of bolts at the junction of lamellas result in pure tension in bolt as bolt line is at right angle to the outer two lamellas:

Therefore, $Z_t = N \times \cot 2\phi$

where

Z_t = tension in bolt, in N;

N = normal thrust corresponding to maximum moment M_s (in N); and

$= \frac{T_1}{\cos} \times \frac{1}{2}$

T_1 = resultant thrust in transverse direction (in N) per metre length of structure.

Therefore;

Area of bolt (A_t) × tensile stress of steel (F_t) $\geq Z_t$

Area of bolt required for safe design = Z_t/F_t

Select the diameter to engage at least two bolts.

(Required area of bolt is the effective area after considering reduction of area at the threaded end, which is generally 17 percent of the actual bolt diameter).

17.2.1.7 *Design of steel washer at joints*

Area of steel plate = A_t mm^2

Stress perpendicular to grain of wood at the point of contact with steel plate washer = Z_t/A_t N/mm^2

If $Z_t/A_t \leq$ compressive stress perpendicular to grain of the species of timber used, the assumed section is safe.

17.3 Construction

Design and construction of lamella roofs in India assumes the roof surfaces to be cylindrical with every individual lamella an elliptic segment of an elliptical arch of constant curved length but of different curvature. Lamella construction is thus more of an art than science as there is no analytical method available for true generation of schedule of cutting lengths and curvature of curved members forming the lamella grid. Dependence of an engineer on the practical ingenuity of master carpenter is almost final. All the lamella joints shall be accurately cut and fitted to give full bearing without excessive deformation or slip. Bolts at lamella splices shall be adequate to hold the members in their proper position and shall not be over tightened to cause bending of the lamellas or mashing of wood under the bolt heads. Connection of lamellas to the end arches shall be adequate to transmit the thrust or any other force. Sufficient false work or sliding jig shall be provided for the support of lamella roof during actual construction/erection. To avoid excessive deformation in a lamella system, all joints should be carefully fitted and well tightened.

18 NAIL AND SCREW HOLDING POWER OF TIMBER

18.1 General

One of the most common ways of joining timber pieces to one another is by means of common wire nails and wood screws. Timber is used for structural and non-structural purposes in form of scantlings, rafters, joists, boarding, crating and packing cases, etc, needing suitable methods of joining them. Nevertheless, it is the timber which holds the nails or screws and as such pulling of the nails/screws is the chief factor which come into play predominantly. In structural nailed joints, nails are essentially loaded laterally, the design data for which is already available in good practice [C-3A(7)]. Data on holding power of nails/screws in different species is also useful for common commercial purposes. The resistance of mechanical fastenings is a function of the specific gravity of wood, direction of penetration with respect to the grain direction, depth of penetration and the diameter of fastener assuming that the spacing of fasteners should be adequate to preclude splitting of wood.

18.2 Nails

Nails are probably the most common and familiar fastener. They are of many types and sizes in accordance with the accepted standard [C-3A(18)]. In general nails give stronger joints when driven into the side grain of wood than into the end grain. Nails perform best when loaded laterally as compared to axial withdrawal so the nailed joints should be designed for lateral nail bearing in structural design. Information on withdrawal resistance of nails is available and joints may be designed for that kind of loading as and when necessary.

18.3 Screw

Next to the hammer driven nails, the wood screw may be the most commonly used fastener. Wood screws are seldom used in structural work because of their primary advantage is in withdrawal resistance for example for fixing of ceiling boards to joists, purlin cleats, besides the door hinges, etc. They are of considerable structural importance in fixture design and manufacture. Wood screws are generally finished in a variety of head shapes and manufactured in various lengths for different screw diameters or gauges in accordance with the accepted standards [C-3A(19)].

The withdrawal resistance of wood screws is a function of screw diameter, length of engagement of the threaded portion into the member, and the specific gravity of the species of wood. Withdrawal load capacity of wood screws are available for some species and joints may be designed accordingly. End grain load on wood screws are unreliable and wood screws shall not be used for that purpose.

18.4 Nail and screw holding power is one of the very important properties of timber which governs its utilization in diverse industrial and engineering fields. This has been evaluated by experimental method followed for evaluation of such properties as per normal procedure given in the accepted standards [C-3A(20)], using:

a) *Specimen* — of size 150 mm × 50 mm × 50 mm;

b) *Nail* — diamond pointed wire nail of 50 mm length and 2.50 mm shank diameter;

c) *Screw* — galvanized gimlet pointed, No. 8; and

d) *Conditions* — penetration 25 mm.

While nails were driven by a hand hammer, screws were driven by a screw driver in a 2.5 mm diameter prebore on radial, tangential and end faces.

Composite nail and screw holding power of some Indian timbers, evaluated as above, is presented in Table 23 for guidance in design.

Table 23 Composite Nail and Screw Holding Power of Some Indian Timbers

(*Clause* 18.4)

Sl No.	**Timber Species**	**Locality**	**Standard Specific Gravity (Weight Oven Dry)/Volume Green**	**Composite Holding Power** N	
				Nail	Screw
(1)	(2)	(3)	(4)	(5)	(6)
i)	*Acacia catechu* (Khair)	Uttar Pradesh	0.888	2 119	5 454
ii)	*Acacia ferruginea*	Maharashtra	0.876	1 893	5 700
iii)	*Acacia leucophloea*	Madhya Pradesh	0.660	1 776	4 503
iv)	*A. nilotica* (Babul)	Uttar Pradesh	0.670	1 815	5 219
v)	*Acrocarpus fraxinifolius* (Mundani)	Uttar Pradesh	0.662	1 020	2 865
vi)	*Adina oligocephala*	Arunachal Pradesh	0.612	1 795	3 453
vii)	*Aesculus indica* (Horse chestnut)	Himachal Pradesh	0.428	755	2 119
viii)	*Albizia lucida*	Arunachal Pradesh	0.501	1 462	3 188
ix)	*Anogeissus sericea*	Madhya Pradesh	0.738	1 570	4 944
x)	*Aphanamixis polgstachya* (Pitraj)	West Bengal	0.557	1 648	3 110
xi)	*Araucaria cunning hanvil*	Uttar Pradesh	0.486	1 128	2 943
xii)	*Aritocarpus lakoocha* (Lakooch)	Uttar Pradesh	0.530	1 050	2 982
xiii)	*Azadirachta indica* (Neem)	Uttar Pradesh	0.693	2 001	5 219
xiv)	*Betula alnoides* (Birch)	West Bengal	0.569	1 648	3 237
xv)	*Broussonetia papyrifera*	Uttar Pradesh	0.394	746	1 383
xvi)	*Canarium strictum* (White dhup)	Assam	0.486	1 207	2 619
xvii)	*Cassia fistula* (Amaltos)	Uttar Pradesh	0.746	2 109	4 748
xviii)	*Cassia siamea*	Madhya Pradesh	0.697	1 315	3 649

Table 23 (*Continued*)

Sl No.	Timber Species	Locality	Standard Specific Gravity (Weight Oven Dry)/Volume Green	Composite Holding Power N	
				Nail	Screw
(1)	(2)	(3)	(4)	(5)	(6)
xix)	*Castanopsis indica* (Indian chestnut)	Meghalaya	0.591	1 697	3 090
xx)	*Cupressus cashmeriana*	Uttar Pradesh	0.409	903	2 325
xxi)	*Dipterocarpus bourdilloni* (Gurjan)	Kerala	0.577	912	2 766
xxii)	*Dipterocarpus indicus* (Gurjan)	Karnataka	0.618	1 109	2 904
xxiii)	*Eucalyptus hybrid*	Uttar Pradesh	0.632	1 736	2 453
xxiv)	*Exbucklandia –populnea* (Pipli)	West Bengal	0.558	1 403	3 443
xxv)	*Fraxinus udheri*	Uttar Pradesh	0.539	1 354	3 483
xxvi)	*Gluta travancorica* (Gluta)	Tamil Nadu	0.621	1 324	2 923
xxvii)	*Grewia tiliifolia* (Dhaman)	Karnataka	0.679	1 746	2 884
xxviii)	*Holarhena antidysenterica* (Kurchi)	Uttar Pradesh	0.445	1 020	2 698
xxix)	*Lagerstroemia specicosa* (Jarul)	Kerala	0.531	1 697	2 717
xxx)	*Lannea coromendelica* (Jhingan)	Rajasthan	0.497	1 216	2 894
xxxi)	*Magnolia hookeri*	Arunachal Pradesh	0.403	1 128	1 746
xxxii)	*Mangifera indica* (Mango)	Uttar Pradesh	0.411	1 383	2 433
xxxiii)	*Manglietia spp.*	Assam	0.409	912	2 031
xxxiv)	*Mesna assamica* (Sianhor)	Assam	0.687	1 795	3 502
xxxv)	*Michelia champaca* (Champ)	Assam	0.488	1 128	2 737
xxxvi)	*Mimusops elengi*	Karnataka	0.762	2 158	5 101
xxxvii)	*Morus alba* (Mulberry)	Uttar Pradesh	0.557	1 030	4 091
xxxviii)	*Morus laevigata* (Bola)	Assam	0.567	932	2 600
xxxix)	*Morus spp.*	Uttar Pradesh	0.594	1 589	3 129
xl)	*Nephelium litchi*	Uttar Pradesh	0.762	1 825	4 238
xli)	*Oroxylum indicum*	Andaman	0.370	961	1 736
xlii)	*Ougenia oogeinensis* (Sandan)	Uttar Pradesh	0.701	1 570	5 317
xliii)	*Pinus kesiya*	Nagaland	0.489	1 089	2 354
xliv)	*Pinus kesiya*	Orissa	0.453	1 118	2 325
xlv)	*Pinus roxburghii* (Chir)	Uttar Pradesh	0.453	1 128	2 482
xlvi)	*Pinus wallichiana* (Kail)	Himachal Pradesh	0.468	873	1 521
xlvii)	*Pistacia integerrima*	Jammu and Kashmir	0.733	1 324	4 120
xlviii)	*Polyalthia spp.* (Debdara)	Madhya Pradesh	0.586	1 452	2 953
xlix)	*Pometa pinnata*	Andaman	0.636	1 579	3 532

Table 23 (*Concluded*)

Sl No.	Timber Species	Locality	Standard Specific Gravity (Weight Oven Dry)/Volume Green	Composite Holding Power N	
				Nail	Screw
(1)	(2)	(3)	(4)	(5)	(6)
l)	*Prunus nepalensis* (Arupati)	West Bengal	0.482	1 099	2 531
li)	*Pterocarpus marsupium*	Bihar	0.587	1 305	2 982
lii)	*Pterygota alata* (Narikel)	Assam	0.475	1 403	3 463
liii)	*Pterygota alata* (Narikel)	Kerala		1 089	2 639
liv)	*Robinia spp.*	Jammu and Kashmir	0.629	2 227	3 777
lv)	*Sageraea elliptica* (Chooi)	Andaman	0.682	1 805	4 522
lvi)	*Schleichera oleosa* (Kusum)	Bihar	0.841	1 884	4 277
lvii)	*Shorea robusta* (Sal)	Uttar Pradesh	0.774	1 216	3 620
lviii)	*Soymida ferifuga*	Tamil Nadu	0.965	1 687	6 033
lix)	*Tectona grandis* (Teak)	Uttar Pradesh	0.574	1 020	3 404
lx)	*Tectona grandis* (Teak)	Tamil Nadu	0.633	1 364	3 483
lxi)	*Tectona grandis* (Teak)	Maharashtra	0.526	971	3 728
lxii)	*Terminalia alata* (Laurel)	Uttar Pradesh	0.806	2 521	3 806
lxiii)	*Terminalia citrina*	Assam	0.629	1 540	3 855
lxiv)	*Terminalia paniculata* (Kindal)	Kerala	0.630	1 982	3 257
lxv)	*Tetrameles nudiflora* (Maina)	Assam	0.289	667	1 413
lxvi)	*Thespesia populnea* (Bhendi)	Maharashtra	0.647	1 923	5 425
lxvii)	*Tsuga brunonsiana*	West Bengal	0.380	540	2 050
lxviii)	*Ulmus coallichiana* (Elm)	Himachal Pradesh	0.455	834	1 766
lxix)	*Zanthoxylum spp.*	West Bengal	0.496	1 138	3 071

19 PROTECTION AGAINST TERMITE ATTACK IN BUILDINGS

19.1 Two groups of organisms which affect the mechanical and aesthetic properties of wood in houses are fungi and insects. The most important wood destroying insects belong to termites and beetles. Of about 250 species of wood destroying termites recorded in India, not more than a dozen species attack building causing about 90 percent of the damage to timber and other cellulosic materials. Subterranean termites are the most destructive of the insects that infest wood in houses justifying prevention measures to be incorporated in the design and construction of buildings.

19.1.1 Control measures consist in isolating or sealing off the building from termites by chemical and non-chemical construction techniques. It is recognized that 95 percent damage is due to internal travel of the termites from ground upwards rather than external entry through entrance thus calling upon for appropriate control measures in accordance with good practices [C-3A(21)].

19.2 Chemical Methods

Termites live in soil in large colonies and damage the wooden structure in the buildings by eating up the wood or building nests in the wood. Poisoning the soil under and around the building is a normal recommended practice. Spraying of chemical solution in the trenches of foundations in and around walls, areas under floors before and after filling of earth, etc. In already constructed building the treatment can be given by digging trenches all around the building and then giving a liberal dose of chemicals and then closing the trenches.

19.3 Wood Preservatives

Natural resistance against organisms of quite a few wood species provides durability of timber without special protection measure. It is a property of heartwood while sapwood is normally always susceptible to attack by organisms. Preservatives should be well applied with sufficient penetration into timber. For engineers, architects and builders, the following are prime considerations for choice of preservatives:

a) Inflammability of treated timber is not increased and mechanical properties are not decreased;

b) Compatibility with the glue in laminated wood, plywood and board material;

c) Water repellent effect is preferred;

d) Possible suitability for priming coat;

e) Possibility of painting and other finishes;

f) Non-corrosive nature in case of metal fasteners; and

g) Influence on plastics, rubber, tiles and concrete.

19.4 Constructional Method

Protection against potential problem of termite attack can simply be carried out by ordinary good construction which prevents a colony from gaining access by:

a) periodic visual observations on termite galleries to be broken off;

b) specially formed and properly installed metal shield at plinth level; and

c) continuous floor slabs, apron floors and termite grooves on periphery of buildings.

20 CROSS-LAMINATED TIMBER (CLT)

Cross-laminated timber (CLT) is an engineered wood product used as a structural component in mass timber construction. CLT panels shall consist of not less than three layers of solid-sawn lumber or structural composite lumber, with adjacent layers cross-oriented and bonded with structural adhesives to form a solid wood element.

20.1 General Requirements

20.1.1 *Material Specifications*

CLT panels shall be manufactured to meet stringent performance criteria for mechanical properties, including load-bearing capacity, dimensional tolerances, and adhesive bond durability to ensure structural reliability. Panels should also demonstrate resistance to delamination and other essential physical properties through rigorous testing to validate long-term performance under various environmental conditions.

The timber used for CLT production shall be kiln-dried to a moisture content of 12 percent ± 2 percent, ensuring stability and resistance to deformation.

20.1.2 *Dimensions*

CLT panels shall have a minimum thickness of 50 mm, with thicknesses ranging up to 500 mm for structural applications. The typical panel dimensions for commercial use may be up to 18 000 mm in length and 3 000 mm in width.

The number of layers shall be odd (for example, 3, 5, 7), with layer thicknesses adjusted according to structural requirements.

20.2 Physical Properties

20.2.1 *Delamination Resistance*

Delamination testing shall be conducted to ensure that total delamination ($\mathit{Delam}_{\mathrm{tot}}$) shall not exceed 10 percent, and maximum delamination ($\mathit{Delam}_{\mathrm{max}}$) shall not exceed 40 percent, ensuring durability and structural integrity.

Results from studies indicate that CLT made from plantation-grown hardwoods such as Rubberwood, *Melia dubia* (*Malabar Neem*), and Eucalyptus meets these requirements, with delamination values comparable to Radiata pine, a commonly used species in CLT production.

20.2.2 *Water Absorption and Swelling Properties*

CLT panels shall be evaluated for water absorption (WA), thickness swelling (TS), and volumetric swelling (VS) using the water soaking method. These parameters shall be assessed to ensure that the panels meet acceptable limits for moisture-induced dimensional changes, maintaining stability under varying environmental conditions.

Reference to results from studies (Table 24 and Table 25) shows that hardwood species demonstrate comparable performance to Radiata pine, indicating their suitability for structural applications.

For detailed information, a reference may be made to *A Hybrid Approach to Green Building Construction Using Mass Timber February* 2024, DOI: 10.58532/V3BICE3P8CH2 by Ram Kumar V R and Amitava Sil.

Table 24 Physical Properties of Polyurethane (PUR) Bonded Homogenous CLT in Comparison to Radiata Pine CLT

(*Clause* 20.2.2)

Sl No.	**Type of CLT**	$\mathit{Delam}_{\mathrm{tot}}$ Percent	$\mathit{Delam}_{\mathrm{max}}$ Percent	**WA** Percent		**TS** Percent		**VS** Percent	
		CLT	CLT	CLT	Solid wood	CLT	Solid wood	CLT	Solid Wood
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
i)	Rubberwood	6.49 (0.98)	29.01 (2.90)	31.23 (4.19)	52.91 (5.47)	3.26 (0.93)	9.93 (1.82)	3.26 (0.93)	9.93 (1.82)
ii)	*Melia dubia*	6.77 (0.78)	26.65 (3.86)	23.51 (3.48)	39.98 (9.94)	4.38 (2.28)	9.15 (3.29)	7.86 (1.89)	13.58 (6.85)
iii)	Silver oak	8.08 (1.21)	21.3 (4.13)	14.10 (3.66)	35.88 (12.28)	5.05 (1.02)	13.19 (1.89)	8.37 (1.43)	20.83 (2.62)
iv)	Eucalyptus	6.61 (2.29)	34.10 (3.28)	25.68 (7.57)	38.97 (7.57)	4.06 (1.24)	15.08 (7.76)	7.39 (1.70)	17.92 (7.74)
v)	Radiata pine	6.63 (0.86)	26.70 (3.63)	29.35 (5.46)	40.03 (7.20)	4.29 (0.29)	12.47 (3.01)	14.09 (0.66)	20.62 (2.82)

NOTE — Values in the parentheses indicate standard deviation.

Table 25 Physical Properties of Hybrid CLT in Comparison to Radiata Pine CLT

(*Clause* 20.2.2)

Sl No. (1)	Type of CLT (2)	***Delam***$_{tot}$ Percent (3)	***Delam***$_{max}$ Percent (4)	**WA** Percent (5)	**TS** Percent (6)	**VS** Percent (7)
i)	Hybrid with *Eucalyptus* (E) and *Melia dubia*(M) (EME)	7.68 (0.57)	31.62 (4.37)	26.43 (3.66)	6.33 (1.77)	15.86 (1.47)
ii)	Hybrid with *Melia dubia* (M) and *Eucalyptus* (E) (MEM)	6.68 (0.53)	28.65 (3.82)	24.35 (6.86)	5.59 (1.38)	8.85 (1.93)
iii)	Hybrid with *Melia dubia* (M) and Silver oak (S) (MSM)	7.06 (1.22)	28.96 (1.12)	21.86 (5.09)	5.43 (1.84)	7.04 (3.94)
iv)	Hybrid with silver oak (S) and *Melia dubia* (M) (SMS)	7.65 (0.23)	26.62 (1.45)	15.51 (5.6)	8.43 (2.30)	8.24 (2.96)
v)	Radiata pine	6.63 (0.86)	26.70 (3.63)	29.35 (5.46)	4.29 (0.29)	14.09 (0.66)

NOTE — Values in the parentheses indicate standard deviation.

20.2.3 *Density*

The density of CLT panels shall be determined according to the timber species and adhesive used. The density of CLT panels shall range from 5 500 kg/m³ to 8 500 kg/m³, depending on the species (for example, Rubberwood, Eucalyptus). Table 26 provides the density values for different species used in CLT production.

Table 26 Density of CLT Panels

(*Clause* 20.2.3)

Sl No. (1)	**Species** (2)	**Density of Wood (at 12 Percent Moisture Content)** kg/m^3 (3)	**Density of CLT** kg/m^3 (4)
i)	Rubberwood	6 200 (0.05)	6 500 (0.08)
ii)	*Melia dubia*	5 100 (0.04)	5 500 (0.01)
iii)	Eucalyptus	8 000 (0.05)	8 500 (0.03)
iv)	Silver oak	6 200 (0.02)	6 800 (0.02)
v)	Radiata pine	4 200 (0.03)	4 500 (0.03)
vi)	EME	–	7 700 (0.02)
vii)	MEM	–	6 400 (0.03)
viii)	MSM	–	5 500 (0.02)
ix)	SMS	–	6 700 (0.01)

NOTE — Values in the parentheses indicate standard deviation.

20.3 Mechanical Properties

20.3.1 *Bending, Compression, and Shear Strength*

Mechanical testing shall include four-point bending tests, compression parallel to grain tests and block shear tests. The results shall comply with the minimum strength requirements for structural applications as specified in Part C 'Structural Design, Section 1 Loads and Load Effects' of this NBCS.

Table 27 and Table 28 present the mechanical properties of homogeneous and hybrid CLT panels, showing adequate performance for structural uses. Rubberwood CLT exhibited higher mechanical properties than hybrid configurations in some tests.

20.3.2 *Impact of Adhesive Type on Mechanical Performance*

The choice of adhesive (for example, phenol resorcinol formaldehyde, PUR) shall be considered, as it affects the bonding strength and durability. Mechanical properties of CLT bonded with different adhesives, indicating that PRF-bonded panels have superior performance.

Table 27 Mechanical Properties of Homogeneous CLT Panels

(*Clause* 20.3.1)

Sl No. (1)	**CLT Made from** (2)	**MoE** MPa (3)	**MoR** MPa (4)	**Compression Parallel to Grain** MPa (5)	**Block Shear Strength** MPa (6)
i)	Rubberwood	8 600 (328.3)	48.7 (13.8)	25.0 (2.3)	6.7 (1.4)
ii)	*Melia dubia*	6 758 (598.6)	44.8 (5.7)	23.0 (1.8)	6.3 (0.7)
iii)	Silver oak	8 835 (739.5)	64.2 (6.9)	26.34 (2.0)	6.7 (0.5)
iv)	*Eucalyptus*	13 811 (1468.7)	81.6 (8.3)	35.40 (6.7)	6.65 (0.6)
v)	Radiata pine	4 542 (1 024.3)	49.6 (10.3)	16.4 (2.3)	3.1 (0.5)

NOTE — Values in the parentheses indicate standard deviation.

Table 28 Mechanical Properties of Hybrid CLT Panels

(*Clause* 20.3.1)

Sl No. (1)	**CLT Made from** (2)	**MoE** MPa (3)	**MoR** MPa (4)	**Compression Parallel to Grain** MPa (5)	**Block Shear Strength** MPa (6)
i)	EME	10 943 (1 074.8)	70.0 (7.2)	30.5 (3.7)	5.8 (0.6)
ii)	MEM	7 770 (938.5)	47.0 (4.5)	24.6 (2.2)	5.8 (0.6)
iii)	SMS	7 701 (600.5)	61.6 (7.5)	33.5 (4.0)	5.6 (0.5)
iv)	MSM	6 328 (652.8)	45.5 (4.3)	24.2 (3.1)	5.3 (0.5)

NOTE — Values in the parentheses indicate standard deviation.

20.4 Fire Safety Requirements

20.4.1 *Fire Resistance Ratings*

CLT panels should have a fire-resistance rating in accordance with Part F 'Fire and Life Safety' of this NBCS. This shall be achieved through inherent fire resistance, encapsulation with materials like gypsum board (minimum thickness 13 mm), or a combination of methods.

The charring rate of CLT shall be considered in fire design calculations, with a recommended charring rate of 0.65 mm/min for calculating the load-bearing capacity during fire exposure.

20.4.2 *Protection of Connections*

Steel connectors and other metal components shall be protected with fire-resistant coatings or encased in non-combustible materials to ensure structural integrity during a fire.

20.5 Durability and Biological Resistance

20.5.1 *Preservative Treatments*

CLT panels shall be treated with preservatives like bifenthrin or copper chrome borate to enhance resistance to biological degradation. Testing has shown that preservative-treated CLT has improved resistance to termite and fungal attacks compared to untreated samples (*see* Table 29 for termite degradation results).

Table 29 Degradation of Samples due to Termite Attack

(*Clause* 20.5.1)

Sl No. (1)	**Sample** (2)	**Average Degradation** percent (3)	**Duration of Exposure** months (4)
i)	Control solid wood	100	6
ii)	Control CLT	100	9
iii)	Calcium channel blockers (CCB) treated CLT	60	36
iv)	Bifenthrin treated CLT	0	36

20.5.2 *Performance Under Biological Exposure*

Durability testing shall include assessments for resistance to termites, white rot and brown rot fungi. Untreated rubberwood is highly susceptible to biological degradation, while treated samples showed minimal degradation after prolonged exposure.

20.5.3 *Effect of Preservatives on Mechanical Properties*

The use of preservatives should not adversely affect the mechanical properties of CLT. Block shear strength tests indicate that treated panels retain comparable mechanical performance to untreated panels.

20.6 Handling, Storage and Installation

20.6.1 *Moisture Protection*

During construction, CLT panels shall be protected from moisture exposure. Panels should be stored in a dry environment and water infiltration during transportation and installation shall be minimized.

21 MASS TIMBER

Structural elements primarily composed of solid, built-up, panelized, or engineered wood products are categorized as products which include, but are not limited to, cross-laminated timber (CLT), glued-laminated timber (glulam), and laminated veneer lumber (LVL). It consists of multiple layers of wood, mechanically or adhesively bonded together to create large, strong and stable components suitable for load-bearing and non-load-bearing uses in construction. Mass timber elements can be used for structural framing, walls, floors, roofs and columns. It applies to the construction of residential, commercial, and public buildings where structural elements, including floors, walls, roofs and columns, are made from engineered wood products like cross-laminated timber (CLT), glued-laminated timber (glulam) and other solid or panellised wood products.

These load-bearing and non-load-bearing products include:

a) Cross-laminated timber (CLT);

b) Glued-laminated timber (Glulam);

c) Nail-laminated timber (NLT); and

d) Laminated veneer lumber (LVL).

21.1 Design and Structural Integrity

21.1.1 *Structural Design Requirements*

a) *Load-bearing capacity* — Mass timber elements shall be designed to carry the vertical and lateral loads imposed on the building in compliance with Part C ‘Structural Design, Section 1 Loads and Load Effects’ of this NBCS. The design shall account for dead loads, live loads, wind loads, seismic loads and other imposed loads;

b) *Cross-sectional dimensions* — The minimum cross-sectional dimensions for mass timber elements (for example, columns, beams, floor slabs) shall be specified based on building height, function and occupancy. For example, CLT panels used for floor slabs should meet a minimum thickness of 100 mm, depending on the structural requirements; and

c) *Deflection limits* — The design of mass timber structures shall ensure that the deflection under service load conditions remains within acceptable limits as defined in this Part of this NBCS.

21.1.2 *Hybrid Systems*

Where mass timber is used in conjunction with steel or concrete, the design should ensure that load paths are continuous and that materials are compatible. Load transfer mechanisms shall be adequately designed to prevent failure at the connection points between materials.

21.1.3 *Seismic Performance*

Mass timber buildings located in seismic zones should be designed to accommodate lateral loads and displacements as per Part C ‘Structural Design, Section 1 Loads and Load Effects’ of this NBCS. Timber's flexibility can offer good seismic performance, but connections and structural integrity should be robustly designed to prevent failure.

21.2 Fire and Life Safety

It should be ensured in accordance with Part F ‘Fire and Life Safety’ of this NBCS.

21.2.1 *Protection of Connections*

All steel connectors, bolts and fasteners used in mass timber construction shall be protected with fire-resistant coatings or enclosed within non-combustible materials to prevent failure during fire exposure.

21.3 Minimum Dimensions and Thickness of Mass Timber Elements

21.3.1 *Columns and Beams*

Mass timber columns and beams shall be designed to meet the structural load requirements with a minimum cross-sectional dimension of 200 mm for columns and 150 mm for beams, depending on the span and load requirements.

21.3.2 *Floor and Roof Panels*

CLT panels used for floor and roof assemblies should meet a minimum thickness of 100 mm for floor systems and 85 mm for roof systems to achieve the required fire and structural performance.

21.3.3 *Wall Panels*

CLT or NLT wall panels shall meet a minimum thickness of 125 mm to ensure fire resistance and structural stability under lateral and vertical loads.

21.4 Construction Practices

21.4.1 *Handling and Installation of Mass Timber Elements*

During construction, care should be taken to protect mass timber elements from moisture. Elements shall be stored in dry conditions and protected from water exposure during construction to prevent damage and degradation.

21.4.2 *Assembly and Connections*

Connections between mass timber elements (for example, floor-to-wall, beam-to-column) should be engineered to handle both static and dynamic loads. These connections shall be made using metal connectors, dowels, or bolts designed to prevent movement and ensure continuous load transfer. Special attention should be paid to fire protection at these connection points.

21.4.3 *Fire Sealing of Penetrations*

Any penetrations for services (for example, plumbing, electrical) through mass timber elements shall be sealed with approved fire-rated materials to maintain the integrity of the fire-rated assembly.

21.5 Sustainability and Environmental Benefits

21.5.1 *Environmental Performance*

Mass timber is recognized for its carbon sequestration properties, where wood captures and stores carbon dioxide. Buildings made from mass timber reduce the overall carbon footprint of the construction process compared to traditional materials like steel and concrete.

21.5.2 *Energy Efficiency*

Mass timber inherent thermal insulation properties help to regulate indoor temperatures, thereby reducing energy consumption for heating and cooling. The thermal resistance of wood should be considered in the building envelope design, allowing for thinner wall assemblies with better insulation compared to conventional materials.

22 LIFE CYCLE ASSESSMENT (LCA) OF TIMBER FOR USE IN BUILDINGS

22.1 Timber used in building structures and elements shall undergo a comprehensive life cycle assessment (LCA) to evaluate its environmental impacts across its entire lifecycle, from raw material extraction to disposal or recycling. LCA provides valuable insights into the sustainability of timber and its environmental footprint in building applications. The assessment shall cover the following stages:

a) *Production and Construction* — This stage evaluates the energy and resources required for the extraction, transportation and processing of raw timber into building materials. It also includes the energy consumption and waste generated during the construction process, as well as the transportation of materials to the construction site.

b) *Use Stage* — The use stage assesses the environmental impacts of timber during the building's operational lifespan. This includes maintenance, repairs and potential replacement of timber components, considering the durability, performance and long-term sustainability of the material.

c) *End-of-Life* — At the end of the building's useful life, the timber structure may undergo demolition, with the materials being processed for waste management, recycling, or reuse. This stage assesses the environmental effects of these processes and the potential for timber materials to be repurposed.

d) *Externalized Impacts beyond the System Boundary* — The incidental effects of recycling, reusing and recovering energy, water, or materials beyond the system boundaries of the LCA study are included in this stage. These externalized impacts consider how recycled timber or materials might contribute to environmental benefits outside the building's lifecycle.

22.2 Environmental Impact Categories

The LCA may be used to assess the environmental impact of timber buildings in several categories, which encompass emissions and pollutants generated throughout the lifecycle. These categories include:

a) *Global Warming Potential* — The contribution of greenhouse gas emissions to climate change;

b) *Acidification Potential* — The potential for acidic compounds to form in the environment, affecting ecosystems and infrastructure;

c) *Eutrophication Potential* — The impact of nutrient loading on water bodies, potentially causing excessive algal growth;

d) *Ozone Depletion Potential* — The impact of substances that contribute to the depletion of the ozone layer; and

e) *Smog Formation Potential* — The potential for air pollution to contribute to the formation of ground-level ozone and smog.

All relevant material and process quantities shall be included in the LCA inventory and their impacts shall be calculated using recognized tools and methodologies.

22.3 Requirements for Life Cycle Assessment

In the context of building with timber, LCA may be required for the following purposes:

a) *Decision-Making Support* — Providing building owners and stakeholders with data on the environmental and sustainability aspects of timber, aiding informed decision-making;

b) *Design Evaluation* — Offering insights into material selection and environmental performance across different design possibilities;

c) *Product Comparison* — Demonstrating the environmental advantages of timber in comparison to alternative building materials;

d) *Environmental Benefit Evaluation* — Helping assess the ecological benefits of innovative timber products or policies; and

e) *Performance Benchmarking* — Comparing the environmental performance of timber buildings against established benchmarks and sustainability goals.

22.4 Methodology for Conducting LCA

The LCA of timber buildings may be conducted iteratively, with increasing detail as the design or construction phases progress. The process should follow these steps:

a) Establish the purpose and scope of the LCA, focusing on the objectives of evaluating timber's environmental impact;

b) Gather data on the timber materials, including their types, quantities, lifespans and lifecycle stages. Special attention should be given to materials used in the production and use stages;

c) Using LCA tools (for example, SimaPro, MATLAB), assess the environmental impacts of timber buildings. The evaluation shall include biogenic carbon considerations, as timber stores carbon from the atmosphere, contributing to carbon sequestration during its lifecycle;

d) Interpret the LCA results by categorizing environmental impacts by building component, material type, and lifecycle stage. Identify key contributors to the building's overall environmental footprint and visualize the outcomes; and

e) Document all findings, including assumptions, methodology and conclusions and present the results in reports for stakeholders. The results shall guide sustainable construction practices and decision-making in timber building projects.

22.5 Reporting

The results of the LCA should be documented, including all assumptions, methodologies and conclusions. Reports should be prepared in accordance with relevant standards and may be used to guide sustainable building practices and decision-making in construction.

ANNEX A

(*Clause* 4.1)

MECHANICAL PROPERTIES OF FOREIGN TIMBER SPECIES

A-1 The Table 30 below specifies the mechanical properties of selected foreign timber species, indicating their density, modulus of elasticity, permissible stresses, and preservative characteristics. This information is intended to serve as a reference for designers and engineers, particularly in cases where such species are imported for structural or allied applications, while ensuring that due consideration is given to relevant standards and treatment requirements.

Table 30 Mechanical Properties of Foreign Timber Species

(*Clause* A-1)

Sl No.	**Species**		**Locality from where Tested**	**Average Density at 12 Percent Moisture Content** kg/m^3	**Modulus of Elasticity (All Grades and All Locations) × 10^3** N/mm^2	**Permissible Stress**			
	Botanical Name	Trade Name				Bending-Tension Along Grain, Extreme Fibre Stress N/mm^2	Shear all Locations Horizontal N/mm^2	Compression Parallel to Grain N/mm^2	Compression Perpendicular to Grain N/mm^2
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(8)	(8)
i)	*Pseudotsuga menziesii*	Douglas fir (DF)	Pacific NW, USA	513	13.4	Inside: 11.0 Outside: 9.4 Wet: 9.4	1.24 (Inside) 1.05 (Outside)	Inside: 11.7 Outside: 9.9 Wet: 9.9	2.9
ii)	*Tsuga heterophylla*	Western hemlock (WH)	Pacific NW, USA	500	11.2	Inside: 9.3 Outside: 7.9 Wet: 7.9	1.03 (Inside) 0.88 (Outside)	Inside: 9.3 Outside: 7.9 Wet: 7.9	2.4

NOTE — The above data on foreign timber species is reproduced from the *USDA Wood Handbook* (*USA*). This information is for reference only. At present, no indigenous test data under Indian climatic and service conditions is available for these species. Therefore, before adopting them in structural applications in India, the properties should be verified through appropriate laboratory testing as per accepted standards.

LIST OF STANDARDS

The following list records those standards which are acceptable as 'good practice' and 'accepted standards' in the fulfilment of the requirements of this NBCS. The latest version of a standard shall be adopted at the time of the enforcement of this NBCS. The standards listed may be used for conformance with the requirements of the referred clauses in this NBCS.

In the following list, the number appearing in the first column within parenthesis indicates the number of the reference in this Subsection.

	IS No.	*Title*
(1)	IS 707 : 2011	Timber technology and utilization of wood, bamboo and cane — Glossary of terms (*third revision*)
(2)	IS 1708 (Parts 1 to 18) : 1986	Methods of testing small clear specimens of timber (*second revision*)
	IS 2408 : 1963	Methods of static tests of timbers in structural sizes
	IS 2455 : 1990	Methods of sampling of model trees and logs and their conversion for timer testing (*second revision*)
(3)	IS 4970 : 1973	Key for identification of commercial timbers (*first revision*)
(4)	IS 287 : 1993	Permissible moisture content of timber used for different purposes — Recommendations (*third revision*)
(5)	IS 3629 : 1986	Specification for structural timber in building (*first revision*)
(6)	IS 401 : 2001	Preservation of timber — Code of practice (*fourth revision*)
(7)	IS 2366 : 1983	Nail-jointed timber construction — Code of practice (*first revision*)
(8)	IS 4983 : 1968	Code of practice for design and construction of nailed laminated timber beams
(9)	IS 11096 : 1984	Code of practice for design and construction of bolt jointed timber construction
(10)	IS 4907 : 2004	Methods of testing timber connector joints (*first revision*)
(11)	IS 9188 : 1979	Performance requirements for adhesive for structural laminated wood products for use under exterior exposure conditions
(12)	IS 14616 : 1999	Laminated veneer lumber — Specification
(13)	IS 10701 : 2012	Structural plywood — Specification (*first revision*)
	IS 4990 : 2024	Plywood for concrete shuttering works — Specification (*fourth revision*)
(14)	IS 4924	Method of test for nail-jointed timber trusses:
	(Part 1) : 1968	Destructive test
	(Part 2) : 1968	Proof test
(15)	IS 12120 : 1987	Code of practice for preservation of plywood and other panel products
(16)	IS 4990 : 2024	Plywood for concrete shuttering works — Specification (*fourth revision*)
(17)	IS 9307 (Parts 1 to 8) : 1979	Methods of test for wood-based structural sandwich construction
(18)	IS 723 : 2023	Steel countersunk head wire nails — Specification (*second revision*)
(19)	IS 451 : 1999	Technical supply conditions for wood screws (*third revision*)
	IS 6736 : 1972	Specification for slotted raised countersunk head wood screw

	IS No.	*Title*
	IS 6739 : 1972	Specification for slotted round head wood screws
	IS 6760 : 1972	Specification for slotted countersunk head wood screws
(20)	IS 1708 (Parts 1 to 18) : 1986	Methods of testing small clear specimens of timber (*second revision*)
(21)	IS 6313 (Part 1) : 1981	Code of practice for anti-termite measures in buildings: Part 1 Constructional measures (*first revision*)
	IS 6313	Anti-termite measures in buildings — Code of practice:
	(Part 2) : 2022	Pre-constructional chemical treatment measures (*fourth revision*)
	(Part 3) : 2022	Treatment for existing buildings (*fourth revision*)

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART C STRUCTURAL DESIGN

SECTION 3 TIMBER AND BAMBOO: 3B BAMBOO

BUREAU OF INDIAN STANDARDS

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FOREWORD

This NBCS (Part C/Subsection 3B) covers the general principles involved in the design of structural bamboo in buildings with regard to mechanical resistance and durability of structures. Design of both bamboo (round bamboo, split bamboo, glued laminated bamboo) and bamboo-based panels joined together with adhesives or mechanical fasteners are covered in this Subsection. It also covers minimum strength data, dimensional stability, grading requirements and traditional bamboo joints for quality assurance. Constructional aspects using bamboo, such as, work on site, fabrication of components off-site and their erection on site is also covered to the extent necessary to indicate and ensure the quality of material and standard of workmanship to comply with the assumptions of the design rules and the limitations.

Bamboo is a versatile resource possessing high strength-to-weight ratio and cost ratio and offers considerable ease in working with simpler tools. It has a long and well established tradition as a building material. The application of bamboo as a constructional material is largely based on established traditions and intuitions of forefathers throughout the tropical and sub-tropical regions.

Resilience coupled with light weight makes bamboo an ideal material for housing in disaster prone/earthquake prone areas. It has the capacity to withstand repetitive loadings and absorb more energy and show larger deflections before collapse and as such is safer under earth tremors. As the design guidelines were inadequate, the application of bamboo as an engineering material was largely based on practical and engineering experience. A need was therefore felt to develop a Code for design and construction with bamboo so as to cater to a number of social and trade advantages, engineering recognition and the improved status of bamboo as an engineering material. This was achieved by adding a new chapter in the 2005 revision of this code, covering structural design with bamboo. Forest Research Institute, Dehradun and some other organizations were engaged in bamboo research to establish its silviculture, botanical, entomological and pathological aspects besides creating a utilization base. All these works were utilized in the preparation of the 2005 version of this Subsection of this

Some of the suitable species grown in India and neighbouring countries are enlisted in Annex A along with their local names and source, for general information.

The bamboo culm has a tubular structure consisting essentially of nodes and inter-nodes. In the inter-nodes the cells are axially oriented while the nodes provide the transverse inter-connection. The disposition of the nodes and the wall thickness are significant in imparting strength to bamboo against bending and crushing. In a circular cross-section, bamboo is generally hollow and for structural purposes this form is quite effective and advantageous. Each of the species of bamboo has widely different characteristics affecting its usefulness as constructional material. The strength of bamboo culms, their straightness, lightness combined with hardness, range and size of hollowness make them potentially suitable for a variety of applications both structural and non-structural. With good physical and mechanical properties, low shrinkage and good average density, bamboo is well suited to replace wood in several applications, especially in slats and panel form. Mass production of bamboo components, if required, may be integrated with treatment facilities near to the site of plantation or site of construction, for speed and economy in construction.

The Section on structural design with bamboo was first published in 2005 as a part of National Building Code of India under Subsection 3B of Part 6. In the 1983 version of this code, timber was covered under Section 3 of Part 6 ‘Structural Design’ under the title ‘Wood’, which did not cover bamboo. In the 2005 version of this code, the scope of Section 3 was enlarged as Section 3 ‘Timber and bamboo’, which was subdivided into Subsection 3A ‘Timber’ and Subsection 3B ‘Bamboo’. This Subsection pertains to 3B ‘Bamboo’.

Key changes to the 2016 version included: inclusion of provisions on construction practices using bamboo that was addressed in erstwhile Part 7 ‘Construction Management, Practices and Safety’; updated provisions for bamboo trusses, bamboo foundations; bamboo as reinforcement in concrete; introduction of the use of bamboo-based materials for walling, flooring, roofing, and in-fill panels, along with provisions for reconstituted wood from bamboo; and updates to the terms and definitions related to bamboo-based panel products.

With the standardization on design and construction aspects of bamboo in this Subsection of this code, it was expected to ensure durable structures, however, some specific guidelines were required in the event of tropical cyclones in the sub-continent and the traditional non-engineered structures generally constructed. Keeping this in view, some recommendations are given in Annex B which may be followed in addition to provisions given in the main text of this Subsection.

As a result of experience gained in implementation of 2016 version of this code and further research work done, feedback received as well as revision/updation of some of the existing standards, a need to revise this Subsection was felt. This revision has, therefore, been brought out to take care of these aspects.

In this revision, this publication has been renamed as National Building Construction Standards (NBCS).

The significant changes incorporated in this revision include the following:

a) Bamboo grading, in **4.4**, has been expanded to include special grades based on mean outer diameter;

b) Bamboo mat corrugated sheets (BMCS) are included, in **6.9.9**, as a sustainable roofing material with high strength, resilience, and thermal resistance for diverse climates;

c) Comprehensive life cycle assessment to evaluate environmental impacts from production to end-of-life of bamboo structures;

d) Annex C has been introduced illustrating conventional bamboo construction details such as trusses, roofing, walls, and flooring; and

e) References to all the concerned Indian Standards have been updated.

Reference may be made to Part F 'Fire and Life Safety' of this NBCS for fire protection of the bamboo buildings.

The information contained in this Subsection is largely based on the works carried out at Forest Research Institute, Dehradun; Institute of Wood Science and Technology, Bangalore; International Network for Bamboo and Rattan (INBAR) documents and Indian Standards given below. Assistance has also been derived from ISO 22156 : 2021 'Bamboo structures- Bamboo culms- Structural design', apart from the following:

IS 9096 : 2006	Preservation of bamboo for structural purpose — Code of practice
IS 15912 : 2018	Structural design using bamboo — Code of practice

All standards, whether given herein above or cross-referred to in the main text of this Subsection, are subject to revision. The parties to agreement based on this Subsection are encouraged to investigate the possibility of applying the most recent editions of the standards.

As the regulation of land development and buildings is a State subject and is dealt by the States and local bodies such as urban local bodies within their jurisdiction through building regulatory documents like building regulations, building byelaws, and fire regulations, this document is voluntary in nature and is non-binding. The implementation depends on adoption by concerned parties or stipulations in a contract or by appropriate adoption by the concerned authorities.

For the purpose of deciding whether a particular requirement of this Subsection is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 'Rules for rounding off numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this Subsection.

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Important Explanatory Note for Users of this NBCS

In any Part/Section of this NBCS, where reference is made to **'good practice'** in relation to design, constructional procedures or other related information, and where reference is made to **"accepted standard"** in relation to material specification, testing, or other related information, the Indian Standards listed at the end of the Part/Section shall be used as a guide to the interpretation.

At the time of publication, the editions indicated in the standards were valid. All standards are subject to revision and parties to agreements based on any Part/Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

In the list of standards given at the end of a Part/Section, the number appearing within parentheses in the first column indicates the number of the reference of the standard in the Part/Section. For example:

a) Good practices [C-3B(1)] refers to the Indian Standard(s) give at serial number (1) of the list of standards given at the end of this Subsection, that is, IS 9096 : 2006, 'Code of practice for preservation of bamboo for structural purposes (*first revision*)'

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART C STRUCTURAL DESIGN

SECTION 3 TIMBER AND BAMBOO: 3B BAMBOO

1 SCOPE

1.1 This NBCS (Part C/Subsection 3B) covers the general principles involved in the design of structural bamboo in buildings with regard to mechanical resistance and durability of structures. Design of both bamboo (round bamboo, split bamboo, glued laminated bamboo) and bamboo-based panels joined together with adhesives or mechanical fasteners are covered in this Subsection. It also covers minimum strength data, dimensional stability, grading requirements and traditional bamboo joints for quality assurance. Constructional aspects using bamboo, such as, work on site, fabrication of components off-site and their erection on site are also covered to the extent necessary to indicate and ensure the quality of material and standard of workmanship to comply with the assumptions of the design rules and the limitations.

1.2 The following aspects are not covered in this Subsection:

a) Limit state design and performance of structures; and

b) Scientific designing of bamboo joints and their fastenings.

2 TERMINOLOGY

For the purpose of this Subsection, the following definitions shall apply.

2.1 Anatomical Purpose Definitions

2.1.1 *Bamboo* — Tall perennial grasses found in tropical and sub-tropical regions. They belong to the family *Poaceae* and sub-family *Bambusoideae*.

2.1.2 *Bamboo Culm* — A single shoot of bamboo usually hollow except at nodes which are often swollen.

2.1.3 *Bamboo Clump* — A cluster of bamboo culms emanating from two or more rhizomes in the same place.

2.1.4 *Cellulose* — A carbohydrate, forming the fundamental material of all plants and a main source of the mechanical properties of biological materials.

2.1.5 *Cell* — A fundamental structural unit of plant and animal life, consisting of cytoplasm and usually enclosing a central nucleus and being surrounded by a membrane (animal) or a rigid cell wall (plant).

2.1.6 *Cross Wall* — A wall at the node closing the whole inside circumference and completely separating the hollow cavity below from that above (*Syn*. Diaphragm, that is, horizontal partition in a standing culm) (*see also* 2.2.19 and 2.2.32).

2.1.7 *Hemi Cellulose* — The polysaccharides consisting of only 150 to 200 sugar molecules, also much less than the 10 000 of cellulose.

2.1.8 *Lignin* — A polymer of phenyl propane units, in its simple form ($C_6H_5CH_3CH_2CH_3$).

2.1.9 *Sliver* — Thin strips of bamboo processed from bamboo culm.

2.1.10 *Tissue* — Group of cells, which in higher plants consist of (a) Parenchyma — a soft cell of higher plants as found in stem pith or fruit pulp, (b) Epidermis — the outermost layer of cells covering the surface of a plant, when there are several layers of tissue.

2.2 Structural Purpose Definitions

2.2.1 *Bamboo Mat Board* — A board made of two or more bamboo mats bonded with an adhesive.

2.2.2 *Bamboo Mat Corrugated Sheet* — A sheet made up of adhesive soaked and coated mats assembled and pressed under specified temperature and pressure to obtain sinusoidal or other suitable corrugations.

2.2.3 *Bamboo Mat Corrugated Sheets* (*BMCS*) — Roofing sheets made from woven bamboo mats, treated and pressed with resin to form a durable, weather-resistant corrugated material.

2.2.4 *Bamboo Mat Ridge Cap* (*BMRC*) — It is a specially shaped bamboo composite designed to cover and seal the ridge line of BMCS roofs, providing a weatherproof finish to the roof structure.

2.2.5 *Bamboo Mat Veneer Composite* — Panel manufactured with a combination of bamboo mat and veneer. Bamboo mat can be either as outer skins or as core/cross-bands. However, the composite panel shall be balanced construction on either side of central ply.

2.2.6 *Beam* — A structural member which supports load primarily by its internal resistance to bending.

2.2.7 *Breaking Strength* — A term loosely applied to a given structural member with respect to the ultimate load it can sustain under a given set of conditions.

2.2.8 *Bundle-Column* — A column consisting of three or more number of culms bound as integrated unit with wire or strap type of fastenings.

NOTE — During bunching of beams/columns, binders (5 mm tie bar/wire and 15 mm bamboo dowel pins) may be carefully inserted after proper pre-drilling the holes throughout the assembly as per the requirements of structural design.

2.2.9 *Centre Internode* — A test specimen having its centre between two nodes.

2.2.10 *Characteristic Load* — The value of load which has a 95 percent probability of not exceeding during the life of the structure.

2.2.11 *Characteristic Strength* — The strength of the material below which not more than 5 percent of the test results are expected to fall.

2.2.12 *Cleavability* — The ease with which bamboo can be split along the longitudinal axis. The action of splitting is known as cleavage.

2.2.13 *Column* — A structural member which supports axial load primarily by inducing compressive stress along the fibres.

2.2.14 *Common Rafter* — A roof member which supports roof battens and roof coverings, such as boarding and sheeting.

2.2.15 *Curvature* — The deviation from the straightness of the culm.

2.2.16 *Delamination* — Separation of mats through failure of glue.

2.2.17 *De-structured Bamboo* — Raw material (green bamboo) reduced partially to a condition, as far as practicable, in which the element fibres remain interlocked and in their highly aligned state and which with the help of binder can be reconstituted into a valuable product of a desirable size.

2.2.18 *End Distance* — The distance measured parallel to the fibres of the bamboo from the centre of the fastener to the closest end of the member.

2.2.19 *Flattened Bamboo* — Bamboo consisting of culms that have been cut and unfolded till it is flat. The culm thus is finally spread open, the diaphragms (cross walls) at nodes removed and pressed flat.

2.2.20 *Full Culm* — The naturally available circular section/shape.

2.2.21 *Fundamental or Ultimate Stress* — The stress which is determined on a specified type/size of culms of bamboo, in accordance with standard practice and does not take into account the effects of naturally occurring characteristics and other factors.

2.2.22 *Inner Diameter* — Diameter of internal cavity of a hollow piece of bamboo.

2.2.23 *Inside Location* — Position in buildings in which bamboo remains continuously dry or protected from weather.

2.2.24 *Joint* — A connection between two or more bamboo structural elements.

2.2.25 *Joist* — A small beam directly supporting floor, ceiling or roof of a structure.

2.2.26 *Length of Internode* — Distance between adjacent nodes.

2.2.27 *Loaded End or Compression End Distance* — The distance measured from the centre of the fastener to the end towards which the load induced by the fastener acts.

2.2.28 *Machette* — A light cutting and slashing tool in the form of a large knife.

2.2.29 *Mat* — A woven sheet made using thin slivers.

2.2.30 *Mortise and Tenon* — A joint in which the reduced end (tenon) of one member fits into the corresponding slot (mortise) of the other.

2.2.31 *Net Section* — Section obtained by deducting from the gross cross-section (A), the projected areas of all materials removed by boring, grooving or other means.

2.2.32 *Node* — The place in a bamboo culm where branches sprout and a diaphragm is inside the culm and the walls on both sides of node are thicker.

2.2.33 *Outer Diameter* — Diameter of a cross-section of a piece of bamboo measured from two opposite points on the outer surface.

2.2.33.1 *Mean outer diameter* — The diameter taken twice on the outer surface, in direction perpendicular to each other at each cross-section on both the ends. Thus, resulting in mean of four readings for the middle of culm.

2.2.34 *Outside Location* — Position in building in which bamboos are occasionally subjected to wetting and drying as in case of open sheds; and outdoor exposed structures.

2.2.35 *Permissible Stress* — Stress obtained after applying factor of safety to the ultimate stress. This is also the working stress unless adjusted to the particular structural form in design.

2.2.36 *Principal Rafter* — A roof member which supports purlins.

2.2.37 *Purlins* — A roof member directly supporting roof covering or common rafter and roof battens.

2.2.38 *Roof Battens* — A roof member directly supporting tiles, corrugated sheets, slates or other roofing materials.

2.2.39 *Roof Skeleton* — The skeleton consisting of bamboo truss or rafter over which solid bamboo purlins are laid and lashed to the rafter or top chord of a truss by means of galvanized iron wire, cane, grass, bamboo leaves, etc.

2.2.40 *Slenderness Ratio* — The ratio of the length of member to the least radius of gyration is known as slenderness ratio of member (the length of the member is the equivalent length due to end conditions).

2.2.41 *Splits* — The pieces made from quarters by dividing the quarters radially and cutting longitudinally.

2.2.42 *Taper* — The ratio of difference between minimum and maximum outer diameter to length.

2.2.43 *Unloaded End Distance* — The end distance opposite to the loaded end.

2.2.44 *Wall Thickness* — Half the difference between outer diameter and inner diameter of the piece at any cross section.

2.2.44.1 *Mean wall thickness* — The wall thickness taken four times in the same points as the diameter has been measured. Thus, resulting in mean of eight values for the middle of culm.

2.2.45 *Wet Location* — Position in buildings in which the bamboos are almost continuously damp, wet or in contact with earth or water, such as piles and bamboo foundations.

2.3 Definitions Relating to Defects

2.3.1 *Bamboo Bore/GHOON Hole* — The defect caused by bamboo ghoon beetle (*Dinoderus spp*. *Bostrichidae*), which attacks felled culms.

2.3.2 *Crookedness* — A localized deviation from the straightness in a piece of bamboo.

2.3.3 *Discolouration* — A change from the normal colour of the bamboo which does not impair the strength of bamboo or bamboo composite products.

2.4 Definition Relating to Drying Degrades

2.4.1 *Collapse* — The defect occurring on account of excessive shrinkage, particularly in thick walled immature bamboo. When the bamboo wall shrinks, the outer layers containing a larger concentration of strong fibro-vascular bundles set the weaker interior portion embedded in parenchyma in tension, causing the latter to develop cracks. The interior crack develops into a wide split resulting in a depression on the outer surface. This defect also reduces the structural strength of round bamboo.

2.4.2 *End Splitting* — A split at the end of a bamboo. This is not so common a defect as drying occurs both from outer and interior wall surfaces of bamboo as well as the end at the open ends.

2.4.3 *Surface Cracking* — Fine surface cracks not detrimental to strength. However, the cracking which occurs at the nodes reduces the structural strength.

2.4.4 *Wrinkled and Deformed Surface* — Deformation in cross section, during drying, which occurs in immature round bamboos of most species; in thick walled pieces, besides this deformation the outer surface becomes uneven and wrinkled. Very often the interior wall develops a crack below these wrinkles, running parallel to the axis.

3 SYMBOLS

For the purpose of this Subsection, the following letter symbols shall have the meaning indicated against each, unless otherwise stated:

A = cross-sectional area of bamboo (perpendicular to the direction of the principal fibres and vessels), mm^2

= $\frac{\pi}{4}[D^2-(D-2w)^2]$;

A_B = area of reinforcement in bamboo reinforced cement concrete, mm^2;

D = mean outer diameter of bamboo culm, mm;

d = inner diameter, mm

= $(D-2w)$;

E = modulus of elasticity (MOE) in bending, N/mm^2;

f_c = calculated stress in axial compression, N/mm^2;

f_{cp} = permissible stress in compression along the fibres, N/mm^2;

I = moment of inertia (the second moment of area) of culm section, mm^4

= $\frac{\pi}{64}[D^4-(D-2w)^4]$;

ℓ = unsupported length of column, mm;

m = moisture content, percent;

r = radius of gyration, mm

= $\sqrt{\frac{I}{A}}$;

R = modulus of rupture (MOR), N/mm^2;

w = mean of wall thickness of bamboo culm, mm;

Z = section modulus, mm^3

= $\frac{\pi}{32}\left[\frac{D^4-(D-2w)^4}{D}\right]$; and

δ = deflection or deformation, mm.

4 MATERIALS

The requirements shall be met by the choice of suitable materials, by appropriate design and detailing and by specifying control procedures for production, construction and use.

4.1 Species of Bamboo

More than 100 species of bamboo are native to India and a few of them are solid but most of them are hollow in structure. In all 20 species have been systematically tested so far. Sixteen species of bamboo are recommended for structural usages in round form. Some physical and mechanical properties of the same are given in Table 1 both for air-dry conditions and green conditions.

4.1.1 Matured bamboo of at least 4 years of age shall be used. The bamboo shall be used after at least six weeks of felling period.

4.1.2 Bamboo shall be properly treated in accordance with the good practice [C-3B(1)].

4.1.3 Solid bamboos or bamboos whose wall thickness is comparatively more and which are generally having nodes very closer are often considered good for structural purposes.

4.1.4 Broken, damaged or collapsed bamboo shall be rejected. Dead and immature bamboos, bore/*Ghoon* holes, decay, collapse, checks more than 3 mm in depth, shall be avoided.

4.2 Grouping

4.2.1 Sixteen species of bamboo recommended for structural applications are classified in three groups on the basis of their strength properties, namely, modulus of elasticity (E) in bending in green condition and modulus of rupture (R) (extreme fibre stress in bending). For structural use in piles and mines' components, an additional criterion of compressive strength is considered in classification. The limits in ultimate strength values of these groups shall be as given in Table 2 (these are corresponding to the spread of properties in structural timber).

4.2.2 Bamboo species may be identified using suitable methods.

NOTE — Methods of identification of bamboo through anatomical characters have not been perfected so far. Identification through morphological characters could be done only on full standing culm by experienced sorters.

4.2.3 Species of bamboo other than those listed in the Table 3 may be used, provided their strength characteristics are determined and found more than the limits specified in Table 2.

4.3 Moisture Content in Bamboo

Normally only dry or seasoned bamboo shall be used otherwise special attention shall be given to dimensional changes occurring during the drying process in the joints, assemblies.

With decrease of moisture content, the strength of bamboo increases exponentially and bamboo has an intersection point (fibre saturation point) at around 25 percent moisture content depending upon the species. A typical moisture strength relationship is given at Fig. 1. The moisture content of bamboo shall be determined in accordance with method given in the accepted standard [C-3B(2)]. Matured culms shall be seasoned to about 15 percent moisture content before use.

Freshly felled bamboo with shoots and leaves intact, dry fairly well in the open sun with lesser surface cracking, etc, and reduced starch contents. Rapid drying in the open can control degrades.

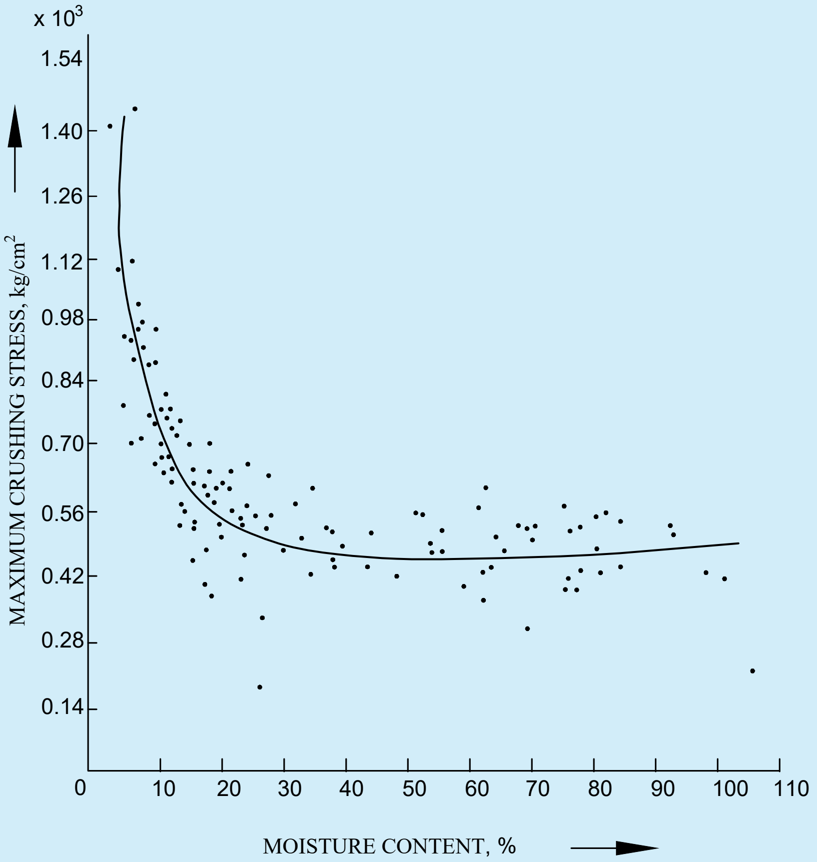


FIG. 1 MOISTURE STRENGTH RELATIONSHIP OF BAMBUSA NUTANS (BAMBOO)

4.4 Grading of Structural Bamboo

Bamboo shall be graded to ensure that the properties of bamboo are satisfactory for use, particularly the strength and stiffness properties. Grading bamboo is a process that ensures its structural integrity, standardization, efficient use, and marketability. It plays a crucial role in enhancing trade and promoting sustainable harvesting by ensuring that bamboo meets the required specifications for various applications. This process is essential for ultimately producing safe and economical structures, encouraging its use in mainstream construction and other industries.

4.4.1 Grading is sorting out bamboo on the basis of characteristics important for structural utilization as under:

a) Diameter and length of culm;

b) Taper of culm;

c) Straightness of culm;

d) Inter nodal length and distribution of nodes;

e) Wall thickness;
f) Density and strength; and
g) Durability and seasoning.

4.4.2 *Diameter and Length of Culm*

4.4.2.1 *Gradation according to the mean outer diameter*

For structural Group A and Group B species, culms shall be segregated in steps of 10 mm of mean outer diameter as follows:

a) Special grade A : 100 mm < Diameter ≤ 130 mm
b) Special grade B : 70 mm < Diameter ≤ 100 mm
c) Grade I : 50 mm < Diameter ≤ 70 mm
d) Grade II : 30 mm < Diameter ≤ 50 mm
e) Grade III : Diameter ≤ 30 mm

For structural Group C species culms shall be segregated in steps of 20 mm of mean outer diameter as follows:

a) Grade I : 80 mm < Diameter ≤ 100 mm
b) Grade II : 60 mm < Diameter ≤ 80 mm
c) Grade III : Diameter ≤ 60 mm

4.4.2.2 The minimum length of culms shall be preferably 4.5 m for facilitating close fittings at joints, etc.

4.4.3 *Taper*

The taper shall not be more than 5.8 mm per metre length (or 0.58 percent) (1 in 170) of bamboo in any grade of bamboo.

4.4.4 *Curvature*

The maximum curvature should not be more than 75 mm in a length of 6 m of any grade of bamboo.

NOTE — Due to the constraint of preferential selection of straighter material out of a lot, more bent material may be accommodated to avoid high cost. Following remedial options may be helpful:

a) Adopt component assembly method to take care of some degree of curvature (bunching done after holding components straight).
b) Cut longer bamboo components with less curvature out of taller bamboo and use cambered ones for shorter length components.

4.4.5 *Wall Thickness*

Preferably minimum wall thickness of 8 mm shall be used for load bearing members unless calculations and the availability dictate otherwise.

4.5 Durability and Treatability

4.5.1 *Durability*

The natural durability of bamboo is low and varies between 12 months and 36 months depending on the species and climatic conditions. In tropical countries the bio-deterioration is very severe. Bamboos are generally destroyed in about one to two years' time when used in the open and in contact with ground; while a service life of two to five years can be expected from bamboo when used under cover and out of contact with ground. The mechanical strength of bamboo deteriorates rapidly with the onset of fungal decay in the sclerenchymatous fibres. Split bamboo is more rapidly destroyed than round bamboo

4.5.2 Fire safety of bamboo structures shall be ensured, for which the treatment prescribed in 7.3.4 may be followed.

5 PERMISSIBLE STRESSES

5.1 Ultimate stress values of different species and groups of bamboo shall be determined according to the accepted standard [C-3B(2)]. These values shall then be divided by appropriate factors of safety to obtain permissible stresses to cover the effects of variability, long term loading, grade, location of use and expected dynamic loading.

NOTE — As an information, it may be noted that the method of test for split bamboos is covered in the accepted standard [C-3B(4)].

5.1.1 The strength factors for deriving safe working stresses of bamboo shall be as under:

a) Extreme fibre stress in beams : 4

b) Modulus of elasticity : 4.5

c) Maximum compressive stress parallel to grain/fibres : 3.5

5.2 The available data for the safe working stresses for 16 species of bamboos are given in Table 3.

5.3 For change in duration of load other than continuous (long-term), the permissible stresses given in Table 3 shall be multiplied by the modification factors given below:

a) For permanent loads : 1.0

b) For imposed or medium term loading (permanent + temporary load) : 1.25

c) For short term loading (permanent + temporary load + wind load) : 1.50

Table 1 Physical and Mechanical Properties of Indian Bamboos (in Round Form)

(*Clause* 4.1)

Sl No.	**Species**	**Properties**							
		In Green Condition				In Air Dry Condition			
		Density kg/m^3	Modulus of Rupture N/mm^2	Modulus of Elasticity $\times 10^3 N/mm^2$	Maximum Compressive Strength N/mm^2	Density kg/m^3	Modulus of Rupture N/mm^2	Modulus of Elasticity $\times 10^3 N/mm^2$	Maximum Compressive Strength N/mm^2
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
i)	*Bambusa auriculata*	594	65.1	15.01	36.7	670	89.1	21.41	54.3
ii)	*B. balcooa*	783	65.4	7.31	46.7	–	–	–	60.6
iii)	*B. bambos* (*Syn. B. arundinacea*)	559	58.3	5.95	35.3	663	80.1	8.96	53.4
iv)	*B. burmanica*	570	59.7	11.01	39.9	672	105.0	17.81	65.2
v)	*B. glancescens* (*Syn. B. nana*)	691	82.8	14.77	53.9	–	–	–	–
vi)	*B. nutans*	603	52.9	6.62	45.6	673	52.4	10.72	47.9
vii)	*B. pallida*	731	55.2	12.90	54.0	–	–	–	–
viii)	*B. tulda*	658	51.1	7.98	40.7	722	66.7	10.07	68.0
ix)	*B. ventricosa*	626	34.1	3.38	36.1	–	–	–	–
x)	*B. vulgaris*	626	41.5	2.87	38.6	–	–	–	–
xi)	*Cephalostachyum pergracile*	601	52.6	11.16	36.7	640	71.3	19.22	49.4
xii)	*Dendrocalamus longispathus*	711	33.1	5.51	42.1	684	47.8	6.06	61.1

Table 1 (*Concluded*)

Sl No.	**Species**	**Properties**							
		In Green Condition				In Air Dry Conditions			
		Density kg/m^3	Modulus of Rupture N/mm^2	Modulus of Elasticity $\times 10^3$ N/mm^2	Maximum Compressive Strength N/mm^2	Density kg/m^3	Modulus of Rupture N/mm^2	Modulus of Elasticity $\times 10^3$ N/mm^2	Maximum Compressive Strength N/mm^2
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
xiii)	*D. strictus*	631	73.4	11.98	35.9	728	119.1	15.00	69.1
xiv)	*Melocanna baccifera*	817	53.2	11.39	53.8	751	57.6	12.93	69.9
xv)	*Oxytenanthera abyssinicia*	688	83.6	14.96	46.6	–	–	–	–
xvi)	*Thyrsostachys oliveri*	733	61.9	9.72	46.9	758	90.0	12.15	58.0

NOTE — The values of stress in N/mm^2 have been obtained by converting the values in kgf/cm^2 by dividing the same by 10.

Table 2 Properties of Structural Bamboo

(*Clauses* 4.2.1 *and* 4.2.3)

Sl No.	Group	Modulus of Rupture (*R*) N/mm^2	Modulus of Elasticity in Bending (*E*) × 10^3 N/mm^2	Maximum Compressive Strength ($f_{c,\max}$) N/mm^2
(1)	(2)	(3)	(4)	(5)
i)	A	$R > 70$	$E > 9$	$MCS > 35$
ii)	B	$70 \geq R > 50$	$9 \geq E > 6$	$35 > MCS > 30$
iii)	C	$50 \geq R > 30$	$6 \geq E > 3$	$30 > MCS > 25$

Table 3 Safe Permissible Stresses of Bamboos for Structural Designing[1)]

(*Clauses* 4.2.3, 5.2 *and* 5.3)

Sl No.	Species	Extreme Fibre Stress in Bending N/mm^2	Modulus of Elasticity × 10^3 N/mm^2	Allowable Compressive Stress N/mm^2
(1)	(2)	(3)	(4)	(5)
i)	Group A:			
	a) *Bambusa glancescens* (Syn. B.nana)	20.7	3.28	15.4
	a) *Dendrocalamus strictus*	18.4	2.66	10.3
	b) *Oxytenanthera abyssinicia*	20.9	3.31	13.3
ii)	Group B:			
	a) *Bambusa balcooa*	16.4	1.62	13.3
	b) *B.pallida*	13.8	2.87	15.4
	c) *B.nutans*	13.2	1.47	13.0
	d) *B.tulda*	12.8	1.77	11.6
	e) *B.auriculata*	16.3	3.34	10.5
	f) *B.burmanica*	14.9	2.45	11.4
	g) *Cephalostachyum pergracile*	13.2	2.48	10.5
	h) *Melocanna baccifera* (*Syn. M.bambusoides*)	13.3	2.53	15.4
	j) *Thyrsotachys oliveri*	15.5	2.16	13.4
iii)	Group C:			
	a) *Bambusa arundinacea* (*Syn. B.bambos*)	14.6	1.32	10.1
	b) *B.ventricosa*	8.5	0.75	10.3

[1)] The values given pertain to testing of bamboo in green condition.

Table 3 (*Concluded*)

Sl No.	Species	Extreme Fibre Stress in Bending N/mm^2 (3)	Modulus of Elasticity $\times 10^3$ N/mm^2 (4)	Allowable Compressive Stress N/mm^2 (5)
(1)	(2)			
c)	*B.vulgaris*	10.4	0 .64	11.0
d)	*Dendrocalamus longispathus*	8.3	1.22	12.0

NOTE — The values of stress in N/mm^2 have been obtained by converting the values in kgf/cm^2 by dividing the same by 10.

NOTE — The above properties are based on the accepted standard [C-3B(2)].

6 DESIGN CONSIDERATIONS

6.1 Basic Requirements

A structure shall be designed and constructed by personnel having the appropriate skill and experience in such a way that:

a) With acceptable probability, it will remain fit for the use for which it is required, having due regard to its intended life and costs;

b) With appropriate degree of reliability, it will sustain all forces and effects likely to occur during execution and use and have adequate durability in relation to maintenance costs;

c) The structure will be adequately maintained;

d) The structure will be used in accordance with design limit briefs;

e) All structural members, assemblies or framework in a building shall be capable of sustaining, without exceeding the limits of relevant stress specified, the worst combination of all loadings;

f) A fundamental aspect of design will be to determine the forces to which the structure/structural element might be subjected to, starting from the roof and working down to the soil by transferring the forces through various components and connections;

g) Accepted principles of mechanics for analysis and specified design procedures shall be applied (or) the design requirements may be satisfied by prototype testing;

h) Loads shall be in accordance with Part C ‘Structural Design, Section 1 Loads and Load Effects’ of this NBCS, keeping into consideration that permeability of walls, floors and roof made from bamboo cause internal pressure and can therefore affect the wind load factor; and

j) The worst combination and location of loads shall be considered for design. Also, wind and seismic forces shall not be considered to act simultaneously.

6.2 Unlike timber, bamboo properties do not relate well to species, being dependent among other factors, on position of the culm, geographic location and age. The practice in timber engineering is to base designs on safe working stresses (*see* Note) and the same may be adopted to bamboo with the limitations that traditional experience rather than precise calculations generally govern the detailing.

NOTE — Limit states are states beyond which the structure no longer satisfies the design performance requirements. Limit states are classified into ultimate limit state relating to collapse mode and serviceability limit states associated with deformations, vibrations, etc. Design is usually based on ultimate stages with partial factors of safety.

6.3 Age old traditional experience of construction with bamboo is to be well preserved as non-standard practices for similar situations considered as an informal based on general social pattern and wisdom. Confirmation of such structures be based on reports after they have sustained the severity of earthquakes, cyclones, etc, as criteria for recommendations by the evaluation by competent engineer/builder with adequate experience in the field.

6.4 Net Section

It is determined by passing a plane or a series of connected planes transversely through the members. Least net sectional area is used for calculating load carrying capacity of a member. In the design of an intermediate or a long column, gross section shall be used in calculating load carrying capacity of column.

6.5 Structural Components

6.5.1 Main structural applications in bamboo may include roofing and flooring, shear walls, wall panelling, beams, piles, columns, arches, etc. Both from the point of view of capacity and deformation, trusses and framed skeletons are much better options in bamboo.

6.5.2 *Peculiarity of Bamboo as a Design Material*

This shall be based on the principles of applied mechanics involving the following assumptions:

a) Elastic behaviour of bamboo, until failure (plastic behaviour being considered to be not significant);

b) Bamboo culms are analyzed as hollow-tube structures (not perfectly straight) member on mean diameter and mean wall thickness basis. Designing as a variable thickness hollow-tube structure is a bit complex;

c) Nodes do not occur at constant intervals;

d) Structural elements of bamboo shall be appropriately supported near the nodes of culm as and where the structural system demands. The joints in the design shall be located near nodes;

e) Bamboo structures are designed like any other conventional structural analysis taking care of details with regards to supports and joints; and the diameter, wall thickness and initial curvature; and

f) Joints shall be considered to generally act as a hinge or as pinned, unless substantiating data justify a fixed joint.

6.6 Flexural Members

6.6.1 All flexural members may be designed using the principles of beam theory.

NOTE — The tendency of bamboo beams to acquire larger deflections under long continual loading (including creep) has to be taken care of either by giving a factor of safety to E or by considering double the design dead loading in calculation of deflections.

6.6.2 The moment of inertia, I shall be determined as follows:

a) Outside diameter and the wall thickness shall be measured at both ends, correct up to 1 mm for diameter of culm and 0.1 mm for the wall thickness; and

b) With these values the mean diameter and the mean thickness for the middle of the beam shall be calculated and moment of inertia determined.

6.6.3 The maximum bending stress shall be calculated and should be within the allowable stress.

6.6.4 The deflection shall be within the prescribed limits. The initial curvature shall also be considered in the calculation of the deflection.

6.6.5 The shear stress in the neutral layer at the small end shall be checked, if the length of the beam is less than 25 times the diameter at that end.

6.6.6 Forces acting on a beam, being loads or reaction forces at supports, shall act in nodes or as near to nodes as by any means possible.

6.7 Columns (Predominantly Loaded in Axial Direction)

6.7.1 Columns and struts are essential components sustaining compressive forces in a structure. They transfer load to the supporting media.

6.7.2 Design of columns shall be based on one of the following two criteria:

a) Full scale buckling tests on the same species, size and other relevant variables; and

b) Calculations, based on the following:

   1) Moment of inertia shall be determined as per 6.6.2;

   2) For bamboo columns the best available straight bamboo culms shall be selected; and

   3) Bending stresses due to initial curvature, eccentricities and induced deflection shall be taken into account, in addition to those due to any lateral load.

   NOTE — Unlike timber, MOE has already been provided a factor of safety in case of bamboo. This is on the basis of studies on variability of MOR and MOE. In the case of timber, no factor of safety for MOE was used because there has been an understanding that there is no variability in MOE. Subsequently it was confirmed that MOE varies as the MOR and there is very strong, highly significant correlation between the two. In fact, this correlation has formed the basis of development of machine grading of timber world-over. However, somehow the practice of not giving factor of safety to MOE continued in Indian Standard. Later on when the standard on structural use of bamboo was formulated, factor of safety was given both in MOR and MOE on the basis of latest variability studies on strength of bamboo.

6.7.3 Buckling calculation shall be according to Euler, with a reduction to 90 percent of moment of inertia, to take into account the effect of the taper which shall be less than 1 : 170.

6.7.4 For strength and stability, larger diameter thick walled sections of bamboo with closely spaced nodes shall be used. Alternatively, smaller sections may be tied together as a bundle-column.

6.8 A single bamboo culm is not an optimum component to structurally design different load bearing members. Bunching of bamboo is inevitable to fabricate beams, columns, etc. There is no end to the number of culmns in bunching. However, different components pose manufacturing problems during assembly, which should be appropriately taken care of (*see also* Fig. 9D and Fig. 9E).

6.8.1 Following precautions shall be taken to avoid possible split/crack in walling of bamboo:

a) Maintaining a minimum 100 mm distance of the drills from the end of the main bamboo culms drilled;

b) Choosing drilling points preferably within 30 mm from node;

c) Maintaining the interference fit between bamboo body and binders as under:

   1) For wall thickness ≥ 8 mm : 0.25 to 0.30 mm; and

   2) For wall thickness < 8 mm : 0.20 to 0.25 mm.

d) The inserting ends of the dowel pins may be dressed as tapered (conical).

6.9 Assemblies and Roof Trusses

6.9.1 Elements in structure are generally built-up in the form of assembled members for which a triangle is a simple figure of stability. Besides sloped chords, parallel chord construction is also appropriate as external profile.

6.9.2 A truss is essentially a plane structure which is very stiff in the plane of the members, that is the plane in which it is expected to carry load, but very flexible in every other direction. Roof truss generally consists of a number of triangulated frames, the members of which are fastened at ends and the nature of stresses at joints is either tensile or compressive and designed as pin-ended joints (*see* Fig. 2A). Bamboo trusses may also be formed using bamboo mat board or bamboo mat-veneer composite or plywood gusset (*see* Fig. 2B).

6.9.3 Trusses shall be analysed for the determination of axial forces in members and the deformation of joints. For the influence of eccentricities, due allowance shall be made in design.

6.9.4 The truss height shall exceed 0.15 times the span in case of a triangular truss (pitched roofing) and 0.10 times the span in case of a rectangular (parallel) truss.

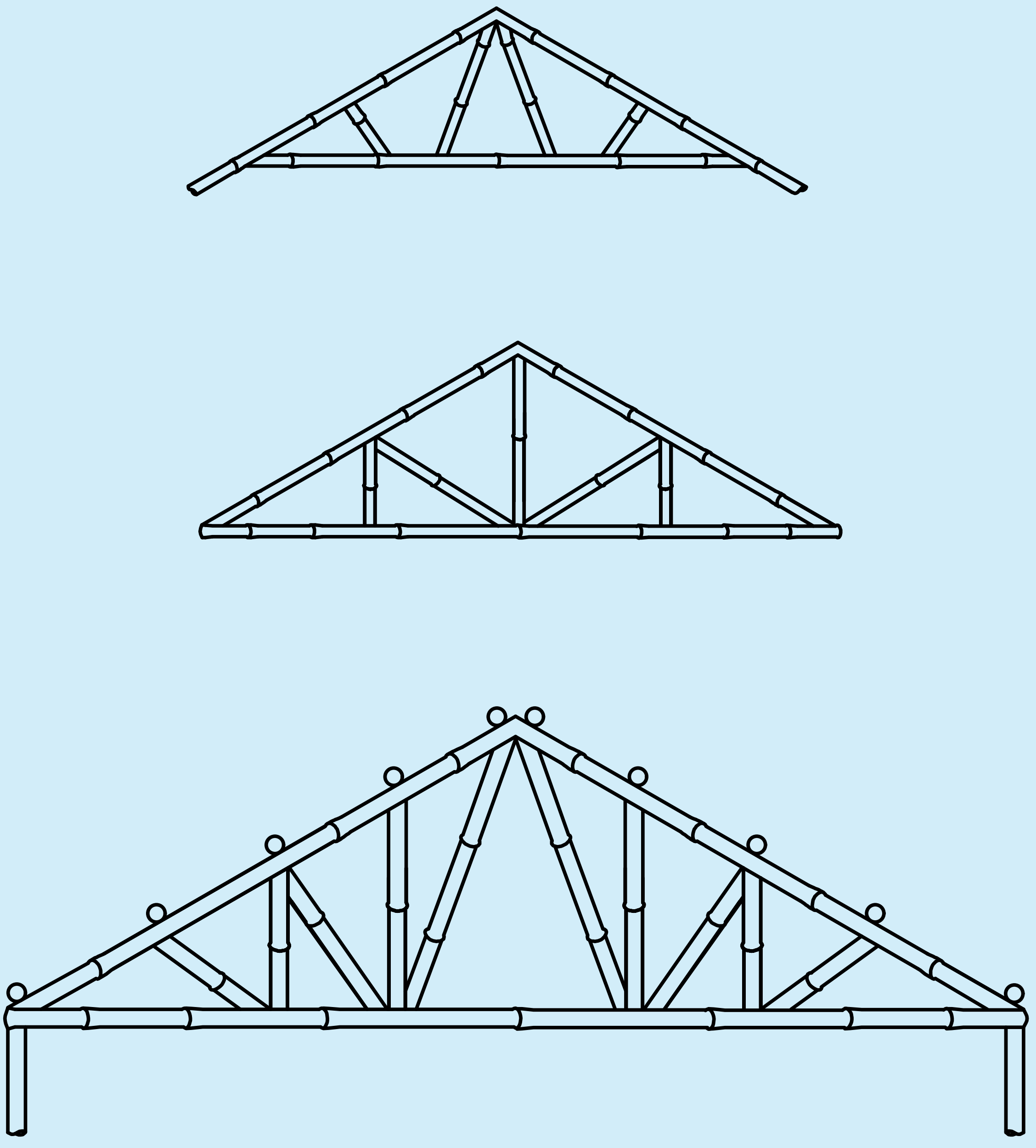
6.9.5 For members in compression, the effective length for in-plane strength verification shall be taken as the distance between two adjacent points of contraflexure. For fully triangulated trusses, effective length for simple span members without especially rigid end-connection shall be taken as the span length.

6.9.6 The spacing of trusses shall be consistent with use of bamboo purlins.

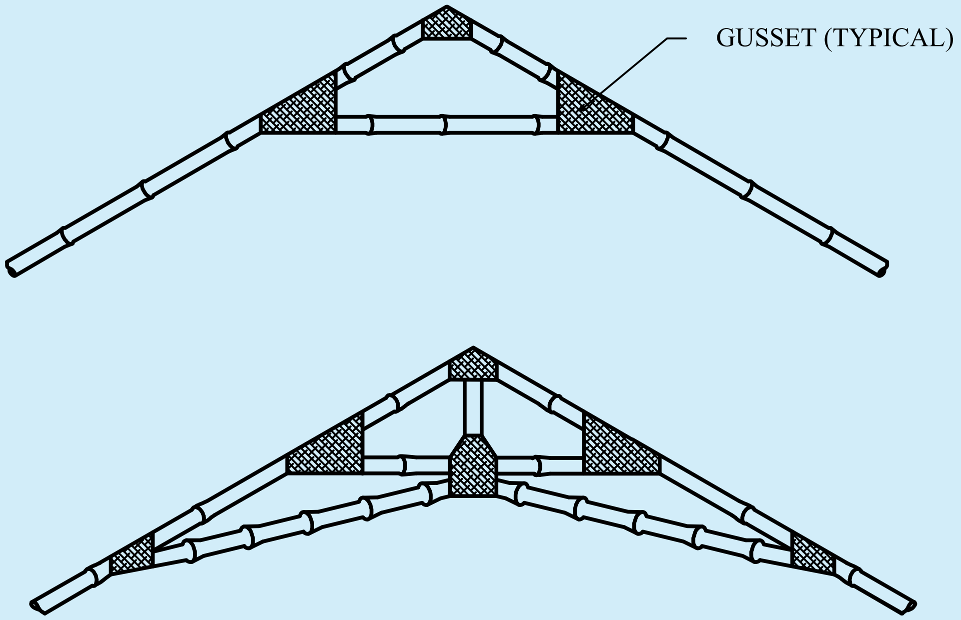
6.9.7 The ends in open beams, joists, rafters, purlins shall be suitably plugged. Bamboo roof coverings shall be considered as non-structural in function.

6.9.8 Bamboo trusses with wire bound joints using bamboo pins and/or wooden splice plates fastened with bamboo pins when tested at load for factor of safety of at least 5, result in deflection within permissible range at design load; good recovery but abnormal deflection beyond ultimate load without collapse was observed.

NOTE — This is based on the work done on prototypes of a few bamboo trusses (span 4 m) tested at Forest Research Institute, Dehradun.



2A PIN ENDED JOINT TRUSSES



2B GUSSET JOINT TRUSSES

FIG. 2 SOME TYPICAL CONFIGRATIONS FOR SMALL AND LARGE TRUSSES IN BAMBOO

6.9.9 *Bamboo Mat Corrugated Sheets for Building Roofs*

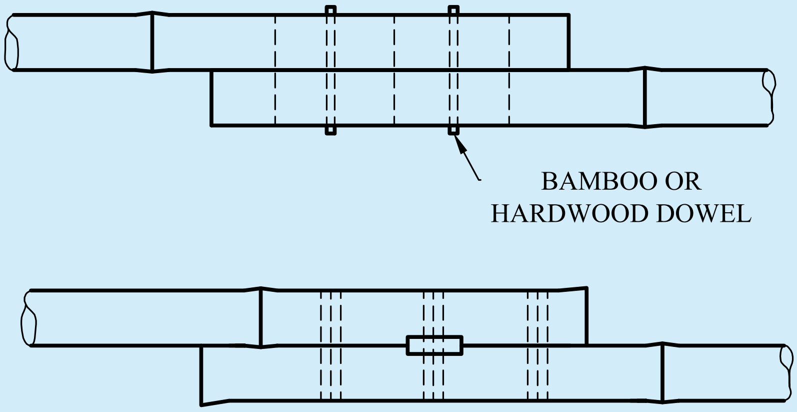
Bamboo mat corrugated sheets (BMCS) shall be used as a sustainable roofing material suitable for residential, commercial, and institutional buildings. BMCS are made from woven bamboo mats treated with phenolic resin and pressed under heat and pressure, these sheets offer a durable and eco-friendly alternative to traditional roofing materials. BMCS sheets shall provide high strength, resilience, and resistance to water, decay, and UV exposure, making them suitable for varied climates. These sheets should contribute to energy efficiency by offering thermal resistance and natural temperature regulation. BMCS shall comply with the accepted standard [C-3B(5)], meeting the necessary performance requirements for load-bearing capacity, impermeability, water absorption, and fire resistance.

6.9.10 *Bamboo Mat Ridge Cap (BMRC)*

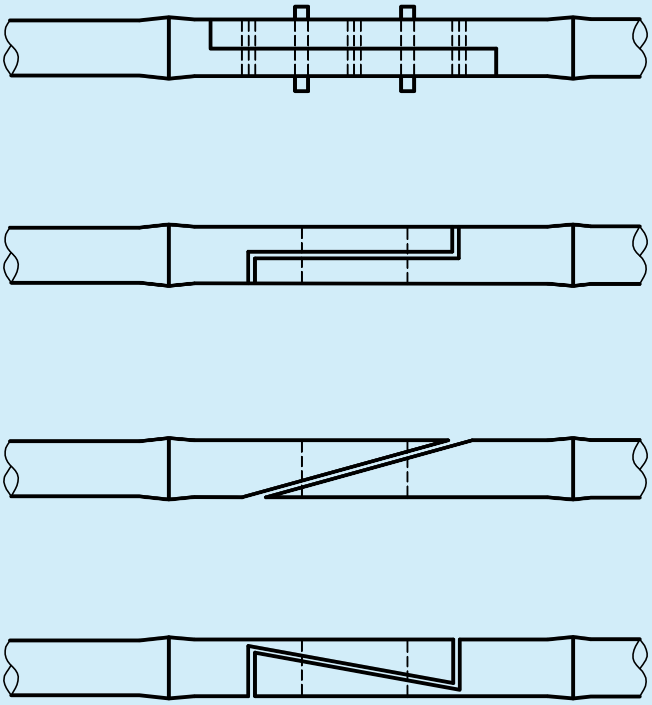
Bamboo mat ridge cap (BMRC) is a sustainable, lightweight, and eco-friendly roofing solution developed to complement bamboo mat corrugated sheets (BMCS) in building construction. Produced from bamboo mats, BMRCs are designed to cover the ridge (top edges) of BMCS roofs, providing strong physical and mechanical properties suitable for roofing applications. BMRCs are energy-efficient and cost-effective, offering a high strength-to-weight ratio, low thermal conductivity, and an aesthetically pleasing appearance.

7 DESIGN, TECHNIQUES OF JOINTS AND CONSTRUCTION PRACTICES

7.1 Connecting the load-bearing elements together for effective transfer of stress and to achieve continuity between elements with controlled displacements is one of the serious problem. As joints are a source of weakness in any bamboo structure, they have to be made as strong and rigid as possible. Joints are quite critical in assemblies, and these should be stable in relation to time. For general information, the diagrams of typical joints given in Figs. 3 to 7 may be used based on tests for adequacy of strength.

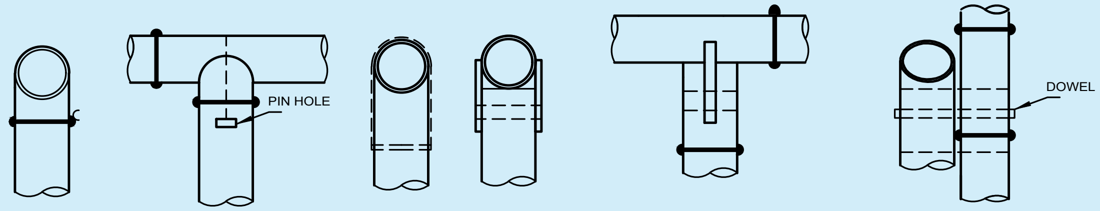

BAMBOO OR
HARDWOOD DOWEL

3A FULL LAPPED JOINT



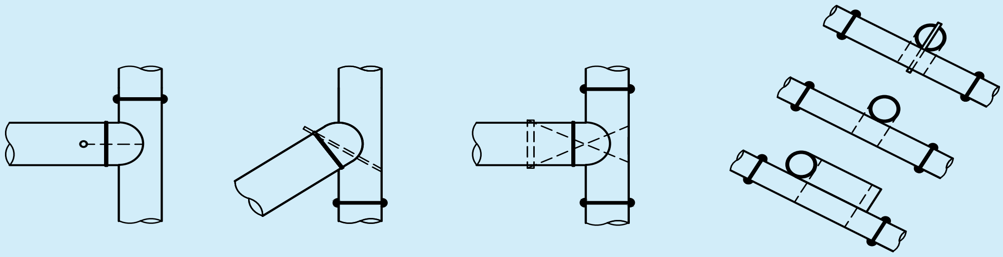
3B HALF LAPPED JOINT
(REBATED/SPLAYED)

FIG. 3 SPLICED JOINT


PIN HOLE
DOWEL

4A SADDLE JOINT WITH LASHING AND SIDE PLATES (or Seated Joints)

4B BEAM SUPPORTED ON INDEPENDENT SHORT CULM TIED TO THE POST



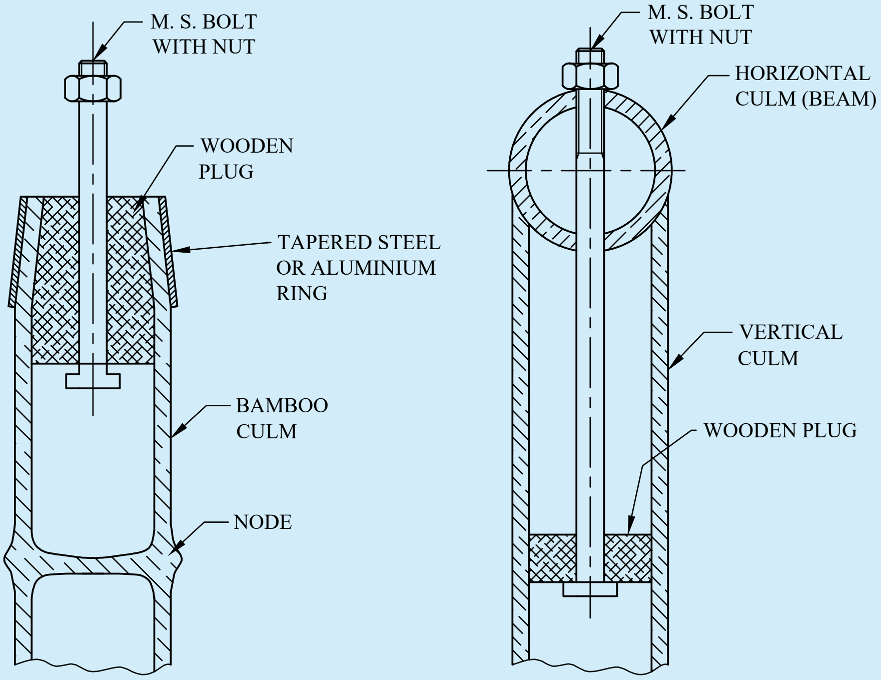
4C TIES PASSING THROUGH A PRE-DRILLED HOLE OR AROUND PEG

4D PEGGED AND TIED SYSTEM

4E DOWELLED AND TIED SYSTEM

4F PURLIN TIED TO RAFTER

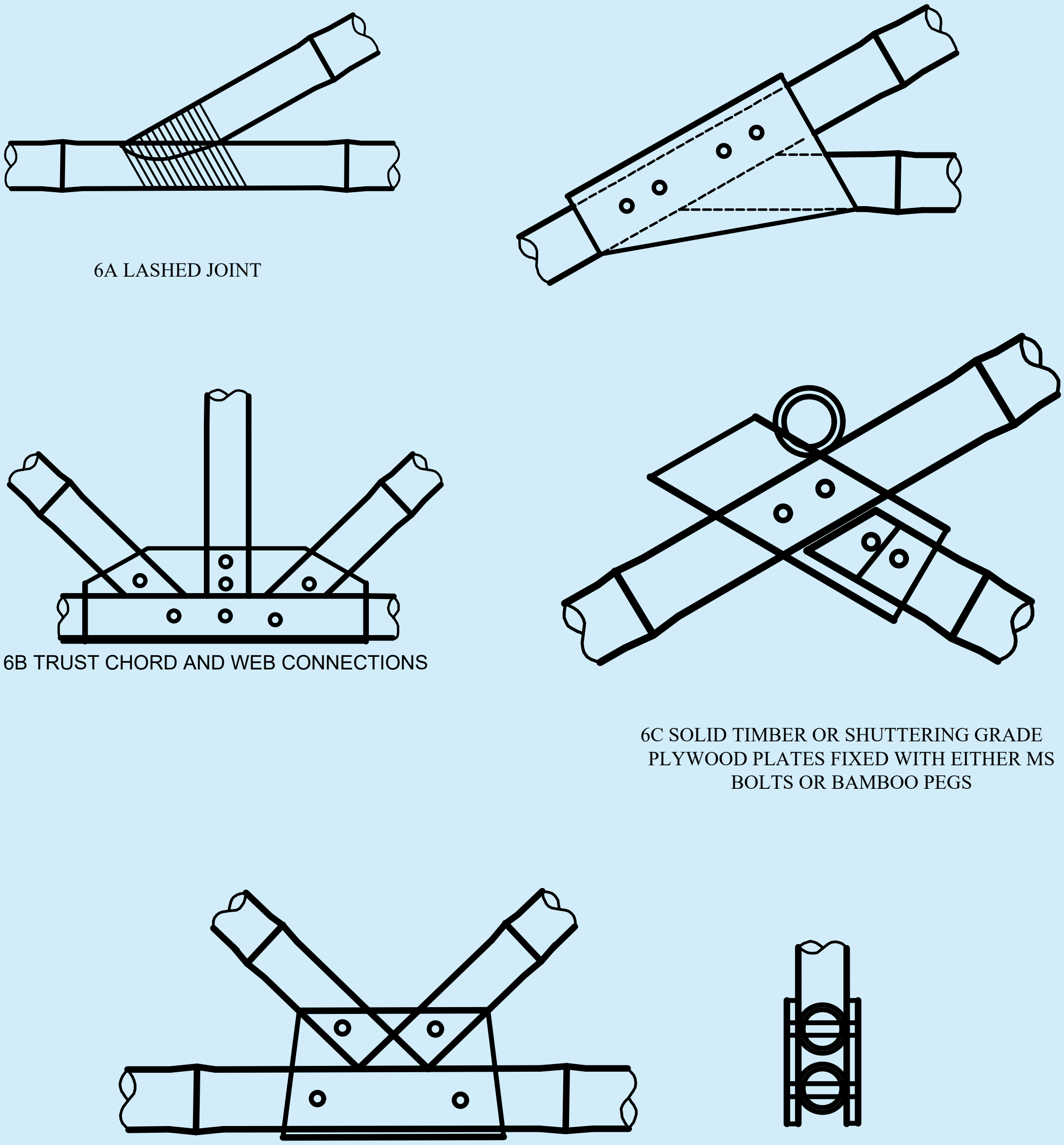
FIG. 4 BEARING JOINTS


M. S. BOLT
WITH NUT
WOODEN
PLUG
TAPERED STEEL
OR ALUMINIUM
RING
BAMBOO
CULM
NODE
M. S. BOLT
WITH NUT
HORIZONTAL
CULM (BEAM)
VERTICAL
CULM
WOODEN PLUG

5A SYSTEM WITH NARROWED END

5B ARRANGEMENT FOR BEARING WITH USE OF NUT AND BOLT

FIG. 5 SOME NUT BOLT JOINERY DETAILS

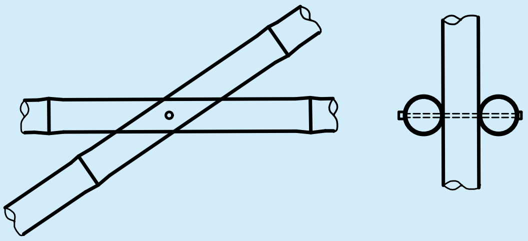


6A LASHED JOINT

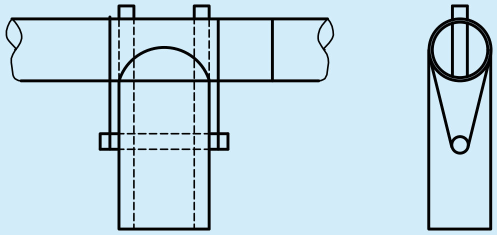
6B TRUST CHORD AND WEB CONNECTIONS

6C SOLID TIMBER OR SHUTTERING GRADE PLYWOOD PLATES FIXED WITH EITHER MS BOLTS OR BAMBOO PEGS

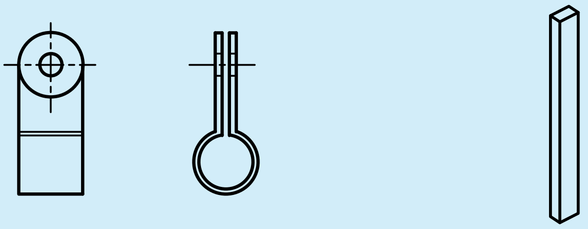
FIG. 6 GUSSET PLATED JOINTS



7A SIMPLY BOLTED CONNECTION WITH MS ARC WASHERS

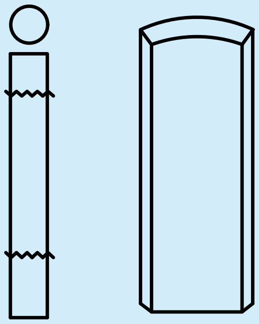


7B HORNED JOINT WITH PIN AND ROPE LASHING



7C STEEL BAND TO BE FITTED AROUND BAMBOO SECTION

7D HARDWOOD DOWEL (SQUARE OR CIRCULAR)



7E SOLID BAMBOO OR SPLIT BAMBOO PINS (WITH SKIN ON)

FIG. 7 OTHER JOINTS AND SECTIONS

7.2 Bamboo Joints

Susceptibility to crushing at the open ends, splitting tendency, variation in diameter, wall thickness and straightness are some of the associated issues which have to be taken care of while designing and detailing the connections with bamboo.

Joints shall be designed to include force transmissions in a required manner, predictable deformations to be within prescribed limits and specific geometry/load direction.

Tests on full scale joints or on components shall be carried out in accordance with the good practice [C-3B(6)] and the accepted standards [C-3B(7)] as for nailed jointed timber structures.

7.2.1 *Traditional Practices*

Such joining methods revolve around lashing or tying by rope or string with or without pegs or dowels. Such joints lack stiffness and have low efficiency but have served the mankind for long in traditional bamboo construction.

7.2.1.1 *Lengthening joints* (*end jointing*) (*see* Fig. 3)

7.2.1.1.1 *Lap joint*

End of one piece of bamboo is made to lap over that of the other in line and the whole is suitably fastened. It may be full lapping or half lapping. Full section culms are overlapped by at least one internode and tied together in two or three places. Efficiency could be improved by using bamboo or hardwood dowels.

7.2.1.1.2 *Butt joints*

Culms of similar diameter are butted end to end, inter-connected by means of side plates made of quarter-round culm of slightly large diameter bamboo, for two or more internode lengths. Assembly shall be fixed and tied preferably with dowel pins.

7.2.1.1.3 *Sleeves and inserts*

Short length of bamboo of appropriate diameter may be used either externally or internally to join two culms together.

7.2.1.1.4 *Scarf joints*

A scarf joint is formed by cutting a sloping plane 1 in 4 to 1 in 6 on opposite sides from the ends of two similar diameter bamboo culms to be joined. They shall be lapped to form a continuous piece and the assembly suitably fastened by means of lashings or glued.

7.2.1.2 *Bearing joints* (*see Fig.* 4)

For members which either bear against the other or cross each other and transfer the loads at an angle other than parallel to the axis, bearing joints are formed.

7.2.1.2.1 *Saddle joints*

The simplest form consists of a horizontal member supported directly on top of a vertical member. The top of the post may be cut to form a saddle to ensure proper seating of beam for good load transfer. The saddle should be close to a node to reduce risk of splitting.

7.2.1.2.2 *Angled joints*

When two or more members meet or cross other than at right angles, angled joints are formed.

7.2.2 *Improved Practices in Bamboo Jointing*

7.2.2.1 Plywood or solid timber gusset plates may be used at joint assemblies of web and chord connection in a truss and fixed with bamboo pins or mild steel (MS) bolts. Hollow cavities of bamboo need to be stuffed with wooden plugs or otherwise by suitable means.

7.2.2.2 Use of wooden inserts to reinforce the ends of the bamboo before forming the joints. Alternatively, steel bands clamps with integral bolt/eye may be fitted around bamboo sections for jointing.

7.2.3 *Fixing Methods and Fastening Devices*

In case of butt joints the tie-wire may be passed through a pre-drilled hole or around hardwood or bamboo pegs or dowels inserted into preformed holes to act as horns. Pegs are driven from one side, usually at an angle to increase strength and dowels pass right through the member, usually at right angles. Normally 1.60 mm (16 SWG) diameter galvanized iron wire may be used for tight lashing.

NOTE — Drill size needs to be specified in order to avoid possible split/crack in walling of bamboo.

7.2.3.1 *Wire bound joints with or without pins*

Usually 2.00 mm (14 SWG) diameter galvanized iron wire is tightened around the joints by binding the respective pieces together. At least two holes are drilled in each piece and wire is passed through them for good results. Generally, 10 mm to 12 mm diameter bamboo pins are driven and fastened to culms.

7.2.3.2 *Fish plates/Gusset plated joints* (*see Fig.* 6)

At least 25 mm thick hardwood splice plate or 12 mm thick structural grade plywood are used. Solid bamboo pins help in fastening the assembly.

7.2.4 For any complete joint alternative for a given load and geometry, description of all fastening-elements, their sizes and location shall be indicated. Data shall be based on full scale tests.

7.2.5 Tests on full scale joints or on components shall be carried out in a recognized laboratory.

7.2.6 In case of high wind and seismic areas, good construction practices shall be followed taking care of joints, their damping and possible ductility. Bracings in walls shall be taken care of in bamboo structures.

7.2.7 Metal fasteners and other structural joints shall be made inherently corrosion resistant or be protected against corrosion, thereby making the joints more durable.

7.3 Construction Practices

7.3.1 Bamboo being a versatile resource characterized by high strength, low mass and ease of working with simple tools, it is desirable to increasingly make appropriate use of this material. Design of structures using bamboo should be done in accordance with **6**. It should be ensured that the elements of structure satisfy the appropriate fire resistance requirements as specified in Part F ‘Fire and Life Safety’ of this NBCS, and quality of building materials/components used shall be in accordance with Part B ‘Building Materials’ of this NBCS. For construction using bamboo, some of the important constructional provisions given in **7.3.2** to **7.3.7** shall be followed.

7.3.2 The following sound construction practices shall be taken into account:

a) Use of air dry bamboo; and ensure that bamboo in building remains air dry; and in case the bamboo has become wet, shall provide it the opportunity to dry again before the it deteriorates due to moisture;

b) Permeability of walls, floors and roofs made from bamboo, cause internal pressure and can therefore change the net wind-load acting on the roof, wall and floor; and

c) Check whether the workmanship of the labour force is according to the assumptions.

7.3.3 *Working Finishing*

7.3.3.1 Bamboo can be cut and split easily with very simple hand tools. Immature bamboos are soft, pliable and can be moulded to desired shape. It takes polish and paint well.

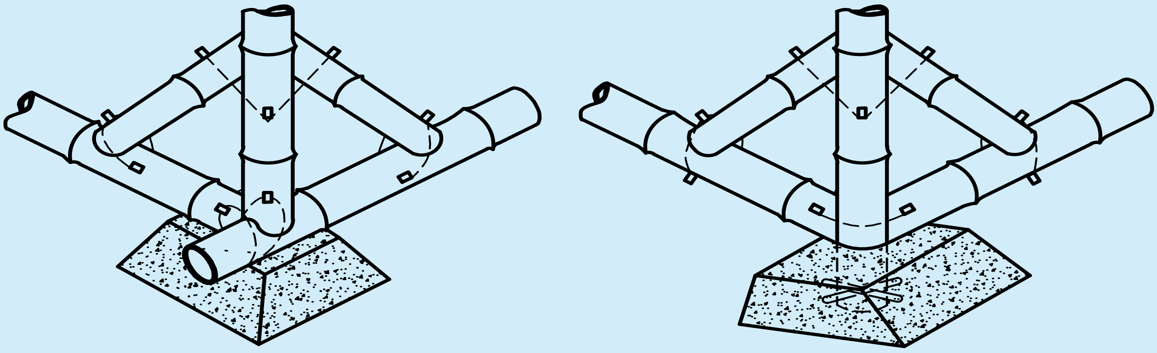
7.3.3.2 While it is possible to work with bamboo simply using a machete, a few basic tools such as, machete, hack saw, axe, hatchet, sharpening tools, adze, chisel (20 mm), drill, wood rasps, steel rod, and pliers, will greatly increase the effectiveness of the construction process.

7.3.4 For providing safety to the structure against fire, bamboo may be given fire retardant treatment using following chemicals; a few drops of concentrated Hcl shall be added to the solution to dissolve the precipitated salts:

Ammonium phosphate	:	3 parts
Boric acid	:	3 parts
Copper sulphate	:	1 part
Zinc chloride	:	5 parts
Sodium dichromate	:	3 parts
Water	:	100 parts

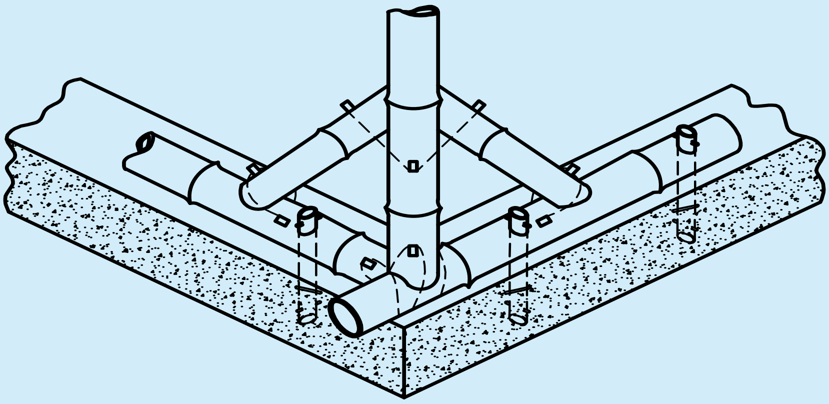
7.3.5 *Foundations*

Bamboo in direct contact with ground, bamboo on rock or preformed concrete footing, bamboo incorporated into concrete, may form the foundation structure (*see* Fig. 8). Also, arrangements with use of metallic strap, C-clamp and bunched bamboo columns embedded in concrete may be used for foundation of bamboo structures (*see* Fig. 9).



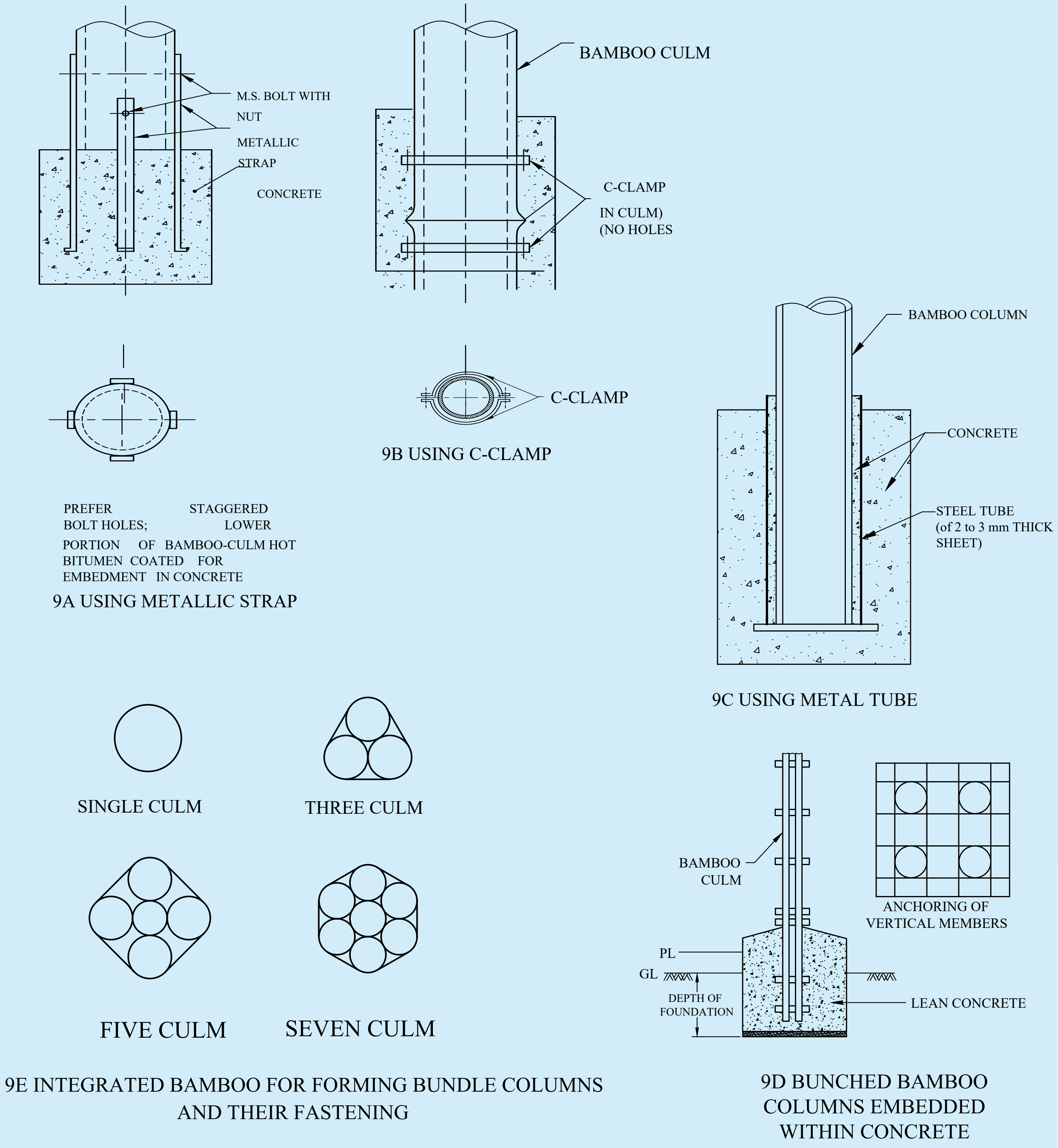
8A BAMBOO ON PREFORMED CONCRETE FOOTINGS

8B BAMBOO INCORPORATED INTO CONCRETE FOOTINGS (SINGLE POST FOOTING)



8C BAMBOO OUT OF GROUND CONTACT ON STRIP FOOTINGS OF CONCRETE (LARGE DIAMETER THICK WALLED BAMBOO WITH CLOSELY SPACED NODES TO BE USED)

FIG. 8 BAMBOO FOUNDATIONS


M.S. BOLT WITH
NUT
METALLIC
STRAP
CONCRETE
PREFER STAGGERED BOLT HOLES; LOWER PORTION OF BAMBOO-CULM HOT BITUMEN COATED FOR EMBEDMENT IN CONCRETE
BAMBOO CULM
C-CLAMP
IN CULM)
(NO HOLES
C-CLAMP
BAMBOO COLUMN
CONCRETE
STEEL TUBE
(of 2 to 3 mm THICK
SHEET)
SINGLE CULM
THREE CULM
FIVE CULM
SEVEN CULM
BAMBOO
CULM
ANCHORING OF
VERTICAL MEMBERS
PL
GL
DEPTH OF
FOUNDATION
LEAN CONCRETE

9A USING METALLIC STRAP

9B USING C-CLAMP

9C USING METAL TUBE

9E INTEGRATED BAMBOO FOR FORMING BUNDLE COLUMNS AND THEIR FASTENING

9D BUNCHED BAMBOO COLUMNS EMBEDDED WITHIN CONCRETE

FIG. 9 BAMBOO COLUMN IN CONCRETE

7.3.6 *Floors*

The floor of bamboo may be at ground level with covering of bamboo matting, etc. In elevated floors, bamboo members become an integral part of structural framework of building. The floor will comprise structural bamboo elements and bamboo decking.

7.3.7 *Jointing Techniques*

The jointing techniques in construction using bamboo shall be in accordance with 7.2.

8 BAMBOO AS REINFORCEMENT IN CONCRETE

8.1 Due to its fibrous texture, bamboo possesses high tensile strength. This can act as an alternate material for reinforcement in concrete within the limitations in design and construction. The ultimate strength of some of the species of bamboo in direct tension is nearly the same as that of steel at its yield point. On an average it varies from 1 400 kg/cm^{2}to 2 000 kg/cm^2. The principles adopted for design of concrete structure with steel is also applicable for the concrete member with bamboo. Strength characteristics of steel, concrete and bamboo are indicated in Table 4 and the design data for balanced section in beams/slabs reinforcement is given in Table 5.

Table 4 Strength Characteristics of Mild Steel, Bamboo and Concrete (For Reinforcement Purposes)

(*Clause* 8.1)

Sl No.	Species	Strength Characteristics kgf/cm^2		
		Mild Steel	Bamboo (Green)	Mass Concrete
(1)	(2)	(3)	(4)	(5)
i)	Modulus of elasticity	2.1×10^6	175 750 to 196 640 (for all locations)	–
ii)	Tensile stress	1 265.5 to 1 400	158, Bending-tension (all locations)	–
iii)	Compressive stress	–	105 (*D. strictus*)	500
iv)	Bond stress	–	3.5 (green) to 5.6 (dry) reported (likely to increase up to 10)	40 to 100
v)	Shear stress	–	115 to 180	50

Table 5 Design Data for Bamboo and Mild Steel Reinforced Cement Concrete for Balanced Section

(*Clause* 8.1)

Sl No.	Design Parameter	Design Data for Balanced Section M 15 (1 : 2 : 4) Bamboo and Mild Steel Reinforced Cement	
		Mild Steel	Bamboo
(1)	(2)	(3)	(4)
i)	Modular ratio	18	1 to 1.4
ii)	Position of neutral axis from the top	0.4d	0.25d to 0.254d
iii)	Lever arm of the resisting moment (MOR)	0.87d	0.917d to 0.915d
iv)	Constant for MOR (Q) where Q= Bending moment/bd^2 , d=depth or thickness, and b= width.	137	86

8.2 The whole bamboo culms are halved longitudinally and again splitted into four and strips of the size of 20 mm to 25 mm width and 9 mm thickness are prepared for use as reinforcement. Bamboo strips with triangular lugs (formed at nodes) due to conversion of bamboo into strips improve the bond strength because of the protruding lugs beings gripped firmly in concrete. Strength properties of split bamboo out of a few species are given in Table 6.

8.3 Bamboo has a tendency to absorb water from concrete which results in initial swelling and subsequent shrinkage leading to cracks in concrete. Following processes are thus recommended as mandatory:

a) Chemical treatment with preference for pressure impregnation (Full cell treatment with warm coal tar creosote is likely to preserve and at the same time act as water repellent); and

b) Treated strips be further given a water repellent treatment with a coating of very hot bitumen 80/100 grade, followed by a liberal coating of coarse sand. Water inhibitor will also help maintain dimensional stability of strips.

8.4 Techniques in Placing the Reinforcement (*see also* Fig. 10)

Reinforcement shall be placed in the following manner:

a) Laid edge wise in sets of twin strips for main reinforcement;

b) Laid flatwise with smooth surface and rough surface alternating as distribution or subsidiary reinforcement (wedge effects increased bond);

c) For negative moments, bamboo strips of length equivalent to $\frac{span}{6}$ laid flatwise in alternate rows of slab reinforcement;

d) For beams and lintels, twin strips are arranged in tiers, placed one above the other depending upon requirement and held in position with the help of vertical strips;

e) Split bamboo strip or preferably steel rod be used for diagonal tension to resist shear in beams, etc; and

f) Bind the reinforcement with the help of galvanized iron binding wire (or nylon thread/bamboo-cane string).

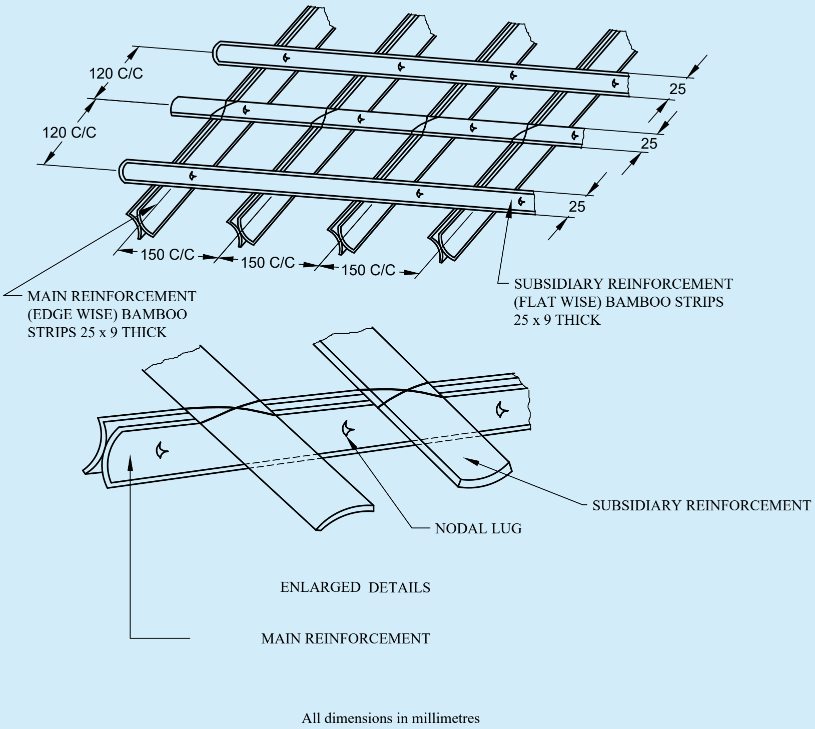
Table 6 Strength Properties of Split Bamboo in Green Condition[1)]

(*Clause* 8.2)

Sl No.	Species	Static Bending			Compression Parallel (Without Node)	Shear Parallel
		Fibre Stress at Elastic Limit kg/cm^2	Modulus of Rupture kg/cm^2	Modulus of Elasticity $\times 10^3$ kg/cm^2	Maximum Crushing Stress kg/cm^2	Maximum Shearing Stress kg/cm^2
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	*Bambusa pallida*[2)]	378	605	32.5	595	97.7
ii)	*B. vulgaris*	464	885	52.3	403	94.4
iii)	*Dendrocalamushamiltonii*	301	524	37.7	414	77.7
iv)	*D. giganteus*	472	848	50.7	360	88.5
v)	*Oxytenanthera abyssinica*[2)]	450	831	33.6	377	112.0

[1)] average of bottom, middle and top portions of culms.

[2)] average of bottom and middle portions only.



120 C/C
120 C/C
25
25
25
150 C/C
150 C/C
150 C/C
MAIN REINFORCEMENT (EDGE WISE) BAMBOO STRIPS 25 x 9 THICK
SUBSIDIARY REINFORCEMENT (FLAT WISE) BAMBOO STRIPS 25 x 9 THICK
SUBSIDIARY REINFORCEMENT
NODAL LUG
ENLARGED DETAILS
MAIN REINFORCEMENT
All dimensions in millimetres

FIG. 10 GENERAL DETAILS OF BAMBOO REINFORCEMENT

9 WALLING, FLOORING, ROOFING, AND IN-FILL PANELS FOR WALL, AND COMMON ROOF COVERING/CLADDING MATERIALS

9.1 Materials

9.1.1 *Bamboo Based Panel Products*

The common roof covering and in-fill materials shall include bamboo mat board, bamboo mat veneer composite, bamboo mat corrugated sheet, bamboo tiles, plastered bamboo reeds, thatch, corrugated galvanized iron sheeting, asphaltic sheets, plain clay tiles, etc. The respective materials shall conform to the following:

a) *Bamboo mat board* — These shall conform to the accepted standard [C-3B(8)];

b) *Bamboo mat veneer composite* — These shall conform to the accepted standard [C-3B(9)];

c) *Bamboo mat corrugated sheet and bamboo mat ridge cap* — These shall conform to the accepted standard [C-3B(5)]; and

d) *Bamboo-jute composite corrugated and semi-corrugated sheets* — These shall conform to the accepted standard [C-3B(10)].

9.1.2 *Reconstituted Wood from Destructured Bamboo*

After lopping, bamboos are cross-cut into small lengths in the round and then split along the axis. The small cross-section strips are then passed between the counter revolving rollers till the material is fully destructured. This is then air dried and resin treated and suitably pressed without much disturbing the natural alignment of fibres thus retaining the directional properties of bamboo.

Some typical strength properties of reconstituted wood from destructured bamboo are given in Table 7. The reconstituted product from bamboo can be sawn, nailed, moulded, bored, screwed, polished and painted. Thus, it offers a good substitute of solid wood for structural uses.

NOTE — Reconstituted boards/wood from destructured bamboo when tested for physical and mechanical properties in accordance with the accepted standards [C-3B(11)] and [C-3B(12)] yielded encouraging results. Gist of mechanical properties of these boards is excellent when compared with *Dendrocalamus strictus* (bamboo), teak and sal.

Table 7 Gist of Mechanical Properties of Reconstituted Wood from Bamboo (*Dendrocalamus strictus*)

(*Clause* 9.1.2)

Sl No.	**Board Material**			**Density**	**Modulus of Rupture**	**Tensile Strength Parallel to Grain**	**Compressive Strength Parallel to Grain**	**Izod Impact**	**Shear Strength**	**Modulus of Elasticity**	**Screw Holding Power**
	Set	Resin Content	Pressure								
		percent	kgf/cm^2	gm/cm^3	kgf/cm^2	kgf/cm^2	kgf/cm^2	kgf/cm	kgf/cm^2	× 10^3 kgf/cm^2	kgf
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
i)	I	6 to 29	56	0.99 to 1.25	1 769 to 2 255	1 049 to 2 024	1 057 to 1 596	343 to 281	202 to 364	278 to 308	398 to 508
						In the increasing order of resin percentage.					
ii)	II	9	21 to 28	0.62 to 0.93	1 062 to 1 615	6 99 to 1 210	675 to 1 030	186 to 202	128 to 247	155 to 232	361 to 486
	Wood/Bamboo										
iii)	*Shorea robusta* (at 12 percent, dry moisture content)			0.749	1 249	–	685	124	110	152.8	369
iv)	*Tectona grandis* (at 12 percent, dry moisture content)			0.596	959	–	532	68	102	119.6	326
v)	*Dendrocalamus strictus*			0.757	1 310	–	624	–	–	180.3	–

9.1.3 *Other Panel Products/Infill Materials*

Other panel products/infill materials shall be in accordance with relevant Indian standards. These shall be such that they maintain their integrity and strength in the assigned service class throughout the expected life of the structure.

9.1.4 *Adhesives*

Adhesive shall maintain their integrity in accordance with the accepted standard [C-3B(13)].

9.2 Structural Usage of Bamboo Based Products

9.2.1 *General*

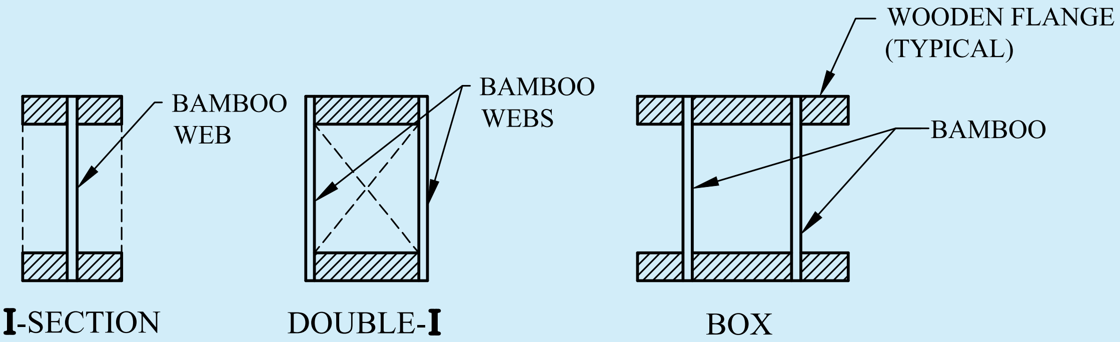
Bamboo mat board (BMB) and bamboo mat veneer composite (BMVC) have high in-plane rigidity and hence high racking strength and are more flexible than equivalent plywood. This property of BMB and BMVC can be advantageously used in many engineering applications such as wall panelling, composite beams, composite floor deck and stress skinned panels. Bamboo mat corrugated sheet (BMCS) is water proof and resistant to decay, termites/insects and fire. These sheets may be used as roofing material. Precast bamboo reinforced cement concrete and reconstituted wood from destructured bamboo can also be used in structural applications.

9.2.2 *Bamboo Composites*

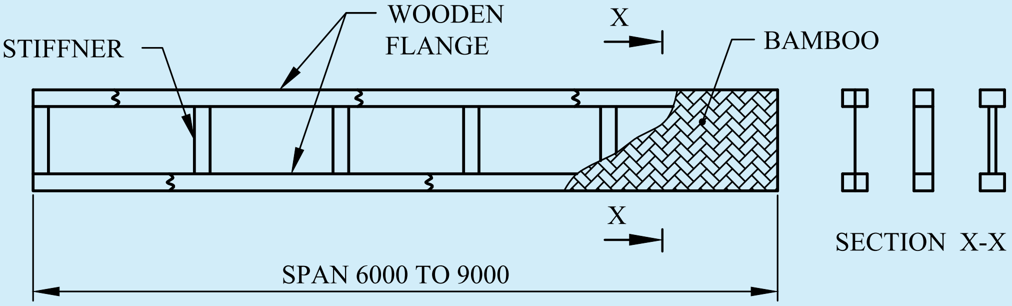
Along with bamboo, bamboo composites such as bamboo mat board, bamboo mat veneer composite, may also be successfully used in combination with timber for making efficient structural components like web because where high shear strength of bamboo mat board and bamboo mat veneer composite can be utilized as web and timber flanges for transmitting tensile and compressive stress. PF, PRF adhesives are commonly used for gluing web and flanges as shown in Fig. 11. Beams can be straight, single tapered, double tapered, haunched, as shown.

Bamboo mat board and bamboo mat veneer composite can also be used for roof and wall sheathing (shear walls) and diaphragms, gussets, arch panels, barrel vaults, etc. It can also be used as skin material in sandwich construction.

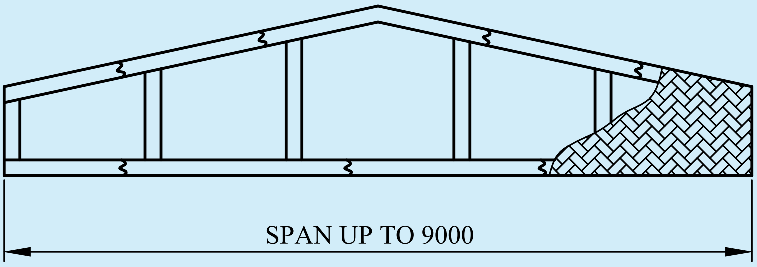
Permissible safe working stresses are given in Table 8.


WOODEN FLANGE (TYPICAL)
BAMBOO WEB
BAMBOO WEBS
BAMBOO
I-SECTION
DOUBLE-I
BOX

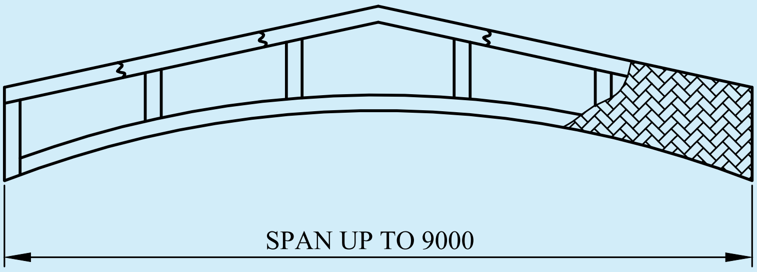
TYPICAL CROSS SECTION OF WEB BEAMS


STIFFNER
WOODEN FLANGE
X
BAMBOO
X
SECTION X-X
SPAN 6000 TO 9000

STRAIGHT


SPAN UP TO 9000

DOUBLE TAPERED


SPAN UP TO 9000

HAUNCHED

WEB BEAM CONFIGURATIONS

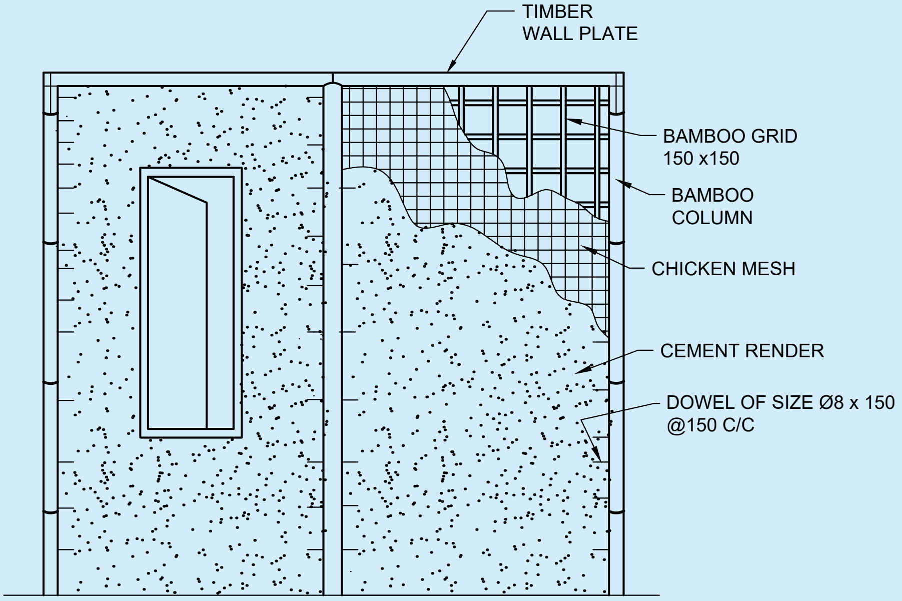
All dimensions in millimetres

FIG. 11 BAMBOO MAT BOARD WEB BEAMS

Table 8 Permissible Safe Working Stresses for Bamboo Mat Board and Bamboo Mat Veneer Composite

(*Clause* 9.2.2)

Sl No.	Property	Bamboo Mat Board N/mm^2	Bamboo Mat Veneer Composite in Direction	
			Along N/mm^2	Across N/mm^2
(1)	(2)	(3)	(4)	(5)
i)	Tensile strength	8.5	10	10
ii)	Compressive strength	10.80	13	6.5
iii)	Modulus of rupture	19.00	19	10.5
iv)	Modulus of elasticity	3 200	4 600	–
v)	Modulus of rigidity	4 970	1 930	–

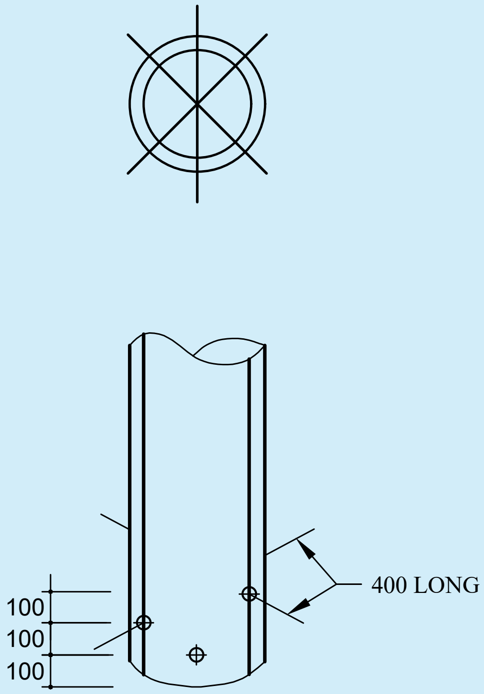

TIMBER WALL PLATE
BAMBOO GRID 150 x150
BAMBOO COLUMN
CHICKEN MESH
CEMENT RENDER
DOWEL OF SIZE Ø8 x 150 @150 C/C

All dimensions in millimetres.

FIG. 12 BAMBOO STRUCTURAL WALLING SYSTEM

9.2.4.1 *Foundation detail*

The columns pierced by steel dowels at 150 mm centre-to-centre provide connection to the bamboo grid infill. Fix 8 mm diameter MS rod of 400 mm length at 100 mm from one end of the column which has undergone treatment. For anchoring, fix two more MS rods of same diameter at 100 mm centre-to-centre starting from the first hole (*see* Fig. 13). Pour the concrete by giving temporary support. Foundation is limited to individual footings of size 400 mm × 400 mm × 600 mm deep for each bamboo column placed at 1 200 mm apart and two coarse concrete blocks or stone or other locally available material for infill wall foundation.



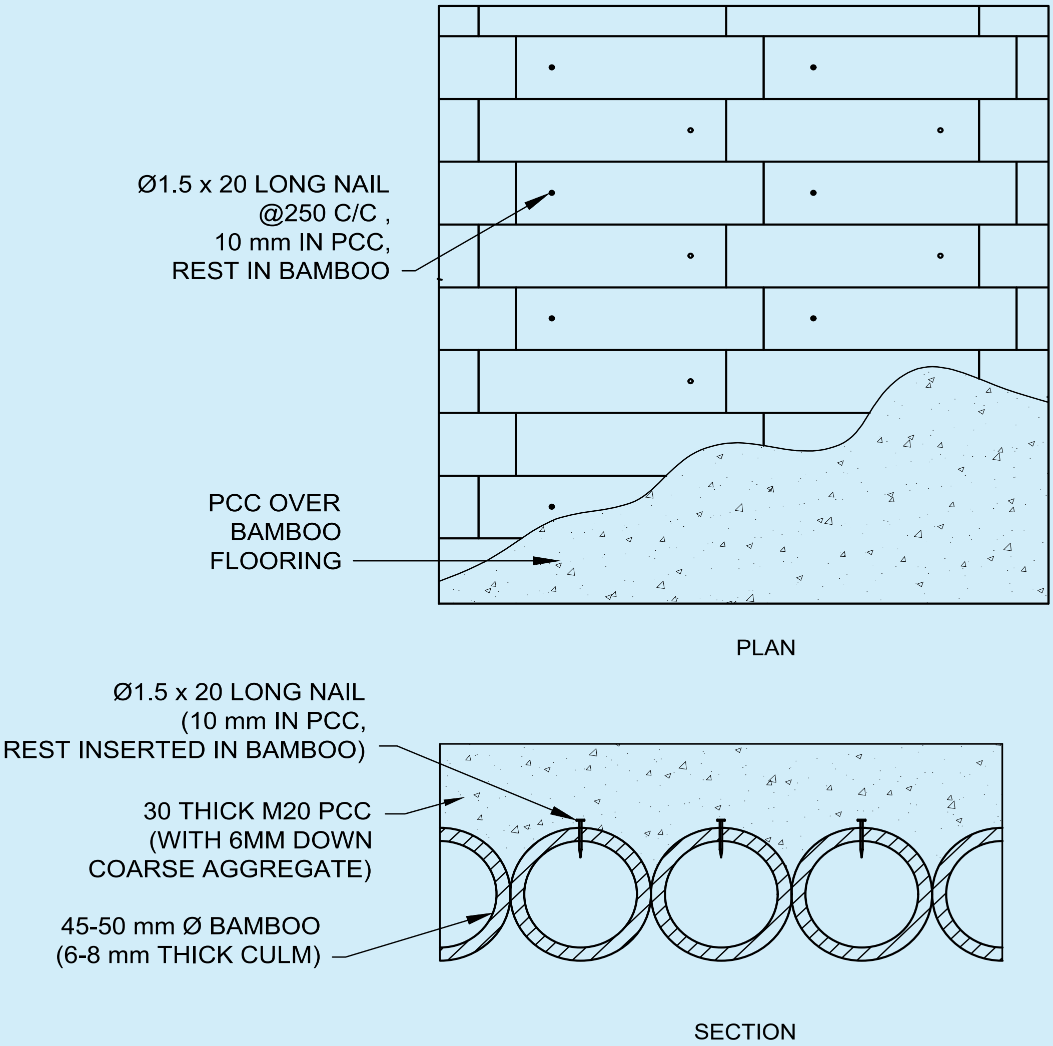
All dimensions in millimetres

FIG. 13 DETAILS OF BOTTOM OF BAMBOO COLUMN FOR ANCHORING IN CONCRETE FOR FOUNDATION

9.2.5 *Bamboo Concrete Flooring Using Round Bamboo*

Technology of such a flooring (for situations needing raised flooring) is based on the method of rigidly fixing round bamboo, where 30 mm thick M20 grade PCC (with 6 mm down coarse aggregate) is placed over 6 mm to 8 mm thick culm, that are arranged side by side to form bamboo flooring.

The rigid fixing is achieved by using shear connectors in the form of 1.5 mm dia. 20 mm long MS nails partially inserted into the bamboo flooring and balance length with the heads of the nails embedded in the PCC layer, holding the two components together. The sectional properties of the combination are calculated based on the concept of flitched beams for design (*see* Fig. 14).


Ø1.5 x 20 LONG NAIL
@250 C/C ,
10 mm IN PCC,
REST IN BAMBOO
PCC OVER
BAMBOO
FLOORING
PLAN
Ø1.5 x 20 LONG NAIL
(10 mm IN PCC,
REST INSERTED IN BAMBOO)
30 THICK M20 PCC
(WITH 6MM DOWN
COARSE AGGREGATE)
45-50 mm Ø BAMBOO
(6-8 mm THICK CULM)
SECTION

All dimensions in millimetres.

FIG. 14 DETAIL OF A TYPICAL BAMBOO CONCRETE FLOORING

9.2.6 *Bamboo Concrete Walling Using Flat Bamboo*

Loads on walls and roof do not generally justify use of round bamboo as such. So, flat or split bamboo is preferred for use in these cases. The flat bamboo works like a wire-net used conventionally to hold cement plaster in critical applications. Partial plastering is done during the first day ensuring entry of plastering material in the gaps of flat bamboo. This provides the base for cement plastering or PCC laying next day. About 5 mm gap is essential for entry of plastering material of sufficient sectional area to sustain shear force. The gaps are generated by inserting a small wedge of bamboo strip and pulling it out after a part of the gap is filled by plaster. Such gaps have to be discontinuous, to retain the character of a wire-net. About 25 percent width of the flat bamboo is assumed to be gaps, part of it is the organized gap of 5 mm width as described, at an interval of about 50 mm width, to sustain shear force and the balance gap remains to be natural to flat bamboo. Minimum thickness of the flat bamboo is assumed to be 6 mm. Bamboo with thicker wall would be stronger.

Expected strength (using *Bambusa balcooa*) may be considered as follows:

a) Walling of 6 mm bamboo with 18 mm thick cement sand plaster in 1 : 3 would be able to withstand wind pressure of 112 kgf/m^2 if used as wall, either supported continuously 1.5 m apart, or supported simply 1.25 m apart; and

b) As a roof, the wind suction load would be partly compensated by the dead load of the roof. The imposed load of a mason sitting at the centre of span needs to be considered. This load can be accommodated by use of 18 mm M 20 PCC with 6 mm flat bamboo, supported 1.0 m apart; neatly finished.

The engineered houses for application of the above bamboo concrete walling are designed with stiffeners and diagonals in all the three planes, keeping the deformation of walls along plane of walls almost nil and deflection of columns across the plane of wall at a minimum.

10 LIFE CYCLE ASSESSMENT OF BAMBOO FOR USE IN BUILDINGS

10.1 Timber used in building structures and elements shall undergo a comprehensive life cycle assessment (LCA) to evaluate its environmental impacts across its entire lifecycle, from raw material extraction to disposal or recycling. LCA provides valuable insights into the sustainability of timber and its environmental footprint in building applications. The assessment shall cover the following stages:

a) *Production and Construction* — This stage evaluates the energy and resources required for the extraction, transportation, and processing of raw timber into building materials. It also includes the energy consumption and waste generated during the construction process, as well as the transportation of materials to the construction site.

b) *Use Stage* — The use stage assesses the environmental impacts of timber during the building's operational lifespan. This includes maintenance, repairs, and potential replacement of timber components, considering the durability, performance, and long-term sustainability of the material.

c) *End-of-Life* — At the end of the building's useful life, the timber structure may undergo demolition, with the materials being processed for waste management, recycling, or reuse. This stage assesses the environmental effects of these processes and the potential for timber materials to be repurposed.

d) *Externalized Impacts Beyond the System Boundary* — The incidental effects of recycling, reusing, and recovering energy, water, or materials beyond the system boundaries of the LCA study are included in this stage. These externalized impacts consider how recycled timber or materials might contribute to environmental benefits outside the building's lifecycle.

10.2 Environmental Impact Categories

The LCA may be used to assess the environmental impact of timber buildings in several categories, which encompass emissions and pollutants generated throughout the lifecycle. These categories include:

a) *Global Warming Potential* — The contribution of greenhouse gas emissions to climate change;

b) *Acidification Potential* — The potential for acidic compounds to form in the environment, affecting ecosystems and infrastructure;

c) *Eutrophication Potential* — The impact of nutrient loading on water bodies, potentially causing excessive algal growth;

d) *Ozone Depletion Potential* — The impact of substances that contribute to the depletion of the ozone layer.

e) *Smog Formation Potential* — The potential for air pollution to contribute to the formation of ground-level ozone and smog; and

All relevant material and process quantities shall be included in the LCA inventory, and their impacts shall be calculated using recognized tools and methodologies.

10.3 Requirements for Life Cycle Assessment

In the context of building with timber, LCA may be required for the following purposes:

a) *Decision-Making Support* — Providing building owners and stakeholders with data on the environmental and sustainability aspects of timber, aiding informed decision-making;

b) *Design Evaluation* — Offering insights into material selection and environmental performance across different design possibilities;

c) *Product Comparison* — Demonstrating the environmental advantages of timber in comparison to alternative building materials;

d) *Environmental Benefit Evaluation* — Helping assess the ecological benefits of innovative timber products or policies; and

e) *Performance Benchmarking* — Comparing the environmental performance of timber buildings against established benchmarks and sustainability goals.

10.4 Methodology for Conducting LCA

The LCA of timber buildings may be conducted iteratively, with increasing detail as the design or construction phases progress. The process should follow these steps:

a) Establish the purpose and scope of the LCA, focusing on the objectives of evaluating timber's environmental impact;

b) Gather data on the timber materials, including their types, quantities, lifespans, and lifecycle stages. Special attention should be given to materials used in the production and use stages;

c) Using LCA tools (for example, SimaPro, MATLAB), assess the environmental impacts of timber buildings. The evaluation shall include biogenic carbon considerations, as timber stores carbon from the atmosphere, contributing to carbon sequestration during its lifecycle;

d) Interpret the LCA results by categorizing environmental impacts by building component, material type, and lifecycle stage. Identify key contributors to the building's overall environmental footprint and visualize the outcomes; and

e) Document all findings, including assumptions, methodology, and conclusions, and present the results in reports for stakeholders. The results shall guide sustainable construction practices and decision-making in timber building projects.

10.5 Reporting

The results of the LCA should be documented, including all assumptions, methodologies, and conclusions. Reports should be prepared in accordance with relevant standards, and may be used to guide sustainable building practices and decision-making in construction.

11 TYPICAL DETAILS OF CONVENTIONAL BAMBOO BUILDING CONSTRUCTION

Typical details of conventional bamboo building construction is given in Annex C, for guidance.

ANNEX A

(*Foreword*)

SOURCE AND LOCAL NAMES OF SOME OF THE SPECIES OF BAMBOO

Sl No. (1)	*Species* (2)	*Source/Local Names* (3)
i)	*Bambusa auriculata*	Assam, Bangladesh, Myanmar; introduced in Calcutta Botanical Garden.
ii)	*B. balcooa*	Asm – Baluka; Ben – Balku bans; Duars – Bora bans; Garo – Wamnah, beru; Tripura – Barak.
iii)	*B. bambos* (*Syn.B. arundinacea*)	Asm – Kotoba; Ben – Baroowa, behor, ketuas, ketwa; Manip – Saneibi; Mah – Katang bamboo, oowga; Oriya – Daba, katuig; Tel – Mulkasveduru, Mulluvedurn; English – Spiny bamboo.
iv)	*B. burmanica*	Asm – Thaikawa.
v)	*B. multiplex* *Syn. B. glancescens* (*Syn. B. nana*)	Sans – keu-fa; Burmese – Pa-lau-pinan-wa; Malay – Bamboo tjeenah; China – Bamboo hower tjeenah.
vi)	*B. nutans*	Asm – Deobans, jotia-makal; Asm – Bidhuli, mukial; Ben – Makia; Bhutia – Jiu; Hin – Malabans; Kangra – Nal; Khasi - Seringjai; Kuki – Wa malang; Lepcha – Malubans, mahlu, mallo; Oriya – Badia bansa; Sylhet (Bangladesh) – Peechli; Tripura – Kali.
vii)	*B. pallida*	Asm – Bijli, jowa, makal, walkthai; Cachar – Bakhal, burwal; Khasi – Seskien, skhen, ineng, usker;

Sl No. (1)	*Species* (2)	*Source/Local Names* (3)
		Lepcha – Pashipo, pshi, pushee; Mikir – Loto; Naga – Tesero, watoi; Tripura – Makal.
viii)	*B. polymorpha*	Asm – Jama betwa, betwa; Ben – Batua, jaibarouwa, jama; Burma – Kyathaung-wa; MP-Korku – Narangi bhas; Tripura – Basi.
ix)	*B. tulda*	Asm – Wamunna, wagi, nal-bans; Ben – Tulda, jowa; Duars – Karanti, matela; Garo – Watti; Hin – Peka; Kamrup – Bijuli, jati, joo, ghora; Tripura – Mirtinga.
x)	*B. vulgaris*	Ben and Manipuri – Bakal; Oriya – Sunarkania bans.
xi)	*B. wamin Syn. B.ventricosa* (*Syn. B. vulgaris var. wamin*)	Common name – Pitcher bamboo.
xii)	*Cephalostachyum pergracile*	MP – Bhalan bans; Manip – Wootang; Naga – Latang; Oriya – Darrgi.
xiii)	*Dendrocalamus giganteous*	English – Giant Bamboo; Asm – Worra; Manip – Maroobeb.
xiv)	*D. hamiltonii*	Nep – Tamo; Asm – Kokwa; Tripura – Pecha.
xv)	*D. Longispathus*	Tripura – Rupai.
xvi)	*D. membranaceus*	Native of Myanmar; introduced in Kerala.
xvii)	*D. strictus*	English – Male bamboo; Ben – Karail; Guj – Nakur bans;

Sl No. (1)	*Species* (2)	*Source/Local Names* (3)
		Kan – Kiri bidiru; Mah – Male bamboo, nanvel; Oriya – Salia; Tam – Kalmungil; Tel – Sadanapa vedur; Tripura – Lathi bans;
xviii)	*Melocanna baccifera*	Hin – Bans kaban, Nav bans; Asm – Tarai; Ben – Muli; Cachar – Wati; Garo – Watrai; Manip – Moubi; Mikir – Artem; Naga – Turiah.
xix)	*Oxytenanthera abyssinicia*	Native of tropical Africa; cultivated at FRI, Dehradun.
xx)	*Thyrsostachys oliveri*	Native of Myanmar; Planted in Haldwani (Uttaranchal), Arunachal Pradesh, Kerala and Tamil Nadu.

NOTES

1 The following abbreviations have been used in the above table:

Asm	Assam
Ben	Bengali
Guj	Gujarati
Hin	Hindi
Kan	Kannada
Mah	Maharashtra
Manip	Manipur
M.P.	Madhya Pradesh
Nep	Nepali
Sans	Sanskrit
Tam	Tamil
Tel	Telugu

2 The above table does not provide an exhaustive list. It only attempts to enlist some of the information readily available in regard to species of bamboo from India and some of the neighbouring countries, and some connected information.

ANNEX B

(*Foreword*)

RECOMMENDATIONS FOR BAMBOO STRUCTURES IN HIGH WIND/CYCLONE PRONE AREAS

B-1 Given below are some recommendations for bamboo structures in high wind/cyclone prone areas, which are based on rapid visual screening (RVS) of the damages of past events:

a) Prefer a square plan of the building symmetrical to the arrangement of partitions and openings for balanced distribution of forces within the structure. Window positioning be planned in such a way that wind entering through window could pass through similar opening on opposite wall in order to reduce built-up pressure, and incorporate ridge vents;

b) A hip-shaped, pyramidal or a conical roofing be preferred to gable end or mono-pitch ones for least wind resistance;

c) Wide mono-pitched *verandas* abutting the entrance to residence should be structurally separated from the main building;

d) Roof overhangs be limited to 450 mm as they contribute to higher negative suction. Large overhangs should be properly tied back to wall frame-work;

e) Roof structure shall be properly secured with vertical load-bearing members (wooden or bamboo columns, brick piers or walling) for eliminating the chances of being blown away from the building. A continuous beam connecting all the columns would increase the framing action;

f) Roof cladding (G.I. sheets, clay tiles or thatch) be properly connected with holding down U-bolts, or sturdy anchorages to ensure safety. Thatch roof be tied by nylon ropes in diagonal pattern;

g) Sufficient depth for anchorage be provided; columns be embedded in pits within the foundation and secured by poured concrete. Wetting of column base be checked by raising it from the floor level;

h) Highest importance be given to strengthening the junctions between structural elements at different levels, that is, foundation, eaves and roof. Walls be linked together suitably by a continued collar beam at floor, sill, lintel and roof level; and

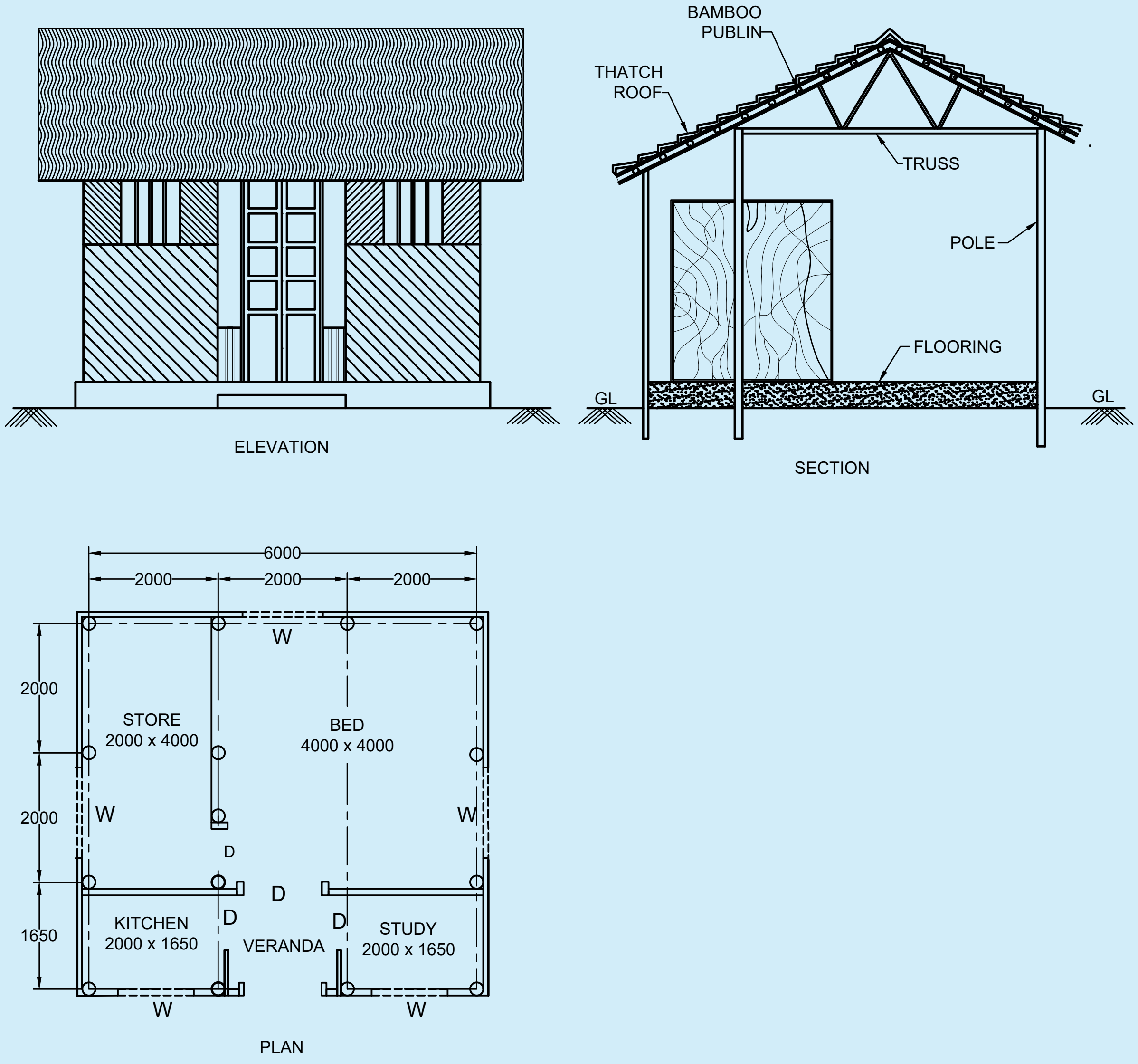
j) Fastening any two mutually perpendicular load bearing members should be done in accordance with good practice of spacing the connecting bolts with reference to loads direction and the centre of stiffness. This will increase the moment-resisting capacity of the joint and prevent hinge formation. A minimum of two bolts be provided to prevent rotation of members at a joint.

ANNEX C

(*Foreword*, *Clause* 11)

REPRESENTATIVE DESIGNS AND CONSTRUCTION DETAILS FOR BAMBOO STRUCTURES

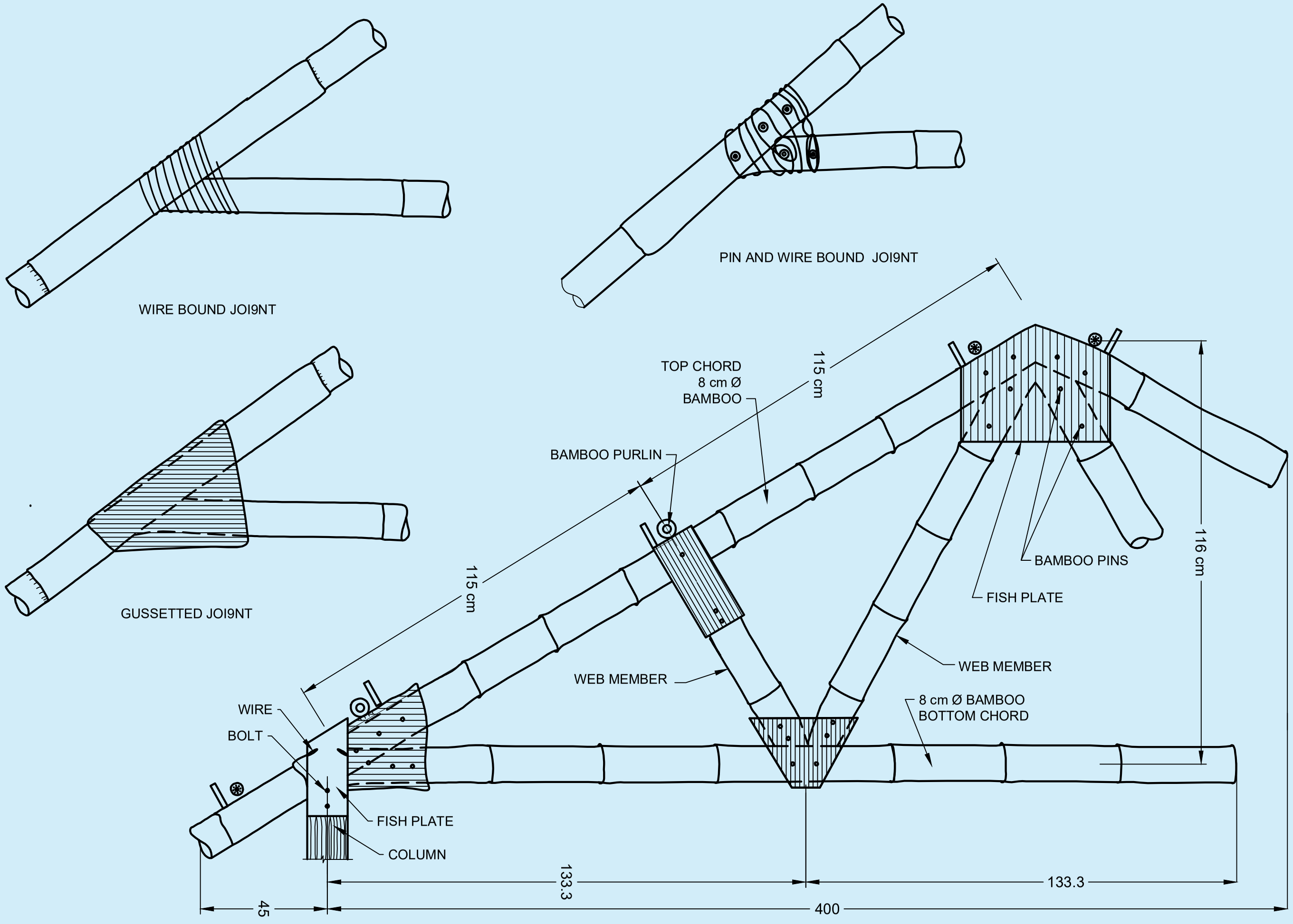
C-1 For guidance in conventional bamboo construction, typical details are presented in the Fig. 15 These details illustrate common applications of bamboo in trusses, roofing, walls, and flooring. They are intended to serve as indicative examples and not as substitutes for structural design.


BAMBOO PUBLIN
THATCH ROOF
TRUSS
POLE
FLOORING
GL
GL
ELEVATION
SECTION
6000
2000
2000
2000
2000
2000
1650
W
W
W
W
W
STORE
2000 x 4000
BED
4000 x 4000
D
D
D
D
KITCHEN
2000 x 1650
VERANDA
STUDY
2000 x 1650
PLAN

All dimensions are in millimetres

FIG. 15 BAMBOO HUT

C-1.1 Figure 16 shows a typical bamboo truss arrangement used in conventional bamboo structures. It highlights jointing methods generally adopted in practice. The illustration is indicative and not a design substitute.


WIRE BOUND JOI9NT
PIN AND WIRE BOUND JOI9NT
GUSSETTED JOI9NT
TOP CHORD
8 cm Ø
BAMBOO
115 cm
BAMBOO PURLIN
115 cm
116 cm
BAMBOO PINS
FISH PLATE
WEB MEMBER
WEB MEMBER
8 cm Ø BAMBOO
BOTTOM CHORD
WIRE
BOLT
FISH PLATE
COLUMN
45
133.3
133.3
400

All dimensions in centimeters

BAMBOO TRUSS WITH JOINTING TECHNIQUE & FIXING DETAILS WITH COLUMN

FIG. 16 BAMBOO TRUSS WITH JOINTING TECHNIQUE & FIXING DETAILS WITH COLUMN

C-1.2 Figure 17 presents a representative bamboo roofing system for conventional bamboo structures. It demonstrates the use of bamboo members in roof framing. The figure is for reference only, not a structural design.

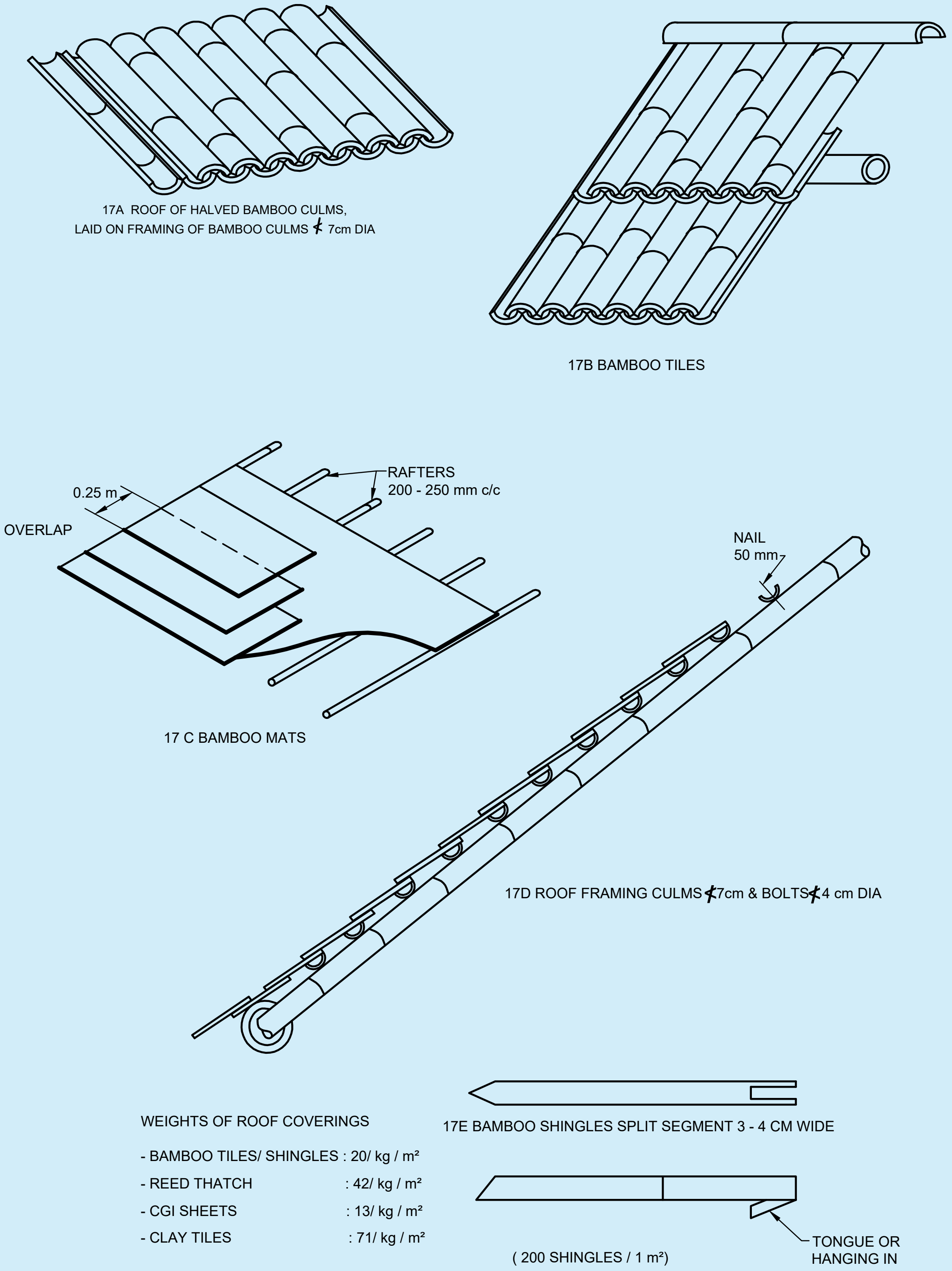

17A ROOF OF HALVED BAMBOO CULMS,
LAID ON FRAMING OF BAMBOO CULMS Ø 7cm DIA
17B BAMBOO TILES
0.25 m
OVERLAP
RAFTERS
200 - 250 mm c/c
17 C BAMBOO MATS
NAIL
50 mm
17D ROOF FRAMING CULMS Ø7cm & BOLTS Ø4 cm DIA
WEIGHTS OF ROOF COVERINGS
- BAMBOO TILES/ SHINGLES : 20/ kg / m²
- REED THATCH : 42/ kg / m²
- CGI SHEETS : 13/ kg / m²
- CLAY TILES : 71/ kg / m²
17E BAMBOO SHINGLES SPLIT SEGMENT 3 - 4 CM WIDE
(200 SHINGLES / 1 m²)
TONGUE OR
HANGING IN

FIG.17 BAMBOO ROOFING

C-1.3 Figure 18 depicts bamboo used as walling elements in conventional bamboo structures. It illustrates construction arrangements commonly followed. The drawing is illustrative and not a substitute for design.

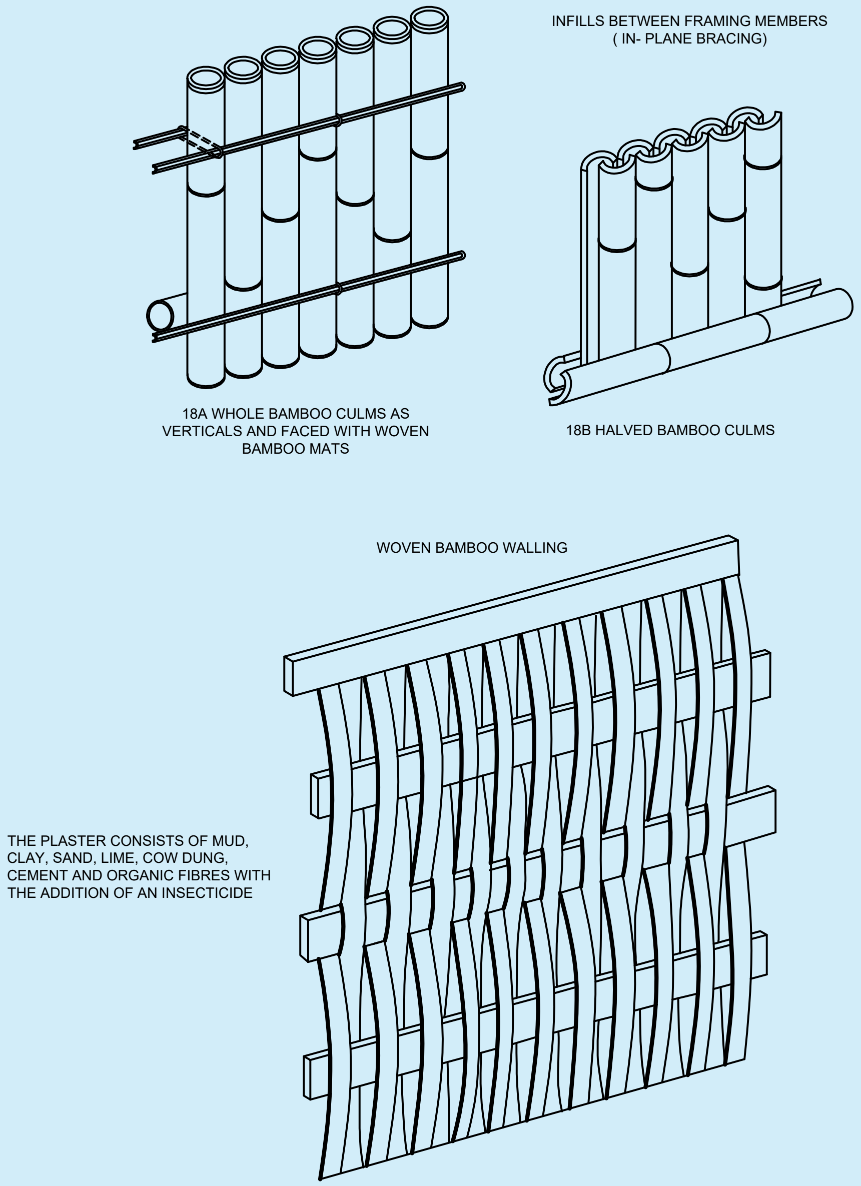
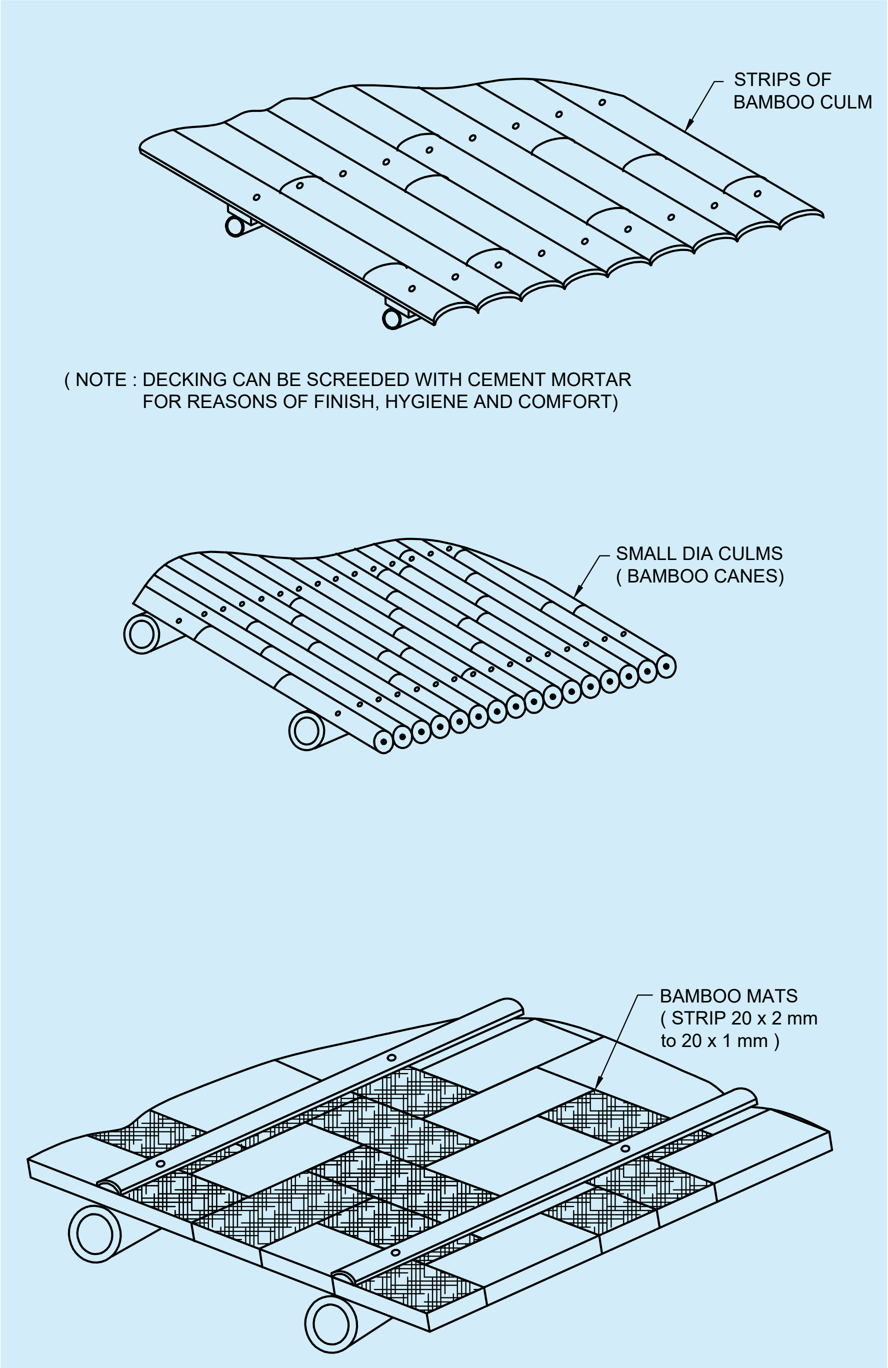

INFILLS BETWEEN FRAMING MEMBERS
(IN- PLANE BRACING)
18A WHOLE BAMBOO CULMS AS VERTICALS AND FACED WITH WOVEN BAMBOO MATS
18B HALVED BAMBOO CULMS
WOVEN BAMBOO WALLING
THE PLASTER CONSISTS OF MUD, CLAY, SAND, LIME, COW DUNG, CEMENT AND ORGANIC FIBRES WITH THE ADDITION OF AN INSECTICIDE

FIG.18 BAMBOO WALLS

C-1.4 Figure 19 shows the application of bamboo in floor decking for conventional bamboo structures. It highlights a representative arrangement for structural flooring. The figure is illustrative only and not for design purposes.


STRIPS OF
BAMBOO CULM
SMALL DIA CULMS
(BAMBOO CANES)
BAMBOO MATS
(STRIP 20 x 2 mm
to 20 x 1 mm)

(NOTE : DECKING CAN BE SCREEDED WITH CEMENT MORTAR FOR REASONS OF FINISH, HYGIENE AND COMFORT)

Fig. 19 Bamboo Floor Decking

LIST OF STANDARDS

The following list records those standards which are acceptable as 'good practice' and 'accepted standards' in the fulfilment of the requirements of this NBCS. The latest version of the standard shall be adopted at the time of enforcement of this NBCS. The standards listed may be used for conformance with the requirements of the referred clauses in this NBCS.

In the following list, the number appearing in the first column within parenthesis indicates the number of the reference in this Subsection.

	IS No.	*Title*
(1)	IS 9096 : 2006	Preservation of bamboo for structural purposes — Code of practice (*first revision*)
(2)	IS 6874 : 2008	Method of tests for bamboo (*first revision*)
(3)	IS 1902 : 2006	Preservation of bamboo and cane for non-structural purposes — Code of practice (*second revision*)
(4)	IS 8242 : 1976	Bamboo mat corrugated sheets — Specification
(5)	IS 15476 : 2004	Specification for bamboo mat corrugated sheets
(6)	IS 2366 : 1983	Code of practice for nail-jointed timber construction (*first revision*)
(7)	IS 4924	Method of test for nail-jointed timber trusses
	(Part 1) : 1968	Destructive test
	(Part 2) : 1968	Proof test
(8)	IS 13958 : 1994	Bamboo mat board for general purposes — Specification
(9)	IS 14588 : 1999	Bamboo mat-veneer composite for general purposes — Specification
(10)	IS 15972 : 2012	Bamboo-jute composite corrugated and semi-corrugated sheets — Specification
(11)	IS 1734 (Parts 1 to 20) : 1983	Methods of test for plywood (*second revision*)
(12)	IS 1708 (Parts 1 to 18) : 1986	Methods of testing of small clear specimens of timber (*second revision*)
(13)	IS 848 : 2025	Synthetic resin adhesives for plywood (phenolic, aminoplastic and bio-materials based) — Specification (*third revision*)

NATIONAL BUILDING CONSTRUCTION STANDARDS
PART C STRUCTURAL DESIGN
SECTION 4 MASONRY

BUREAU OF INDIAN STANDARDS

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National Building Code Sectional Committee, CED 46

FOREWORD

This NBCS (Part C/Section 4) covers the structural design of unreinforced and reinforced masonry elements in buildings. Provisions on reinforced brick and reinforced brick concrete floors and roofs have also been dealt with.

This Section was first published in 1970 and subsequently revised in 1983, 2005 and 2016 as a chapter of National Building Code of India. The first revision of this Section was modified in 1987 through Amendment No. 2 to bring this Section in line with the latest revised masonry code. In the amendment, certain provisions were updated following the revision of IS 1905 'Code of practice for structural use of unreinforced masonry' on which the earlier version was based. In the amendment, requirements of masonry element for stability were modified; in the design of free standing wall, provisions were made for taking advantage of the tensile resistance in masonry under certain conditions; provision regarding effective height of masonry wall between openings was modified; method of working out effective height of wall with a membrane type DPC was modified; the criteria for working out effective length of wall having openings was modified; some general guidelines for dealing with concentrated loads for design of walls were included; and provision of cutting and chases in walls were amplified. The Section was thereafter revised in 2005.

In the second revision of this Section in 2005, the provisions of special considerations in earthquake zones were aligned in line with the revised Indian Standard, IS 4326 : 1993 'Code of practice for earthquake resistant design and construction of buildings'; a new clause covering guidelines for improving earthquake resistance of low strength masonry buildings was added; and reference to design of reinforced brick and reinforced brick concrete floors and roofs was included.

In the third revision of this Section in 2016, the detailed provisions relating to reinforced masonry and durability criteria for selection of masonry mortars had been included. Also, the number of storeys of masonry construction had been limited to 4, in line with the seismic design standards. A new masonry wall construction using rat-trap bond had been included.

In this revision, this publication has been renamed as National Building Construction Standards (NBCS).

As a result of experience gained in the implementation of this Section and feedback received, as well as in view of formulation of new varieties of cement and new types of masonry blocks, a need to revise this Section was again felt. This section has, therefore, been revised to incorporate the following significant changes:

1) New masonry blocks have been included as masonry unit.
2) The admissibility of different structural systems in the earthquake zones is clarified. The following structural systems are admissible to construct earthquake resistant masonry buildings:
    a) Masonry walls with prescriptive bands (MWB);
    b) Masonry walls with prescriptive bands and vertical reinforcement (MWBR);
    c) Confined masonry walls (CMW); and
    d) Reinforced masonry walls (RMW).
3) The clause on confined masonry has been updated.
4) The clause on reinforced masonry has been updated.
5) Reference to all the concerned Indian Standards has been updated.

Structural design requirements of this section are largely based on following Indian Standards:

a) IS 1905 : 1987 'Code of practice for structural use of unreinforced masonry (*third revision*)';
b) IS 4326 : 2013 'Earthquake resistant design and construction of buildings — Code of practice (*third revision*)';

c) IS 10440 :1983 ‘Code of practice for construction of RB and RBC floors and roofs’; and

d) IS 17848 : 2022 ‘Confined masonry for earthquake resistance — Code of practice’.

Buildings with MWB and MWBR systems shall not be of height more than 15 m subject to a maximum of four storeys, measured from the base of the buildings to the roof slab or ridge level.

A reference to SP 20 : 1991 ‘Handbook on masonry design and construction (*first revision*)’, may be useful. In the formulation of this Section, inputs were also derived from the IITK-GSDMA’s publication, ‘Guidelines for structural use of reinforced masonry’.

All standards, whether given herein above or cross-referred to in the main text of this section, are subject to revision. The parties to agreement based on this section are encouraged to investigate the possibility of applying the most recent editions of the standards.

As the regulation of land development and buildings is a State subject and is dealt by the States and local bodies such as urban local bodies within their jurisdiction through building regulatory documents like building regulations, building byelaws, and fire regulations, this document is voluntary in nature and is non-binding. The implementation depends on adoption by concerned parties or stipulations in a contract or by appropriate adoption by the concerned authorities.

For the purpose of deciding whether a particular requirement of this Section is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 ‘Rules for rounding off numerical values (*second revision*)’. The number of significant places retained in the rounded off value should be the same as that of the specified value in this Section.

Important Explanatory Note for Users of the NBCS

In any Part/Section of this NBCS, where reference is made to **'good practice'** in relation to design, constructional procedures or other related information, and where reference is made to **'accepted standard'** in relation to material specification, testing, or other related information, the Indian Standards listed at the end of the Part/Section shall be used as a guide to the interpretation.

At the time of publication, the editions indicated in the standards were valid. All standards are subject to revision and parties to agreements based on any Part/Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

In the list of standards given at the end of a Part/Section, the number appearing within parentheses in the first column indicates the number of the reference of the standard in the Part/Section. For example:

a) Accepted standards [C-4(1)] refers to the Indian Standard(s) give at serial number (1) of the list of standards given at the end of this Part C/Section 4, that is, IS 1077 : 1992 'Specification for common burnt clay building bricks (*fifth revision*)', IS 1725 : 2023 'Specification for stabilized soil blocks used in general building construction (*third revision*)', IS 2180 : 1988 'Specification for heavy duty burnt clay building bricks (*third revision*)', IS 2185 (Part 1) : 2005 'Concrete masonry units — Specification: Part 1 Hollow and solid concrete blocks (*third revision*)', IS 2185 (Part 2) : 1983 'Concrete masonry units — Specification: Part 2 Hollow and solid light weight concrete blocks (*first revision*) (superseding IS 3590)', IS 2185 (Part 3) : 1984 'Concrete masonry units— Specification: Part 3 Autoclaved cellular (aerated) concrete blocks (*first revision*)(superseding IS 5482)', IS 2185 (Part 4) : 2008 'Concrete masonry units — Specification: Part 4 Cellular preformed foam cellular concrete blocks', IS 2222 : 1991 'Specification for burnt clay perforated building bricks (*fourth revision*)', IS 2849 : 1983 'Specification for non-load bearing gypsum partition blocks (solid and hollow types)(*first revision*)', IS 3115 : 1992 'Specification for lime based blocks (*second revision*)', IS 3316 : 1974 'Specification for structural granite (*first revision*)', IS 3620 : 1979 'Specification for laterite stone block for masonry (*first revision*)', IS 3952 : 2013 'Burnt clay hollow bricks and blocks for walls and partitions — Specification (*third revision*)', IS 4139 : 1989 'Specification for calcium silicate bricks (*second revision*)', IS 12440 : 1988 'Specification for precast concrete stone masonry blocks', IS 12894 : 2002 'Specification for pulverized fuel ash lime bricks (*first revision*)', IS 13757 : 1993 'Specification for burnt clay fly ash building bricks' and IS 16720 : 2018 'Pulverized fuel ash-cement bricks — Specification'.

b) Good practice [C-4(4)] refers to the Indian Standard(s) give at serial number (4) of the list of standards given at the end of this Part C/Section 4, that is,IS 2250 : 1981 'Code of practice for preparation and use of masonry mortars (*first revision*)'.

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART C STRUCTURAL DESIGN

SECTION 4 MASONRY

1 SCOPE

1.1 This NBCS (Part C/Section 4) covers the structural design aspects of unreinforced load bearing and non-load bearing walls, constructed with masonry units permitted in accordance with this Section.

1.2 This Section also deals with the selection of materials, special features of design and construction for masonry construction using rectangular masonry units. It also covers guidelines regarding earthquake resistant buildings constructed using masonry of low strength.

1.3 This Section also covers provisions for design of reinforced brick and reinforced brick concrete floors and roofs.

1.4 This Section also gives the recommendations for structural design aspects of reinforced load bearing and non-load bearing walls, constructed with different types of bricks and blocks.

1.5 The recommendations of the Section do not apply to walls constructed in mud mortars.

2 TERMINOLOGY

For the purpose of this Section, the following definitions shall apply.

2.1 Bed Block — A block bedded on a wall, column or pier to disperse a concentrated load on a masonry element.

2.2 Bond — Arrangement of masonry units in successive courses to tie the masonry together both longitudinally and transversely; the arrangement is usually worked out to ensure that no vertical joint of one course is exactly over the one in the next course above or below it, and there is maximum possible amount of lap.

2.3 Column, Pier and Buttress

a) *Column* — An isolated vertical load bearing member, width of which does not exceed four times the thickness;

b) *Pier* — A thickened section forming integral part of a wall placed at intervals along the wall, to increase the stiffness of the wall or to carry a vertical concentrated load. Thickness of a pier is the overall thickness including the thickness of the wall or, when bonded into a leaf of a cavity wall, the thickness obtained by treating that leaf as an independent wall (*see* Fig. 1)

c) *Buttress* — A pier of masonry built as an integral part of wall and projecting from either or both surfaces, decreasing in cross-sectional area from base to top.

2.4 Cross-Sectional Area of Masonry Unit — Net cross-sectional area of a masonry unit shall be taken as the gross cross-sectional area minus the area of cellular space. Gross cross-sectional area of cored units shall be determined to the outside of the coring but cross-sectional area of grooves shall not be deducted from the gross cross-sectional area to obtain the net cross-sectional area.

2.5 Curtain Wall — A non-load bearing wall subject to lateral loads. It may be laterally supported by vertical or horizontal structural members, where necessary (*see* Fig. 2).

2.6 Effective Height — The height of a wall or column, to be considered for calculating slenderness ratio.

2.7 Effective Length — The length of a wall to be considered for calculating slenderness ratio.

2.8 Effective Thickness — The thickness of a wall or column to be considered for calculating slenderness ratio.

2.9 Hollow Unit — A masonry unit of which net cross-sectional area in any plane parallel to the bearing surface is less than 75 percent of its gross cross-sectional area measured in the same plane.

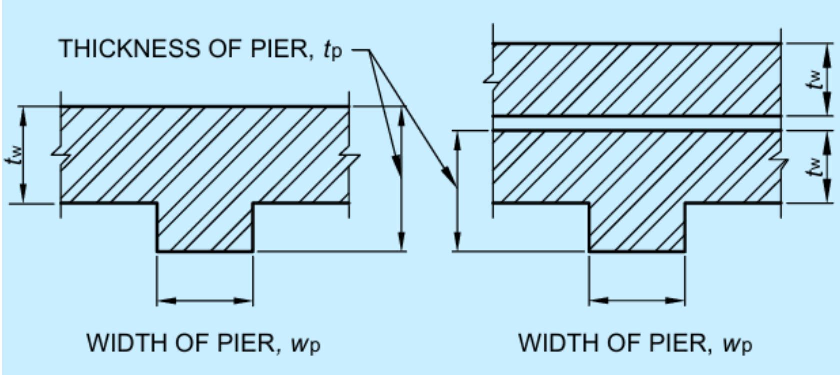
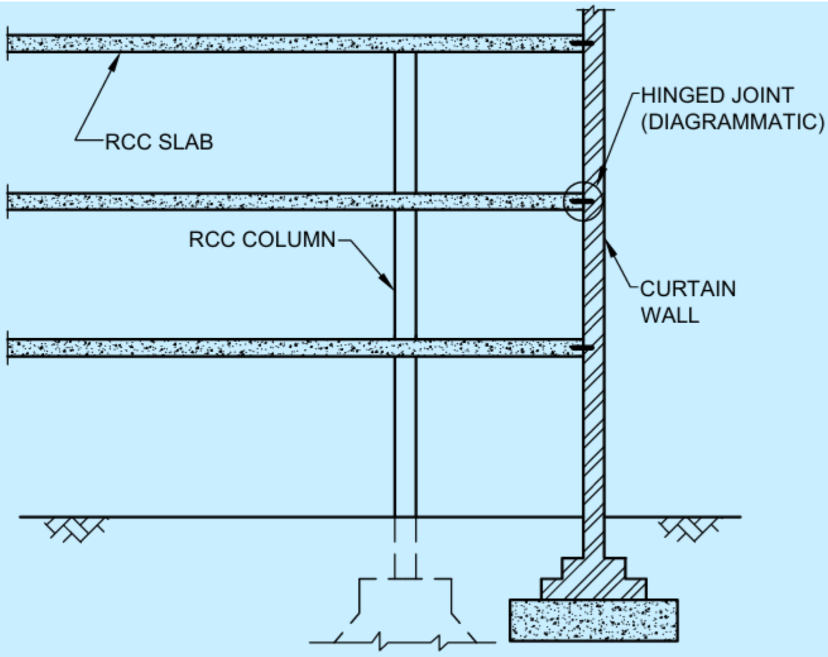

THICKNESS OF PIER, t_p
t_w
t_w
t_w
WIDTH OF PIER, w_p
WIDTH OF PIER, w_p

FIG. 1 DEFINITION OF PIER


RCC SLAB
HINGED JOINT (DIAGRAMMATIC)
RCC COLUMN
CURTAIN WALL

NOTE — The figure is only illustrative to explain about the term curtain wall and is not intended to be an exhaustive provision.

FIG. 2 TYPICAL MASONRY CURTAIN WALL

2.10 Grout — Mortar of pourable consistency.

2.11 Joint — A junction of masonry units, which can be classified as:

a) *Bed Joint* — A horizontal mortar joint upon which masonry units are laid;

b) *Cross Joint* — A vertical joint, normal to the face of the wall; and

c) *Wall Joint* — A vertical joint parallel to the face of the wall.

2.12 Leaf — Inner or outer section of a cavity wall.

2.13 Lateral Support — A support which enables a masonry element to resist lateral load and/or restrains lateral deflection of a masonry element at the point of support.

2.14 Load Bearing Wall — A wall designed to carry an imposed vertical load in addition to its own weight, together with any lateral load.

2.15 Masonry — An assemblage of masonry units properly bonded together with mortar.

2.16 Masonry Unit — Individual units which are bonded together with the help of mortar to form a masonry element such as wall, column, pier, buttress, etc.

2.17 Partition Wall — An interior non-load bearing wall, one storey or part storey in height.

2.18 Panel Wall — An exterior non-load bearing wall in framed construction, wholly supported at each storey but subjected to lateral loads.

2.19 Shear Wall — A wall designed to carry horizontal forces acting in its plane with or without vertical imposed loads.

2.20 Slenderness Ratio — Ratio of effective height or effective length to effective thickness of a masonry element.

2.21 Types of Walls

a) *Cavity Wall* — A wall comprising two leaves, each leaf being built of masonry units and separated by a cavity and tied together with metal ties or bonding units to ensure that the two leaves act as one structural unit, the space between the leaves being either left as continuous cavity or filled with a non-load bearing insulating and water-proofing material;

b) *Faced Wall* — A wall in which facing and backing of two different materials are bonded together to ensure common action under load (*see* Fig. 3).

NOTE — To ensure monolithic action in faced walls, shear strength between the facing and the backing shall be provided by toothing, bonding or other means; and

c) *Veneered Wall* — A wall in which the facing is attached to the backing but not so bonded as to result in a common action under load.

2.22 Reinforced Brick Slab (RB Slab) — Reinforced brick slab is particularly same as reinforced concrete slab in all its essential features except that brickwork is substituted partly for cement concrete. *See* Fig. 4(A) for details.

2.23 Reinforced Brick Concrete Slab (RBC Slab) — These are reinforced brick slab using concrete in the joints and on the top of bricks. *See* Fig. 4(B) for details.

3 MATERIALS

3.1 General

The materials used in masonry construction shall be in accordance with Part B 'Building Materials' of this NBCS. Storage of materials shall be in accordance with good practice [C-4(2)].

3.2 Masonry Units

Masonry units used in construction shall conform to accepted standards [C-4(1)].

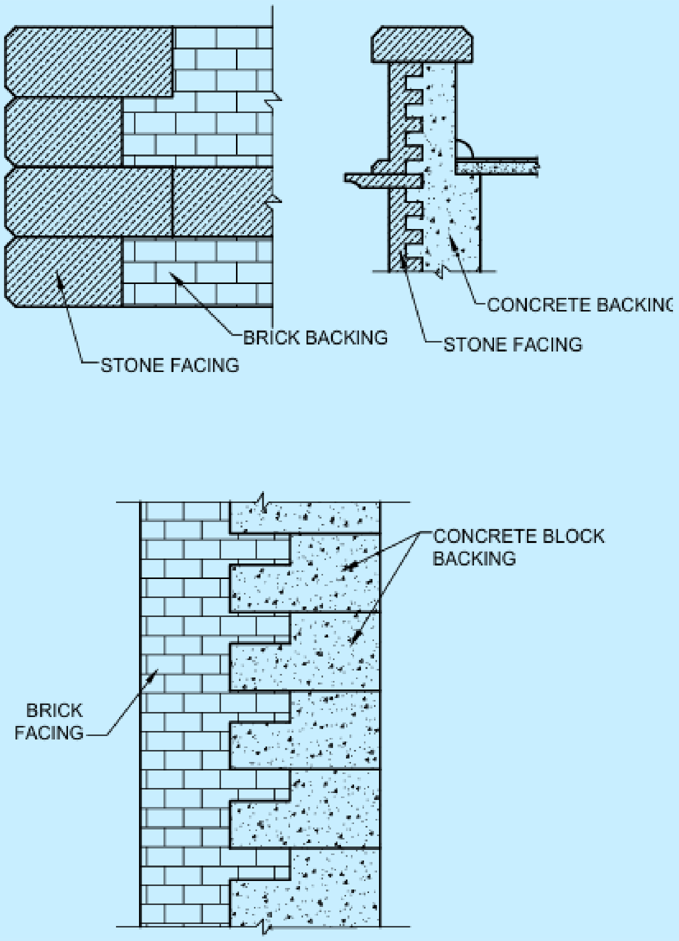

CONCRETE BACKIN
BRICK BACKING
STONE FACING
STONE FACING
CONCRETE BLOCK
BACKING
BRICK
FACING

FIG. 3 TYPICAL FACED WALL

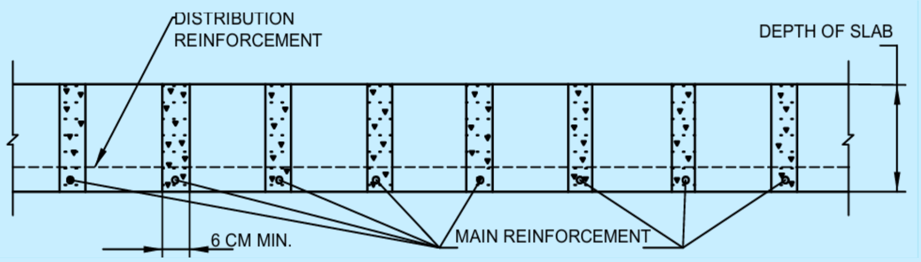

DISTRIBUTION
REINFORCEMENT
DEPTH OF SLAB
6 CM MIN.
MAIN REINFORCEMENT

FIG. 4(A) CROSS-SECTION OF RB SLAB

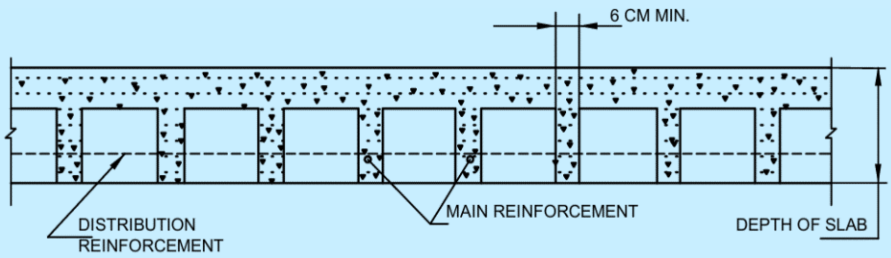

6 CM MIN.
DISTRIBUTION
REINFORCEMENT
MAIN REINFORCEMENT
DEPTH OF SLAB

FIG. 4(B) CROSS-SECTION OF RBC SLAB

FIG. 4 CROSS-SECTIONS OF RB AND RBC SLABS

3.2.1 Masonry units may be of the following types:

a) Common burnt clay building bricks;
b) Burnt clay fly ash building bricks;
c) Pulverized fuel ash lime bricks;
d) Pulverized fuel ash cement bricks;
e) Stones (in regular sized units);
f) Sand-lime bricks;
g) Concrete blocks (solid and hollow);
h) Lime based blocks;
j) Burnt clay hollow blocks;
k) Gypsum partition blocks,
m) Autoclaved cellular concrete blocks;
n) Stabilized soil blocks; and
p) Concrete stone masonry blocks.

NOTES

1 Gypsum partition blocks are used only for construction of non-load bearing partition walls.

2 Use of other masonry units such as precast stone blocks, fly-ash-lime-gypsum bricks, stabilized soil blocks and other bricks/blocks not covered by the above specifications may also be permitted based on test results.

3.2.2 Masonry units that have been previously used shall not be reused in brickwork or blockwork construction, unless they have been thoroughly cleaned and conform to this Section for similar new masonry units.

3.3 Mortar

Mortar for masonry shall conform to accepted standard [C-4(3)].

3.3.1 Minimum compressive strength for different grades of mortar on the basis of mix proportions as per **3.3.2** are given in Table 1.

3.3.2 Mix proportions and compressive strengths of some of the commonly used mortars are given in Table 2.

Table 1 Compressive Strength for Different Grades of Mortar

(*Clauses* 3.3.1, 3.4.1, 5.4.3, G-4.1 *and* Table 9)

Sl No.	Grade of Mortar	Minimum Compressive Strength at 28 Days N/mm^2
(1)	(2)	(3)
i)	H1	10
ii)	H2	6.0
iii)	M1	5.0
iv)	M2	3.0
v)	M3	1.5
vi)	L1	0.7
vii)	L2	0.5

3.4 Durability Criteria for Selection of Masonry Mortars

3.4.1 The selection of masonry mortars from durability considerations shall cover both the loading and exposure conditions of the masonry. The requirements for masonry mortar shall generally be as given in **3.4.2** to **3.4.6** (*see also* Table 1).

3.4.2 In the case of masonry exposed frequently to rains and where there is further protection by way of plastering or rendering or other finishes, the grade of mortar shall not be less than M3 but shall preferably be of grade M2. Where no protection is provided, the grade of mortar for external walls shall not be less than M2.

3.4.3 In the case of load bearing internal walls, the grade of mortar shall preferably be M3 or more for high durability but in no case less than L1.

3.4.4 In the case of masonry in foundations laid below damp-proof course, the grades of mortar for use in masonry shall be as specified below:

a) Where soil has little moisture, masonry mortar of grade not less M3 shall be used;

b) Where soil is very damp, masonry mortar of grade preferably M2 or more shall be used. But in no case shall the grade of mortar be less than L1 and M3; and

c) Where soil is saturated with water, masonry mortar of grade M1 shall be used but in no case shall the grade of mortar be less than M2.

3.4.5 For masonry in buildings subject to vibration of machinery, the grade of mortar shall not be less than M1.

3.4.6 For parapets, where the height is greater than three times the thickness, the grade of masonry mortar used shall not be less than M1. In the case of low parapets, the grade of mortar shall be the same as that used in the wall masonry below.

3.4.7 The grade of mortar for bedding joints in masonry with large concrete blocks shall not be less than M1.

4 DESIGN CONSIDERATIONS

4.1 General

Masonry structures gain stability from the support offered by cross walls, floors, roof and other elements such as piers and buttresses. Load bearing walls are structurally more efficient when the load is uniformly distributed and the structure is so planned that eccentricity of loading on the members is as small as possible. Avoidance of eccentric loading by providing adequate bearing of floor/roof on the walls providing adequate stiffness in slabs and avoiding fixity at the supports, etc, is especially important in load bearing walls in multistorey structures. These matters should receive careful consideration during the planning stage of masonry structures.

4.2 Lateral Supports and Stability

4.2.1 *Lateral Supports*

Lateral supports for a masonry element such as load bearing wall or column are intended,

a) to limit slenderness of a masonry element so as to prevent or reduce possibility of buckling of the member due to vertical loads; and

b) to resist horizontal components of forces so as to ensure stability of a structure against overturning.

4.2.1.1 Lateral support may be in the vertical or horizontal direction, the former consisting of floor/roof bearing on the wall or properly anchored to the same and latter consisting of cross walls, piers or buttresses.

Table 2 Mix Proportions and Strength of Mortars for Masonry

(*Clause* 3.3.2 *and* Table 23)

Sl No.	Mix Proportions (By Mass)					Minimum Compressive Strength at 28 Days in N/mm^2 (with Cement Compressive Strength at 28 Days, in N/mm^2, between 33 and 43)	Minimum Compressive Strength of Cement : Sand Mortar at 28 Days in N/mm^2 (with Cement Compressive Strength at 28 Days, in N/mm$^2 \geq 43$)
	Cement	Lime	Lime - Pozzolana Mixture	Pozzolana	Sand		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	1	¼ C or B	0	0	3	10	—
2(a)	1	¼ C or B	0	0	4	7.5	—
2(b)	1	½ C or B	0	0	4 ½	6	—
2(c)	1	0	0	0	4	6	7
3(a)	1	0	0	0	5	5	6
3(b)	1	1 C or B	0	0	6	3	—
3(c)	0	0	1(LP–40)	0	1 ½	3	—
4(a)	1	0	0	0	6	3	4
4(b)	1	2B	0	0	9	2	—
4(c)	0	1A	0	0	2	2	—
4(d)	0	1 B	0	1	1	2	—
4(e)	0	1 C or B	0	2	0	2	—
4(f)	0	0	1(LP–40)	0	1 ¾	2	—
5(a)	1	0	0	0	7	2	3
5(b)	1	3 B	0	0	12	1.5	—
5(c)	0	1 A	0	0	3	1.5	—
5(d)	0	1 B	0	2	1	1.5	—

Table 2 (*Concluded*)

Sl No.	**Mix Proportions (By Mass)**					**Minimum Compressive Strength at 28 Days in N/mm^2 (with Cement Compressive Strength at 28 Days, in N/mm^2, between 33 and 43)**	**Minimum Compressive Strength of Cement : Sand Mortar at 28 Days in N/mm^2 (with Cement Compressive Strength at 28 Days, in N/mm^2 $\geq$ 43)**
	Cement	Lime	Lime - Pozzolana Mixture	Pozzolana	Sand		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
5(e)	0	1 C or B	0	3	0	1.5	—
5(f)	0	0	1(LP-40)	0	2	1.5	—
6(a)	1	0	0	0	8	1	2
6(b)	0	1 B	0	1	2	0.7	—
6(c)	0	1 C or B	0	2	1	0.7	—
6(d)	0	0	1(LP-40)	0	2 ¼	0.7	—
6(e)	0	0	1(LP-20)	0	1 ½	0.7	—
7(a)	0	1 B	0	0	3	0.5	—
7(b)	0	1 C or B	0	1	2	0.5	—
7(c)	0	0	1(LP-7)	0	1 ½	0.5	—

NOTES

1 Sand for making mortar should be well graded. In case sand is not well graded, its proportions shall be reduced in order to achieve the minimum specified strength.

2 For mixes in Sl No. 1 and Sl No. 2, use of lime is not essential from consideration of strength as it does not result in increase in strength. However, its use is highly recommended since if improves workability.

3 For mixes in Sl No. 3(a), 4(a), 5(a) and 6(a) either lime C or B to the extent of ¼ part of cement (by mass) or some plasticizer should be added for improving workability.

4 For mixes in Sl No. 4(b) and 5(b), lime and sand should first be ground in mortar mill and then cement added to coarse stuff.

5 It is essential that mixes in Sl No. 4(c), 4(d), 5(d), 5(e), 6(b), 6(c), 7(a) and 7(b) are prepared by grinding in a mortar mill.

6 A, B and C denote eminently hydraulic lime, semi-hydraulic lime and fat lime respectively, as specified in appropriate standards listed in Part B ‘Building Materials’ of this NBCS.

4.2.1.2 Requirements of **4.2.1**(a) from consideration of slenderness may be deemed to have been met with, if:

a) in case of a wall, where slenderness ratio is based on effective height, any of the following constructions are provided;

   1) RCC floor/roof slab (or beams and slab) irrespective of the direction of span, bears on the supported wall as well as cross walls, to the extent of at least 90 mm;

   2) RCC floor/roof slab not bearing on the supported wall or cross wall is anchored to it with non-corrodible metal ties of 600 mm length and of section not less than 6 mm × 30 mm, and at intervals not exceeding 2 m, as shown in Fig. 5; and

   3) Timber floor/roof, anchored by non-corrodible metal ties of length 600 mm and of minimum section 6 mm × 30 mm, securely fastened to joists and built into walls as shown in Fig. 6 and Fig. 7. The anchors shall be provided in the direction of span of timber joists as well as in its perpendicular direction, at intervals of not more than 2 m in buildings up to two storeys and 1.25 m for buildings more than two storeys in height.

   NOTES

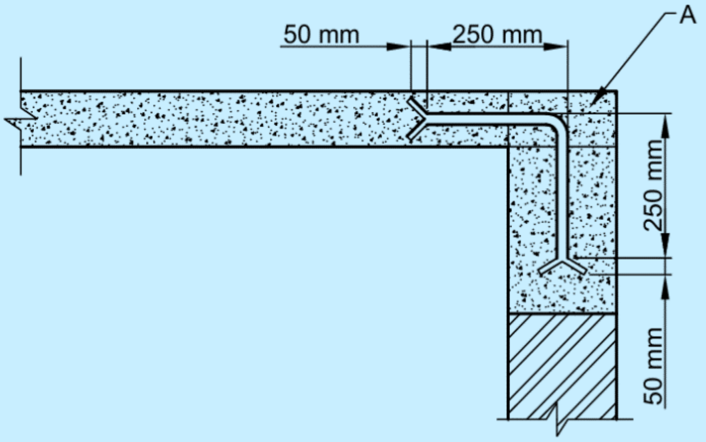
   1 In case precast RCC units are used for floors and roofs, it is necessary to interconnect them and suitably anchor them to the cross walls so that they can transfer lateral forces to the cross walls.

   2 In case of small houses of conventional designs, not exceeding two storeys in height, stiffening effect of partitions and cross walls is such that metal anchors are normally not necessary in case of timber floor/roof and precast RCC floor/roof units.

b) in case of a wall, when slenderness ratio is based on its effective length; a cross wall/pier/buttress of thickness equal to or more than half the thickness of the supported wall or 90 mm, whichever is more, and length equal to or more than one fifth of the height of wall, is built at right angle to the wall (*see* Fig. 8) and bonded to it according to provision of **4.2.2.2** (**d**);

c) in case of a column, an RCC or timber beam/RS joist/roof truss, is supported on the column. In this case, the column will not be deemed to be laterally supported in the direction at right angle to it; and

d) in case of a column, an RCC beam forming a part of beam and slab construction is supported on the column, and slab adequately bears on stiffening walls. This construction will provide lateral support to the column, in the direction of both horizontal axes.



A = Cement concrete only at places where anchors are provided
(200 mm in width in the direction perpendicular to the plane of paper)

FIG. 5 ANCHORING OF RCC SLAB WITH MASONRY WALL (WHEN SLAB DOES NOT BEAR ON WALL)

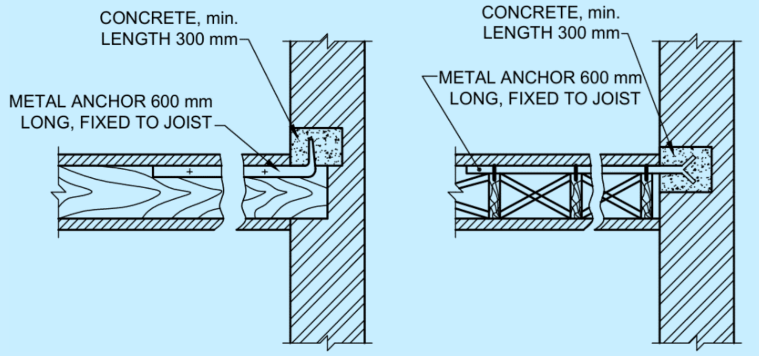

CONCRETE, min.
LENGTH 300 mm
METAL ANCHOR 600 mm
LONG, FIXED TO JOIST
CONCRETE, min.
LENGTH 300 mm
METAL ANCHOR 600 mm
LONG, FIXED TO JOIST

Fig. 6(A) Joists at Right Angle to Wall Fig. 6(B) Joists Parallel to Wall

Fig. 6 Typical Details for Anchorage of Solid Walls

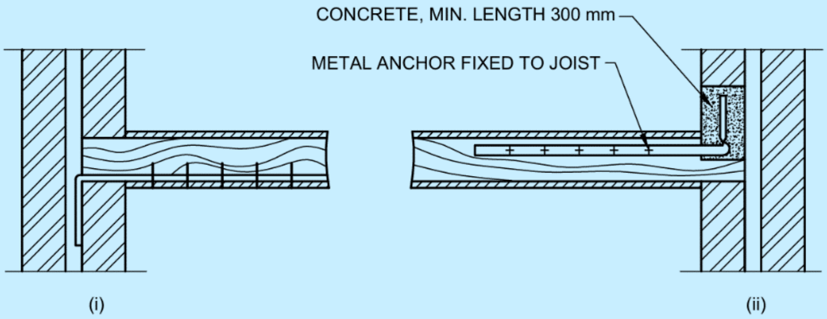

CONCRETE, MIN. LENGTH 300 mm
METAL ANCHOR FIXED TO JOIST
(i)
(ii)

Fig. 7(A) Timber Joists at Right Angles to Wall

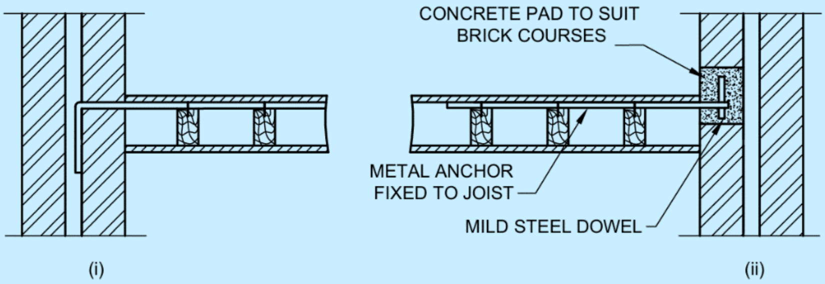

CONCRETE PAD TO SUIT
BRICK COURSES
METAL ANCHOR
FIXED TO JOIST
MILD STEEL DOWEL
(i)
(ii)

Fig. 7(B) Timber Joists Parallel to Wall

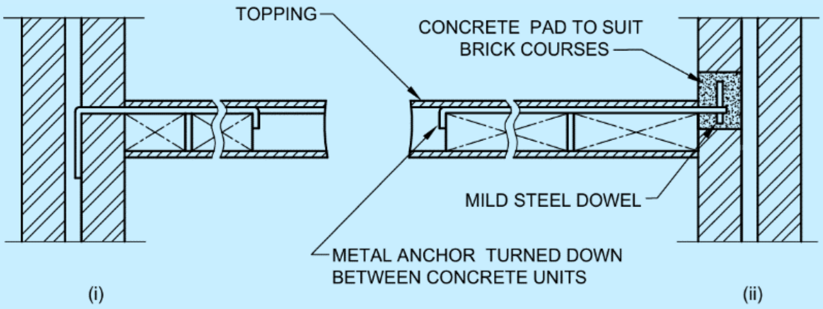

TOPPING
CONCRETE PAD TO SUIT
BRICK COURSES
MILD STEEL DOWEL
METAL ANCHOR TURNED DOWN
BETWEEN CONCRETE UNITS
(i)
(ii)

Fig. 7(C) Precast Concrete Floor Units Parallel to Wall

Fig. 7 Typical Details for Anchorage of Cavity Walls

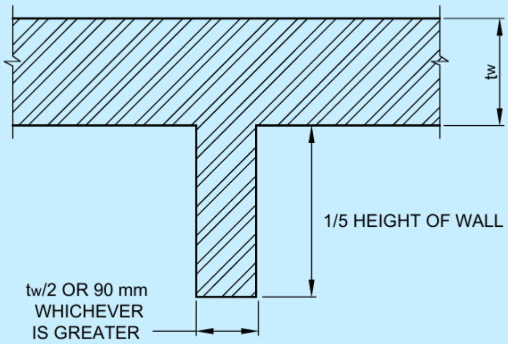


FIG. 8 MINIMUM DIMENSION FOR MASONRY WALL OR BUTTRESS EFFECTIVE LATERAL SUPPORT

4.2.2 *Stability*

A wall or column subjected to vertical and lateral loads may be considered to be provided with adequate lateral support from consideration of stability, if the construction providing the support is capable of resisting some of the following forces:

a) Simple static reactions at the point of lateral support to all the lateral loads; plus

b) 2.5 percent of the total vertical load that the wall or column is designed to carry at the point of lateral support.

4.2.2.1 For the purpose specified in **4.2.2**, if the lateral supports are in the vertical direction, these should meet the requirements given in **4.2.1.2** (a) and should also be capable of acting as horizontal girders duly anchored to the cross wall so as to transmit the lateral loads to the foundations without exceeding the permissible stresses in the cross walls.

4.2.2.2 In case of load bearing buildings up to four storeys, stability requirements of **4.2.2** may be deemed to have been met with, if:

a) height to width ratio of building does not exceed 2;

b) cross walls acting as stiffening walls continuous from outer wall to outer wall or outer wall to a load bearing inner wall, and of thickness and spacings as given in Table 3 are provided. If stiffening wall or walls that are in a line, are interrupted by openings, length of solid wall or walls in the zone of the wall that is to be stiffened shall be at least one-fifth of height of the opening as shown in Fig. 9;

c) floors and roof either bear on cross walls or are anchored to those walls as in **4.2.1.2** such that all lateral loads are safely transmitted to those walls and through them to the foundation; and

d) cross walls are built jointly with the bearing walls and are jointly mortared, or the two interconnected by toothing. Alternatively, cross walls may be anchored to walls to be supported by ties of non-corrodible metal of minimum section 6 mm × 35 mm and length 600 mm with ends bend at least 50 mm; maximum vertical spacing of ties being 1.2 m (*see* Fig. 10).

4.2.2.3 In case of halls exceeding 8.0 m in length, safety and adequacy of lateral supports shall always be checked by structural analysis.

4.2.2.4 A trussed roofing may not provide lateral support unless special measures are adopted to brace and anchor the roofing. However, in case of residential and similar buildings of conventional design with trussed roofing having cross walls, it may be assumed that stability requirements are met with by the cross walls and structural analysis for stability may be dispensed with.

4.2.2.5 Capacity of a cross wall, also called shear wall, sometimes to take horizontal loads and consequently bending moments increases, when parts of bearing walls act as flanges to the cross wall. Maximum overhanging length of bearing wall which could effectively function as a flange should be taken as 12*t* or *H*/6, whichever is less in case of *T/I* shaped walls, and 6*t* or *H*/16, whichever is less in case of *L/U* shaped walls, where *t* is the thickness of bearing wall and *H* is the total height of wall above the level being considered, as shown in Fig. 11.

4.2.2.6 *External walls of basement and plinth*

In case of external walls of basement and plinth, stability requirements of **4.2.2** may be deemed to have been met with, if:

a) bricks used in basement and plinth have a minimum crushing strength of 5 N/mm^2 and mortar used in masonry is of Grade M1 or better;

b) clear height of ceiling in basement does not exceed 2.6 m;

c) walls are stiffened according to provisions of **4.2.2.1**;

d) in the zone of action of soil pressure on basement walls, traffic load excluding any surcharge due to adjoining buildings does not exceed 5 kN/m^2 and terrain does not rise; and

e) minimum thickness of basement walls is in accordance with Table 4. However, if percentage opening in the basement wall for purposes like ventilation are more than 25 percent, then stability analysis/check need to be performed particularly for resistance to seismic loads.

NOTE — In case there is surcharge on basement walls from adjoining buildings, thickness of basement walls shall be based on structural analysis.

4.2.2.7 *Walls mainly subjected to lateral loads*

a) *Free standing wall* — A free standing wall such as compound wall or parapet wall is acted upon by wind force which tends to overturn it. This tendency to over-turning is resisted by gravity force due to self-weight of wall, and also by flexural moment of resistance on account of tensile strength of masonry. Free standing walls shall thus be designed as in **5.5.2.1**. If mortar used for masonry cannot be relied upon for taking flexural tension (*see* **5.4.2**), stability of free standing wall shall be ensured such that stability moment of wall due to self-weight equals or exceeds 1.5 times the overturning moment; and

b) *Retaining wall* — Stability for retaining walls shall normally be achieved through gravity action but flexural moment of resistance could also be taken advantage of under special circumstances at the discretion of the designer (*see* **5.4.2**).

Table 3 Thickness and Spacing of Stiffening Walls

[*Clause* 4.2.2.2(b) and G-4.6.2]

Sl No.	**Thickness of Load Bearing Wall to be Stiffened**	**Height[1] of Storey Not to Exceed**	**Stiffening Wall[1]**		
			Minimum Thickness		Maximum Spacing
			For 1 to 3 Storeys	For 4 Storeys	
	mm	m	mm	mm	m
(1)	(2)	(3)	(4)	(5)	(6)
i)	100	3.2	100	—	4.5
ii)	200	3.2	100	200	6.0
iii)	300	3.4	100	200	8.0
iv)	Above 300	5.0	100	200	8.0

[1] Storey height and maximum spacings as given are centre-to-centre dimensions.

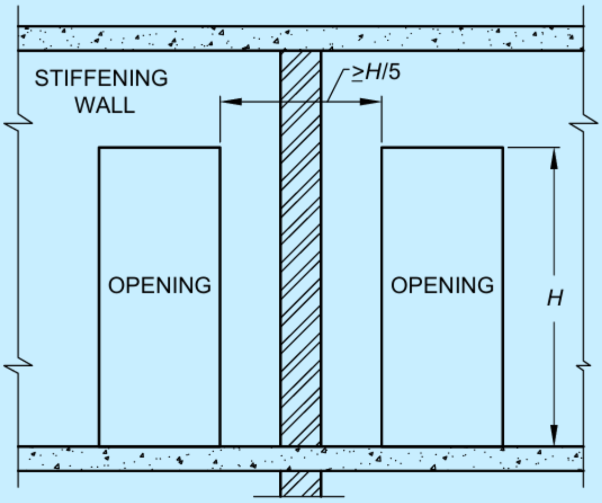


FIG. 9 OPENING IN STIFFENING WALL

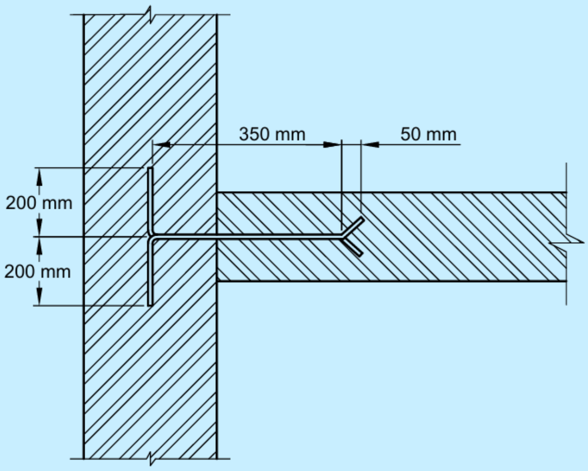


FIG. 10 ANCHORING OF STIFFENING WALL WITH SUPPORT WALL

Table 4 Minimum Thickness of Basement Walls

[*Clause* 4.2.2.6(e)]

Sl No.	Height of the Ground above Basement Floor Level		Minimum Nominal Thickness of Basement Wall
	Wall loading (permanent load) less than 50 kN/m	Wall loading (permanent load) more than 50 kN/m	
(1)	(2)	(3)	(4)
i)	Up to 1.4 m	Up to 1.75 m	300 mm
ii)	Up to 2 m	Up to 2.5 m	400 mm

4.3 Effective Height

4.3.1 *Wall*

Effective height of a wall shall be taken as shown in Table 5 (*see* Fig. 12).

NOTE — A roof truss or beam supported on a column meeting the requirements of **4.2.2.1** is deemed to provide lateral support to the column only in the direction of the beam/truss.

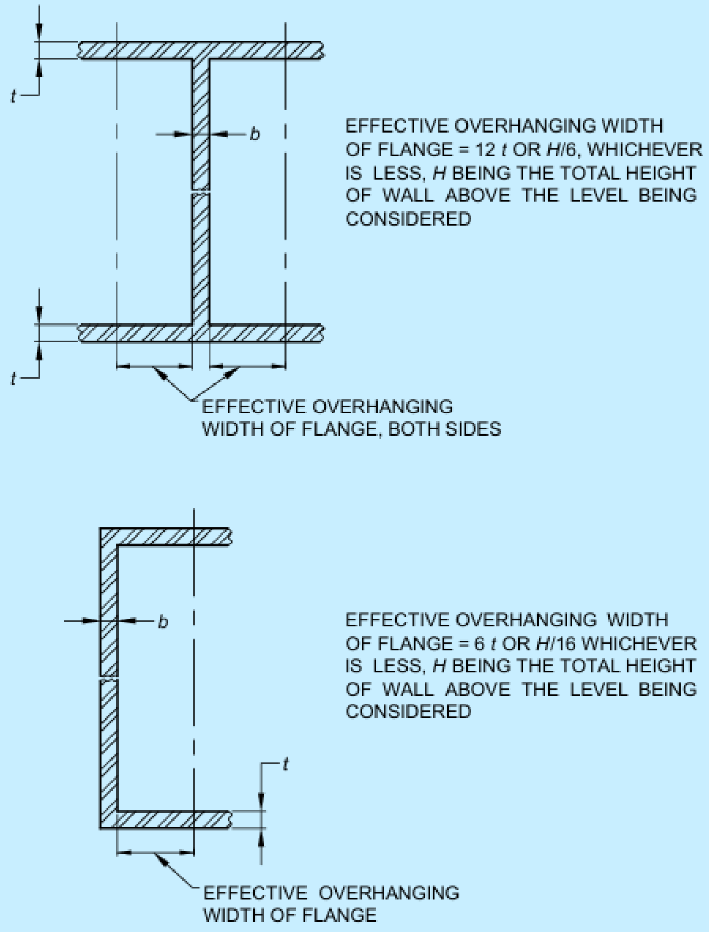

t
b
EFFECTIVE OVERHANGING WIDTH OF FLANGE = 12 t OR H/6, WHICHEVER IS LESS, H BEING THE TOTAL HEIGHT OF WALL ABOVE THE LEVEL BEING CONSIDERED
t
EFFECTIVE OVERHANGING WIDTH OF FLANGE, BOTH SIDES
b
EFFECTIVE OVERHANGING WIDTH OF FLANGE = 6 t OR H/16 WHICHEVER IS LESS, H BEING THE TOTAL HEIGHT ABOVE THE LEVEL BEING CONSIDERED
t
EFFECTIVE OVERHANGING WIDTH OF FLANGE

FIG. 11 TYPICAL DETAILS FOR ANCHORAGE OF SOLID WALLS

Table 5 Effective Height of Walls

(*Clause* 4.3.1, 8.7.9.3, Table 22 *and* Table 23)

Sl No. (1)	**Condition of Support** (2)	**Effective Height** (3)
i)	Lateral as well as rotational restraint (that is, full restraint) at top and bottom. For example, when the floor/roof spans on the walls so that reaction to load of floor/roof is provided by the walls, or when an RCC floor/roof has bearing on the wall (minimum 90 mm), irrespective of the direction of the span foundation footings of a wall give lateral as well as rotational restraint	0.75 *H*
ii)	Lateral as well as rotational restraint (that is, full restraint) at one end and only lateral restraint (that is, partial restraint) at the other. For example, RCC floor/roof at one end spanning or adequately bearing on the wall and timber floor/roof not spanning on wall, but adequately anchored to it, on the other end	0.85 *H*
iii)	Lateral restraint, without rotational restraint (that is, partial restraint) on both ends. For example, timber floor/roof, not spanning on the wall but adequately anchored to it on both ends of the wall, that is, top and bottom	1.00 *H*
iv)	Lateral restraint as well as rotational restraint (that is, full restraint) at bottom but have no restraint at the top. For example, parapet walls with RCC roof having adequate bearing on the lower wall, or a compound wall with proper foundation on the soil.	1.50 *H*

Table 5 (*Concluded*)

NOTES

1 *H* is the height of wall between centres of support in case of RCC slabs and timber floors. In case of footings or foundation block, height (*H*) is measured from top of footing or foundation block. In case of roof truss, height (*H*) is measured up to bottom of the tie beam. In case of beam and slab construction, height should be measured from centre of bottom slab to centre of top beam. All these cases are illustrated by means of examples shown in Fig. 12.

2 For working out effective height, it is assumed that concrete DPC, when properly bonded with masonry, does not cause discontinuity in the wall.

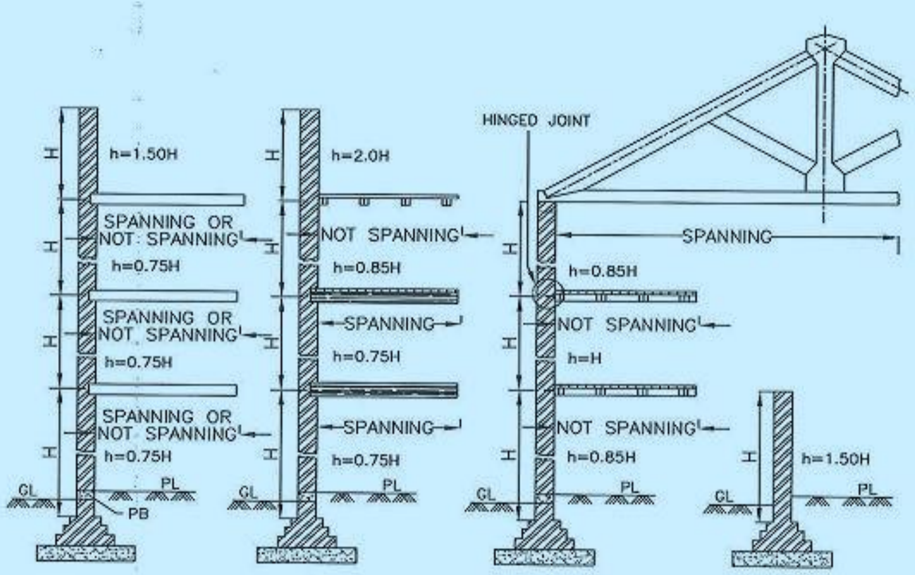
3 Where membrane type damp-proof course or termite shield causes a discontinuity in bond, the effective height of wall may be taken to be greater of the two values calculated as follows:

a) Consider *H* from top of footing ignoring DPC and take effective height as 0.75 *H*; and

b) Consider *H* from top of DPC and take effective height as 0.85 *H*.

4 When assessing effective height of walls, floors not adequately anchored to walls shall not be considered as providing lateral support to such walls.

5 When thickness of a wall bonded to a pier is at least two-thirds of the thickness of the pier measured in the same direction, the wall and pier may be deemed to act as one structural element.


h=1.50H
SPANNING OR NOT SPANNING
h=0.75H
SPANNING OR NOT SPANNING
h=0.75H
SPANNING OR NOT SPANNING
h=0.75H
GL
PL
PB
h=2.0H
NOT SPANNING
h=0.85H
SPANNING
h=0.75H
SPANNING
h=0.75H
GL
PL
HINGED JOINT
SPANNING
h=0.85H
NOT SPANNING
h=H
NOT SPANNING
h=0.85H
GL
PL
h=1.50H
GL
PL
H

12A RCC FLOOR/ROOF BEING ON WALL IRRESPECTIVE OF DIRECTION OF SPAN

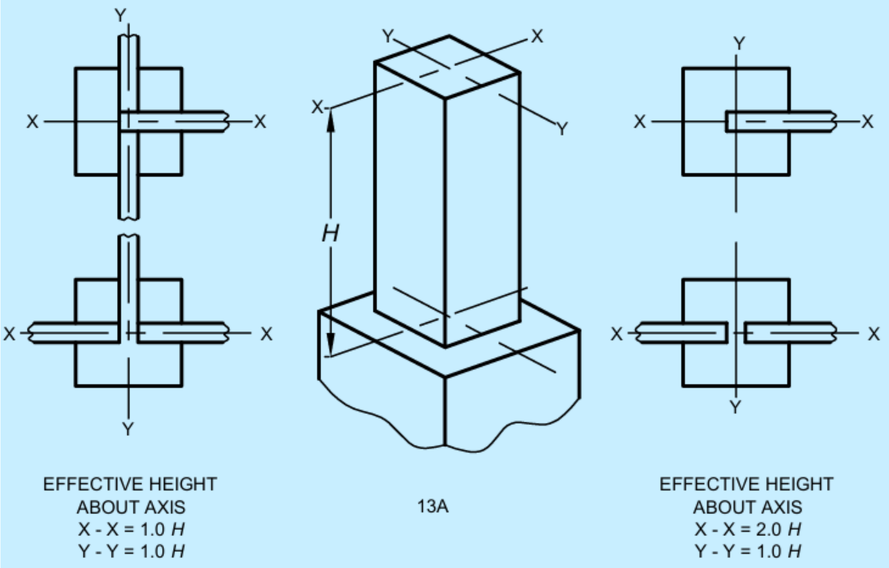
12B TIMBER FLOOR /ROOF

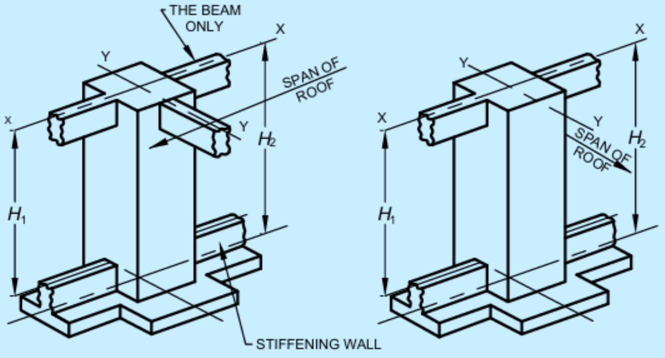
12C TIMBER FLOOR AND TRUSSED ROOF

12D FREE STANDING WALL

FIG. 12 EFFECTIVE HEIGHT OF WALL

NOTE — If Plinth band (PB) is equal to or more than 150 mm, height can be taken from above the plinth band.


Y
X
X
X
X
Y
EFFECTIVE HEIGHT
ABOUT AXIS
X - X = 1.0 H
Y - Y = 1.0 H
Y
X
X
Y
H
13A
Y
X
X
X
X
Y
EFFECTIVE HEIGHT
ABOUT AXIS
X - X = 2.0 H
Y - Y = 1.0 H



13B

13C

ROOF CONSTRUCTION	EFFECTIVE HEIGHT ABOVE AXIS FIG. 13B	EFFECTIVE HEIGHT ABOVE AXI FIG. 13C
WITH PRECAST CONCRETE UNITS OF OF IN- SIDE CONCRETE FLOOR	X - X = 1.0 H_2 Y - Y = 1.0 H_1 Y - Y = 1.5 H_1 (NO TIES)	X - X = 1.5 H_2 Y - Y = 1.0 H_1
WITH LIGHT DECK OR SIMILAR ROOF	X - X = 1.0 H_2 Y - Y = 1.0 H_1 Y - Y = 2.0 H_1 (NO TIES)	X - X = 2.0 H_2 Y - Y = 1.0 H_1

FIG. 13 EFFECTIVE HEIGHT OF WALL

4.3.2 *Column*

In case of a column, effective height shall be taken as actual height for the direction it is laterally supported and as twice the actual height for the direction it is not laterally supported (*see* Fig. 13).

NOTES

1 A roof truss or beam supported on a column meeting the requirements of **4.2.2.1** is deemed to provide lateral support to the column only in the direction of the beam/truss.

2 When floor or roof consisting of RCC beams and slabs is supported on columns, the columns would be deemed to be laterally supported in both directions.

4.3.3 *Openings in Walls*

When openings occur in a wall such that masonry between the openings is by definition a column, effective height of masonry between the openings shall be reckoned as follows:

a) *When wall has full restraint at the top*:

   1) Effective height for the direction perpendicular to plane of wall equals 0.75 H plus 0.25 H_1, where H is the distance between supports and H_1 is the height of the taller opening; and

   2) Effective height for the direction parallel to the wall equals H, that is, the distance between the supports.

b) *When wall has partial restraint at the top and bottom:*

   1) Effective height for the direction perpendicular to plane of wall equals H when height of neither opening exceeds 0.5 H and it is equal to 2 H when height of any opening exceeds 0.5 H; and

   2) Effective height for the direction parallel to the plane of the wall equals 2 H.

4.4 Effective Length

Effective length of a wall shall be as given in Table 6.

4.5 Effective Thickness

Effective thickness to be used for calculating slenderness ratio of a wall or column shall be obtained as in **4.5.1** to **4.5.5**.

4.5.1 For solid walls, faced walls or columns, effective thickness shall be the actual thickness.

4.5.2 For solid walls adequately bonded into piers, buttresses, effective thickness for determining slenderness ratio based on effective height shall be the actual thickness of wall multiplied by stiffening coefficient as given in Table 7. No modification in effective thickness, however, shall be made when slenderness ratio is to be based on effective length of walls.

Table 6 Effective Length of Walls

(*Clauses* 4.4)

Sl No. (1)	Conditions of Support (*See* Fig. 14) (2)	Effective Length (3)
i)	Where a wall is continuous and is supported by cross wall and there is no opening within a distance of $H/8$ from the face of cross wall (*see* Fig. 14) or Where a wall is continuous and is supported by piers/buttresses conforming to **4.2.1.2 (b)**	0.8 L
ii)	Where a wall is supported by a cross wall at one end and continuous with cross wall at other end or Where a wall is supported by a pier/buttress at one end and continuous with pier/buttress at other end conforming to **4.2.1.2 (b)**	0.9 L
iii)	Where a wall is supported at each end by cross wall or Where a wall is supported at each end by a pier/buttress conforming to **4.2.1.2 (b)**	1.0 L
iv)	Where a wall is free at one end and continuous with a pier/buttress at the other end or Where a wall is free at one end and continuous with a pier/buttress at the other end conforming to **4.2.1.2 (b)**	1.5 L
v)	Where a wall is free at one end and supported at the other end by a cross wall or Where a wall is free at one end and supported at the other end by a pier/buttress conforming to **4.2.1.2 (b)**	2.0 L

where

L = length of wall from or between centres of cross wall, piers or buttress; and

H = actual height of wall between centres of adequate lateral support.

NOTE — In case there is an opening taller than 0.5 H in a wall, ends of the wall at the opening shall be considered as free. Cross walls shall conform to **4.2.2.2 (d)**.

4.5.3 For solid walls or faced walls stiffened by cross walls, appropriate stiffening coefficient may be determined from Table 7 on the assumption that the cross walls are equivalent to piers of width equal to the thickness of the cross wall and of thickness equal to three times the thickness of stiffened wall.

4.5.4 For cavity walls with both leaves of uniform thickness throughout, effective thickness shall be taken as two-thirds of the sum of the actual thickness of the two leaves.

4.5.5 For cavity walls with one or both leaves adequately bonded into piers, buttresses or cross walls at intervals, the effective thickness of the cavity wall shall be two-thirds of the sum of the effective thickness of each of the two leaves; the effective thickness of each leaf being calculated using **4.5.1** or **4.5.2** as appropriate.

Table 7 Stiffening Coefficient for Walls Stiffened by Piers, Buttresses or Cross Walls

(*Clauses* 4.5.2 *and* 4.5.3)

Sl No.	**Ratio** $\frac{S_p}{w_p}$	**Stiffening Coefficient**		
		$\frac{t_p}{t_w} = 1$	$\frac{t_p}{t_w} = 2$	$\frac{t_p}{t_w} = 3$ or more
(1)	(2)	(3)	(4)	(5)
i)	6	1.0	1.4	2.0
ii)	8	1.0	1.3	1.7
iii)	10	1.0	1.2	1.4
iv)	15	1.0	1.1	1.2
v)	20 or more	1.0	1.0	1.0

where

S_p = centre-to-centre spacing of the pier or cross wall;

t_p = thickness of pier as defined in **2.3** (**b**) (*see* Fig. 1);

t_w = actual thickness of the wall proper (*see* Fig. 1); and

w_p = width of the pier in the direction of the wall or the actual thickness of the cross wall.

NOTE — Linear interpolation between the values given in this table is permissible but not extrapolation outside the limits given.

4.6 Slenderness Ratio

4.6.1 *Walls*

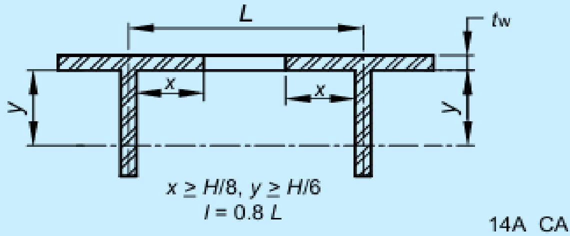
For a wall, slenderness ratio shall be effective height divided by effective thickness or, effective length divided by the effective thickness, whichever is less. In case of a load bearing wall, slenderness ratio shall not exceed that given in Table 8. To reduce the slenderness ratio one and a half brick thick wall shall be up to ground level.

4.6.2 *Columns*

For a column, slenderness ratio shall be taken to be the greater of the ratios of effective heights to the respective effective thickness, in the two principal directions. Slenderness ratio for a load bearing column shall not exceed **12**.

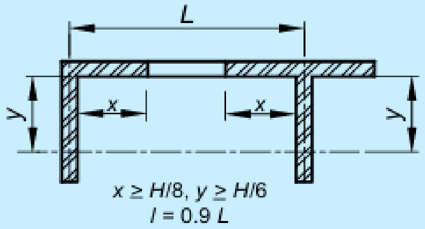
4.7 Eccentricity

Eccentricity of vertical loading at a particular junction in a masonry wall shall depend on factors, such as extent of bearing, magnitude of loads, stiffness of slab or beam, fixity at the support and constructional details at junctions. No exact calculations are possible to make accurate assessment of eccentricity. Extent of eccentricity under any particular circumstances has, therefore, to be decided according to the best judgment of the designer. Some guidelines for assessment of eccentricity are given in Annex A.


L
tw
y
x
x
y
x ≥ H/8, y ≥ H/6
l = 0.8 L

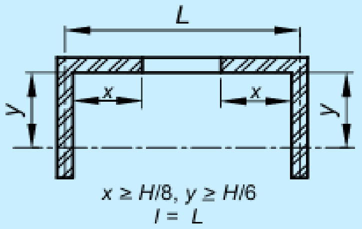
Wall is continuous at both ends and is supported by cross walls of thickness *t*w/2 or 100 mm whichever is more, length of cross wall is not less than *H*/6,opening in wall is not less than *H*/8 from cross wall

14A CASE 1


L
y
x
x
y
x ≥ H/8, y ≥ H/6
l = 0.9 L

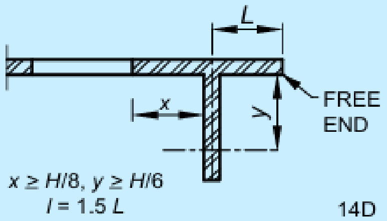
Same as case 1 except that one end of the wall is discontinuous

14B CASE 2


L
y
x
x
y
x ≥ H/8, y ≥ H/6
l = L

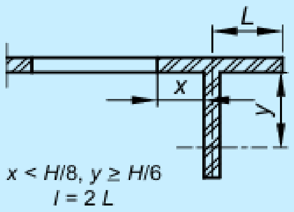
Same as case 1 except that wall is discontinuous on both ends

14C CASE 3


L
x
y
FREE
END
x ≥ H/8, y ≥ H/6
l = 1.5 L

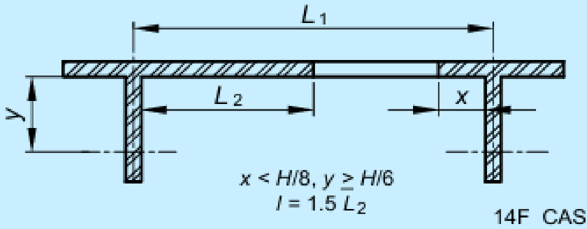
One end of the wall is free, other is supported by a cross wall and is continuous. There being no opening within *H*/8 from cross wall

14D CASE 4


L
x
y
x < H/8, y ≥ H/6
l = 2 L

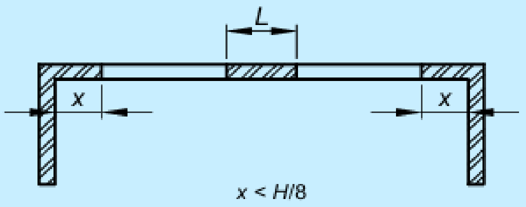
Same as case 4 but opening is within *H*/8 from cross wall and thus that end is taken as discontinuous

14E CASE 5


L1
y
L2
x
x < H/8, y ≥ H/6
l = 1.5 L2

This illustration is with an opening which is within *H*/8 from cross wall

14F CASE 6



Wall length is between two opening which are closer than *H*/8 from cross walls

14G CASE 7

FIG. 14 EFFECTIVE LENGTH OF WALL

Table 8 Maximum Slenderness Ratio for a Load Bearing Wall

(*Clause* 4.6.1)

Sl No.	Number of Storeys	Maximum Slenderness Ratio	
		Using Portland Cement or Portland Pozzolana Cement in Mortar	Using Lime Mortar
(1)	(2)	(3)	(4)
i)	Not exceeding 2	27	20
ii)	Exceeding 2	27	13

5 STRUCTURAL DESIGN

5.1 General

The building as a whole shall be analysed by accepted principles of mechanics to ensure safe and proper functioning in service of its component parts in relation to the whole building. All component parts of the structure shall be capable of sustaining the most adverse combinations of loads, which the building may be reasonably expected to be subjected to during and after construction.

5.2 Design Loads

Loads to be taken into consideration for designing masonry components of a structure are:

a) dead loads of walls, columns, floors and roofs;

b) imposed loads of floors and roof;

c) wind loads on walls and sloping roof; and

d) seismic forces.

NOTE — When a building is subjected to other loads, such as vibration from railways; machinery, etc, these should be taken into consideration accordingly to the best judgment of the designer (*see also* Part C 'Structural Design/Section 1 Loads and Load Effects' of this NBCS).

5.2.1 The design loads and other forces to be taken for the design of masonry structures shall conform to Part C/Section 1 of this NBCS.

NOTE — During construction, suitable measures shall be taken to ensure that masonry is not liable to damage or failure due to action of wind forces, back filling behind walls or temporary construction loads.

5.3 Load Dispersion

5.3.1 *General*

The angle of dispersion of vertical load on walls shall be taken as not more than 30° from the vertical.

5.3.2 *Arching Action*

Account may also be taken of the arching action of well-bonded masonry walls supported on lintels and beams, in accordance with established practice. Increased axial stresses in the masonry associated with arching action in this way, shall not exceed the permissible stresses given in **5.4**.

5.3.3 *Lintels*

Lintels that support masonry construction shall be designed to carry loads from masonry (allowing for arching and dispersion where applicable), and loads received from any other part of the structure. Length of bearing of lintel at each end shall not be less than 90 mm or one-tenth of the span, whichever is more, and area of the bearing shall be sufficient to ensure that stresses in the masonry (combination of wall stresses, stresses due to arching action and bearing stresses from the lintel) do not exceed the stresses permitted in **5.4** (*see* Annex C).

5.4 Permissible Stresses

5.4.1 *Permissible Compressive Stress*

Permissible compressive stress in masonry shall be based on value of basic compressive stress (f_b) as given in Table 9 and multiplying this value by factors known as stress reduction factor (k_s), area reduction factor (k_a) and shape modification factor (k_p) as detailed in **5.4.1.1** to **5.4.1.3**. Values of basic compressive stress given in Table 9 take into consideration crushing strength of masonry unit and grades of mortar, and hold good for values of slenderness ratio not exceeding 6, zero eccentricity and masonry unit having height to width ratio (as laid) equal to 0.75 or less.

Alternatively, basic compressive stress may be based on results of prism test given in Annex B on masonry made from masonry units and mortar to be actually used in a particular job.

Table 9 Basic Compressive Stresses for Masonry (After 28 days)

(*Clauses* 5.4.1, 5.4.5, 6.3.1 *and Table* 14)

Sl No.	Mortar Type (Ref to, Table 1)	Basic Compressive Stresses, in N/mm², Corresponding to Masonry Units of which Height to Width Ratio does not Exceed 0.75 and Crushing Strength, in N/mm², is not Less than											
		3.5	5.0	7.5	10	12.5	15	17.5	20	25	30	35	40
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
i)	H1	0.35	0.50	0.75	1.00	1.16	1.31	1.45	1.59	1.91	2.21	2.5	3.05
ii)	H2	0.35	0.50	0.74	0.96	1.09	1.19	1.30	1.41	1.62	1.85	2.1	2.5
iii)	M1	0.35	0.50	0.74	0.96	1.06	1.13	1.20	1.27	1.47	1.69	1.9	2.2
iv)	M2	0.35	0.44	0.59	0.81	0.94	1.03	1.10	1.17	1.34	1.51	1.65	1.9
v)	M3	0.25	0.41	0.56	0.75	0.87	0.95	1.02	1.10	1.25	1.41	1.55	1.78
vi)	L1	0.25	0.36	0.53	0.67	0.76	0.83	0.90	0.97	1.11	1.26	1.4	1.06
vii)	L2	0.25	0.31	0.42	0.53	0.58	0.61	0.65	0.69	0.73	0.78	0.85	0.95

NOTES

1 The table is valid for slenderness ratio up to 6 and loading with zero eccentricity.

2 The values given for basic compressive stress are applicable only when the masonry is properly cured.

3 Linear interpolation is permissible for units having crushing strengths between those given in the table.

4 The permissible stress for random rubble masonry may be taken as 75 percent of the corresponding stress for coarsed walling of similar materials.

5 The strength of ashlar masonry (natural stone masonry of massive type with thin joints) is closely related to intrinsic strength of the stone and allowable working stress in excess of those given in the table may be allowed for such masonry at the discretion of the designer.

6 For calculation of basic compressive stress of stabilized soil block having thickness 100 mm or more, reference to specialist literature may be made.

7 If the work is inadequately supervised, strength should be reduced to three-fourth or less at the discretion of the designer.

5.4.1.1 *Stress reduction factor*

This factor, as given in Table 10, takes into consideration the slenderness ratio of the element and also the eccentricity of loading.

5.4.1.2 *Area reduction factor*

This factor takes into consideration smallness of the sectional area of the element and is applicable when sectional area of the element is less than 0.2 m^2. The factor $k_a = 0.7 + 1.5A$, A being the area of section, in m^2.

Table 10 Stress Reduction Factor for Slenderness Ratio and Eccentricity

(*Clause* 5.4.1.1, 9.2.2.3, 9.2.2.9 *and* 10.4.1)

Sl No.	Slenderness Ratio	Eccentricity of Loading Divided by the Thickness of the Member					
		0	1/24	1/12	1/6	1/4	1/3
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	6	1.00	1.00	1.00	1.00	1.00	1.00
ii)	8	0.95	0.95	0.94	0.93	0.92	0.91
iii)	10	0.89	0.88	0.87	0.85	0.83	0.81
iv)	12	0.84	0.83	0.81	0.78	0.75	0.72
v)	14	0.78	0.76	0.74	0.70	0.66	0.66
vi)	16	0.73	0.71	0.68	0.63	0.58	0.53
vii)	18	0.67	0.64	0.61	0.55	0.49	0.43
viii)	20	0.62	0.59	0.55	0.48	0.41	0.34
ix)	22	0.56	0.52	0.48	0.40	0.32	0.24
x)	24	0.51	0.47	0.42	0.33	0.24	—
xi)	26	0.45	0.40	0.35	0.25	—	—
xii)	27	0.43	0.38	0.33	0.22	—	—

NOTES

1 Linear interpolation between values is permitted.

2 Where in special cases the eccentricity of loading lies between 1/3 and 1/2 of the thickness of the member, the stress reduction factor should vary linearly between unity and 0.20 for slenderness ratio of 6 and 20, respectively.

3 Slenderness ratio of a member for sections within 1/8 of the height of the member above or below a lateral support may be taken to be 6.

5.4.1.3 *Shape modification factor*

This factor takes into consideration the shape of the unit, that is, height to width ratio (as laid) and is given in Table 11. This factor is applicable for units of crushing strength up to 15 N/mm^2.

5.4.1.4 *Increase in permissible compressive stresses allowed for eccentric vertical loads, lateral loads under certain conditions*

In members subjected to eccentric and/or lateral loads, increase in permissible compressive stress is allowed as follows:

a) When resultant eccentricity ratio exceeds 1/24 but does not exceed 1/6, 25 percent increase in permissible compressive stress is allowed in design; and

b) When resultant eccentricity ratio exceeds 1/6, 25 percent increase in permissible stress is allowed but the area of the section under tension shall be disregarded for computing the load carrying capacity of the member.

NOTE — When resultant eccentricity ratio of loading is 1/24 or less, compressive stress due to bending shall be ignored and only axial stress need to be computed for the purpose of design.

5.4.1.5 *Increase in permissible compressive stress for walls subjected to concentrated loads*

When a wall is subjected to a concentrated load (a load being taken to be concentrated when area of supporting wall equals or exceeds three times the bearing area), certain increase in permissible compressive stress may be allowed because of dispersal of the load. Since, according to the present state of art, there is diversity of views in regard to manner and extent of dispersal, design of walls subjected to concentrated loads may, therefore, be worked out as per the best judgment of the designer. Some guidelines in this regard are given in Annex C.

Table 11 Shape Modification Factor for Masonry Units

(*Clause* 5.4.1.3)

Sl No.	Height to Width Ratio of Units (as Laid)	Shape Modification Factor (k_p) For Units Having Crushing Strength in N/mm^2			
		Up to 5.0	7.5	10.0	15.0
(1)	(2)	(3)	(4)	(5)	(6)
i)	Up to 0.75	1.0	1.0	1.0	1.0
ii)	1.0	1.2	1.1	1.1	1.0
iii)	1.5	1.5	1.3	1.2	1.1
iv)	2.0 to 4.0	1.8	1.5	1.3	1.2

NOTE — Linear interpolation between values is permissible.

5.4.2 *Permissible Tensile Stress*

As a general rule, design of masonry shall be based on the assumption that masonry is not capable of taking any tension. However, in case of lateral loads normal to the plane of wall, which causes flexural tensile stress, as for example, panel, curtain partition and free standing walls, flexural tensile stresses as follows may be permitted in the design for masonry:

a) *Grade M1 or better mortar*:

1) 0.07 N/mm^2 for bending in the vertical direction where tension developed is normal to bed joints; and

2) 0.14 N/mm^2 for bending in the longitudinal direction where tension developed is parallel to bed joints, provided crushing strength of masonry units is not less than 10 N/mm^2.

b) *Grade M2 mortar*:

1) 0.05 N/mm^2 for bending in the vertical direction where tension developed is normal to bed joints; and

2) 0.10 N/mm^2 for bending in the longitudinal direction where tension developed is parallel to bed joints, provided crushing strength of masonry units is not less than 7.5 N/mm^2.

NOTES

1 No tensile stress is permitted in masonry in case of water-retaining structures in view of water in contact with masonry. Also no tensile stress is permitted in earth-retaining structures, in view of the possibility of presence of water at the back of such walls.

2 Allowable tensile stress in bending in the vertical direction may be increased to 0.1 N/mm^2 for M1 mortar and 0.07 N/mm^2 for M2 mortar in case of boundary walls/compound at the discretion of the designer, since there is not much risk to life and property in the event of failure of such walls.

5.4.3 *Permissible Shear Stress*

In case of walls built in mortar not leaner than Grade M1 (*see* Table 1) and resisting horizontal forces in the plane of the wall, permissible shear stress calculated on the area of bed joints, shall not exceed the value obtained by the formula given below, subject to a maximum of 0.5 N/mm^2:

$$f_s = 0.1 + f_d/6$$

where

f_s = permissible shear stress, in N/mm^2; and

f_d = compressive stress due to dead loads, in N/mm^2.

5.4.4 If there is tension in any part of a section of masonry, the area under tension shall be ignored while working out shear stress on the section.

5.4.5 *Specified Compressive Strength*

The specified compressive strength $\boldsymbol{f}_{\mathbf{m}}$ (in MPa) shall be determined by:

a) testing prism specimens as per Annex B; and

b) the expression:

$$f_{\mathrm{m}} = 0.433 f_{\mathrm{b}}^{0.64} f_{\mathrm{m0}}^{0.36}$$

where

f_{b} = compressive strength (in MPa) of clay brick as per Table 9; and

f_{m0} = compressive strength of mortar as per **5.4.1.**

c) as per **5.4.1**.

5.4.6 *Elastic Modulus*

Elastic modulus, E_{m} of masonry shall be determined by testing masonry prisms as per **5.4.5(a)**; the chord modulus of elasticity shall be taken as the slope of the chord between 0.05 Max. and 0.33 of the Max. compressive strength of each prism:

The expressions:

$$E_{\mathrm{m}} = \begin{cases} 550 f_{\mathrm{m}} & \text{clay brick masonry} \\ 850 f_{\mathrm{m}} & \text{concrete block masonry} \end{cases}$$

5.4.7 *Shear Modulus*

The shear modulus, G_{m} shall be determined by:

$$G_{\mathrm{m}} = 0.2 E_{\mathrm{m}}$$

5.5 Design Thickness/Cross-Section

5.5.1 *Walls and Columns Subjected to Vertical Loads*

Walls and columns bearing vertical loads shall be designed on the basis of permissible compressive stress. Design consists in determining thickness in case of walls and section in case of columns in relation to strength of masonry units and grade of mortar to be used, taking into consideration various factors, such as slenderness ratio, eccentricity, area of section, workmanship, quality of supervision, etc, subject further to provisions of **5.5.1.1** to **5.5.1.4**.

5.5.1.1 *Solid walls*

Thickness used for design calculation shall be the actual thickness of masonry computed as the sum of the average dimensions of the masonry units specified in the relevant standard, together with the specified joint thickness. In masonry with raked joints, thickness shall be reduced by the depth of raking of joints for plastering/pointing.

5.5.1.2 *Cavity walls*

a) Thickness of each leaf of a cavity wall shall not be less than 75 mm;

b) Where the outer leaf is half masonry unit in thickness, the uninterrupted height and length of this leaf shall be limited so as to avoid undue loosening of ties due to differential movements between the two leaves. The outer leaf shall, therefore, be supported at least at every third storey or at every 10 m of height, whichever is less and at every 10 m or less along the length;

c) Where the load is carried by both leaves of a wall of a cavity construction, the permissible stress shall be based on the slenderness ratio derived from the effective thickness of the wall as given in **4.5.4** or **4.5.5**. The eccentricity of the load shall be considered with respect to the centre of gravity of the cross-section of the wall; and

d) Where the load is carried by one leaf only, the permissible stress shall be the greater of values calculated by the following two alternative methods:

   1) The slenderness ratio is based on the effective thickness of the cavity wall as a whole as given in **4.5.4** or **4.5.5** and on the eccentricity of the load with respect to the centre of gravity of the cross-section of the whole wall (both leaves) (This is the same method as where the load is carried by both the leaves but the eccentricity will be more when the load is carried by one leaf only); and

   2) The slenderness ratio is based on the effective thickness of the loaded leaf only using **4.5.1** and **4.5.2**, and the eccentricity of the load will also be with respect to the centre of gravity of the loaded leaf only.

In either alternative, only the actual thickness of the load bearing leaf shall be used in arriving at the cross-sectional area resisting the load (*see* **5.5.1.1**).

5.5.1.3 *Faced wall*

The permissible load per length of wall shall be taken as the product of the total thickness of the wall and the permissible stress in the weaker of the two materials. The permissible stress shall be found by using the total thickness of the wall when calculating the slenderness ratio.

5.5.1.4 *Veneered wall*

The facing (veneer) shall be entirely ignored in calculations of strength and stability. For the purpose of determining the permissible stress in the backing, the slenderness ratio shall be based on the thickness of the backing alone.

5.5.2 *Walls and Columns Mainly Subjected to Lateral Loads*

5.5.2.1 *Free standing walls*

a) Free standing walls, subjected to wind pressure or seismic forces shall be designed on the basis of permissible tensile stress in masonry or stability as in **4.2.2.4**. However, in seismic Zones II, free-standing walls may be apportioned without making any design calculations with the help of Table 12 provided the mortar used is of grade not leaner than M1; and

b) If there is a horizontal damp-proof course near the base of the wall, that is, not capable of developing tension vertically, the minimum wall thickness should be the greater of that calculated from either:

   1) the appropriate height to thickness ratio given in Table 12 reduced by 25 percent, reckoning the height from the level of the damp-proof course; or

   2) the appropriate height to thickness ratio given in Table 12 reckoning the height from the lower level at which the wall is restrained laterally.

Table 12 Height to Thickness Ratio of Free Standing Walls Related to Wind Speed

[*Clause* 5.5.2.1(a) *and* (b)]

Sl No.	Design Wind Pressure N/mm^2	Height to Thickness Ratio
(1)	(2)	(3)
i)	Up to 285	10
ii)	575	7
iii)	860	5
iv)	1 150	4

NOTES

1 For intermediate values, linear interpolation is permissible.

2 Height is to be reckoned from 150 mm below ground level or top of footing/foundation block, whichever is higher, and up to the top edge of the wall.

3 The thickness should be measured including the thickness of the plaster.

5.5.2.2 *Retaining walls*

Normally masonry of retaining walls shall be designed on the basis of zero-tension, and permissible compressive stress. However, in case of retaining walls for supporting horizontal thrust from dry materials, retaining walls may be designed on the basis of permissible tensile stress at the discretion of the designers.

5.5.3 *Walls and Columns Subjected to Vertical as well as Lateral Loads*

For walls and columns, stress worked out separately for vertical loads as in **5.5.1** and lateral loads as in **5.5.2** shall be combined and elements designed on the basis of permissible stress.

5.5.4 *Walls Subjected to In-Plane Bending and Vertical Loads* (*Shear Walls*)

Walls subjected to in-plane bending and vertical loads, that is, shear walls shall be designed on the basis of no tension with permissible shear stress and permissible compressive stress.

5.5.5 *Non-Load Bearing Walls*

Non-load bearing walls, such as panel walls, curtain walls and partition walls which are mainly subjected to lateral loads, according to present state of art, are not capable of precise design and only approximate methods based on some tests are available. Guidelines for approximate design of these walls are given in Annex D.

6 GENERAL REQUIREMENTS

6.1 Methods of Construction

6.1.1 *General*

Construction of the following types of load bearing and non-load bearing masonry walls shall be carried out in accordance with good practice [C-4(4)]:

a) brickwork;

b) stone masonry;

c) hollow concrete block masonry;

d) gypsum partition blocks;

e) autoclaved cellular concrete block masonry; and

f) lightweight concrete block masonry.

6.1.2 *Construction of Buildings in Seismic Zones*

Special features of construction for earthquake resistant masonry buildings in zones III and above shall be applicable according to **8**.

6.2 Minimum Thickness of Walls from Consideration Other than Structural

Thickness of walls determined from consideration of strength and stability may not always be adequate in respect of other requirements, such as resistance to fire, thermal insulation, sound insulation and resistance to damp penetration for which reference may be made to the appropriate Parts/Sections of the NBCS, and thickness suitably increased, where found necessary.

6.3 Workmanship

6.3.1 *General*

Workmanship has considerable effect on strength of masonry and bad workmanship may reduce the strength of brick masonry to as low as half the intended strength. The basic compressive stress values for masonry as given in Table 9 holds good for commercially obtainable standards of workmanship with reasonable degree of supervision.

6.3.2 *Bedding of Masonry Units*

Masonry units shall be laid on a full bed of mortar with frog, if any, upward such that cross-joints and wall joints are completely filled with mortar. Masonry units which are moved after initial placement shall be re-laid in fresh mortar, discarding the disturbed mortar.

6.3.3 *Bond*

Cross-joints in any course of one brick thick masonry wall shall be not less than one-fourth of a masonry unit in horizontal direction from the cross-joints in the course below. In masonry walls more than one brick in thickness, bonding through the thickness of wall shall be provided by either header units or by other equivalent means in accordance with good practice [C-4(5)].

6.3.4 *Verticality and Alignment*

All masonry shall be built true and plumb within the tolerances prescribed below; care shall be taken to keep the perpends properly aligned:

a) deviation from vertical within a storey shall not exceed 6 mm per 3 m height;

b) deviation in verticality in total height of any wall of a building more than one storey in height shall not exceed 12.5 mm.;

c) deviation from position shown on plan of any brickwork shall not exceed 12.5 mm;

d) relative displacement between load bearing walls in adjacent storeys intended to be in vertical alignment shall not exceed 6 mm;

e) deviation of bed-joint from horizontal in a length of 12 m shall not exceed 6 mm subject to a maximum deviation of 12 mm; and

f) deviation from the specified thickness of bed joints, cross-joints and perpends shall not exceed one-fifth of the specified thickness.

NOTE — These tolerances have been specified from the point of view of their effect on the strength of masonry. The permissible stress recommended in 5.3 may be considered applicable only, if these tolerances are adhered to.

6.4 Joints to Control Deformation and Cracking

Special provision shall be made to control or isolate thermal and other movements so that damage to the fabric of the building is avoided and its structural sufficiency preserved. Design and installation of joints shall be done according to the appropriate recommendations in accordance with good practice [C-4(6)].

6.5 Chases, Recesses and Holes

6.5.1 Chases, recesses and holes are permissible in masonry only if these do not impair strength and stability of the structure.

6.5.2 In masonry, designed by structural analysis, all chases, recesses and holes shall be considered in structural design and detailed in building plans.

6.5.3 When chases, recesses and holes have not been considered in structural design and are not shown in drawings, these may be provided, subject to the constraints and precautions specified in 6.5.3.1 to 6.5.3.10.

6.5.3.1 As far as possible, services should be planned with the help of vertical chases and use of horizontal chases should be avoided.

6.5.3.2 For load bearing walls, depth of vertical and horizontal chases shall not exceed one-third and one-sixth of the wall thickness, respectively.

6.5.3.3 Vertical chases shall not be closer than 2 m in any stretch of wall and shall not be located within 345 mm of an opening or within 230 mm of a cross wall that serves as a stiffening wall for stability. Width of a vertical chase shall not exceed thickness of wall in which it occurs.

6.5.3.4 When unavoidable horizontal chases of width not exceeding 60 mm in a wall having slenderness ratio not exceeding 15 may be provided. These shall be located in the upper or lower middle third height of wall at a distance not less than 600 mm from a lateral support. No horizontal chase shall exceed 1 m in length and there shall not be more than 2 chases in any one wall. Horizontal chases shall have minimum mutual separation distance of 500 mm. Sum of lengths of all chases and recesses in any horizontal plane shall not exceed one-fourth the length of the wall.

6.5.3.5 Holes for supporting put-logs of scaffolding shall be kept away from bearings of beams, lintels, and other concentrated loads. If unavoidable, stresses in the affected area shall be checked to ensure that these are within safe limits.

6.5.3.6 No chase, recess or hole shall be provided in any stretch of a masonry wall, the length of which is less than four times the thickness of wall, except when found safe by structural analysis.

6.5.3.7 Masonry directly above a recess or a hole, if wider than 300 mm, shall be supported on a lintel. No lintel, however, is necessary in case of a circular recess or hole exceeding 300 mm in diameter provided upper half of the recess or hole is built as a semi-circular arch of adequate thickness and there is an adequate length of masonry on the sides of openings to resist the horizontal thrust.

6.5.3.8 As far as possible, chases, recesses and holes in masonry should be left (inserting sleeves, where necessary) at the time of construction of masonry so as to obviate subsequent cutting. If cutting is unavoidable, it should be done without damage to the surrounding or residual masonry. It is desirable to use such tools for cutting which depend upon rotary and not on heavy impact for cutting action.

6.5.3.9 No chase, recess or hole shall be provided in half-brick load bearing wall, excepting the minimum number of holes needed for scaffolding.

6.5.3.10 Chases, recesses or holes shall not be cut into walls made of hollow or perforated units, after the units have been incorporated in masonry.

6.6 Corbelling

6.6.1 Where corbelling is required for the support of some structural element, maximum projection of masonry unit should not exceed one-half of the height of the unit or one-half of the built-in part of the unit and the maximum horizontal projection of the corbel should not exceed one-third of the wall thickness.

6.6.2 The load per unit length on a corbel shall not be greater than half of the load per unit length on the wall above the corbel. The load on the wall above the corbel, together with four times the load on the corbel, shall not cause the average stress in the supporting wall or leaf to exceed the permissible stresses given in **5.4**.

6.6.3 It is preferable to adopt header courses in the corbelled portion of masonry from considerations of economy and stability.

7 REINFORCED BRICK AND REINFORCED BRICK CONCRETE FLOORS AND ROOFS

The construction and design of reinforced brick and reinforced brick concrete floors and roof shall be in accordance with good practices [C-4(7)].

8 SPECIAL CONSIDERATION FROM EARTHQUAKE POINT OF VIEW

The design and construction of masonry buildings shall be governed by provisions of **4**, except as modified by the provisions of this section for those elements participating in lateral force resistance. The design and construction for earthquake resistant masonry buildings are given in **8**, **9** and **10**. The earthquake resistant design and detailing of masonry buildings having the following structural systems:

a) Masonry Walls with Prescriptive Bands (MWB);

b) Masonry Walls with Prescriptive Bands and Vertical Reinforcements (MWBR);

c) Confined Masonry Walls (CMW) (*see* **9**); and

d) Reinforced Masonry Walls (RMW) (*see* **10**).

Buildings with MWB and MWBR systems shall not be of height more than 15 m subject to a maximum of four storeys, measured from the base of the buildings to the roof slab or ridge level.

8.1 For the purpose of 8 and 9, the following definitions shall apply in addition to those given in 2.

8.1.1 *Separation Section*

The gap of specified width between adjacent buildings or parts of the same building either left uncovered or covered suitably to permit movement to avoid pounding due to earthquake.

8.1.1.1 *Crumple section*

The separation gap filled with appropriate material that crumples or factures in the event of an earthquake.

8.1.2 *Centre of Rigidity*

The point at the floor level of a structure where application of lateral force in a particular principal direction produces equal deflections of the floor components along that direction.

8.1.3 *Load Bearing Wall*

A wall designed to resist axial force, shear force in its own plane and bending moment about its major axis.

8.1.4 *Box System*

A building made of masonry load bearing walls and horizontal floors.

8.1.5 *Band*

A wooden (in low strength masonry buildings), reinforced concrete or reinforced brick runner provided in the walls to tie them together and to impart horizontal bending strength in them.

8.1.6 *Earthquake Zone*

The earthquake zones as classified in **5** of Part C/Section 1 of this NBCS.

8.1.7 *Design Horizontal Acceleration Coefficient*

The horizontal acceleration coefficient A_h computed considering the importance factor and soil-foundation system as specified in **5** of Part C/Section 1 of this NBCS.

8.1.8 *Concrete Strength*

The 28-day compressive strength (in MPa) of concrete cubes of 150 mm size.

8.1.9 *Cross-Sectional Area of Masonry Unit*

The net cross-sectional area of a masonry unit shall be taken as the gross cross-sectional area minus the area of cellular space (if any). Gross cross-sectional area of cored units shall be determined to the outside of the coring, but cross-sectional area of grooves (if any) shall not be deducted from the gross cross-sectional area to obtain the net cross-sectional area.

8.1.10 *Grout*

A mixture of cement, sand, and water of pourable consistency for filling small voids.

8.1.11 *Grouted Masonry*

Masonry in which the masonry units with holes are filled with a mixture of cement and sand.

8.1.11.1 *Grouted hollow-unit masonry*

A form of grouted masonry construction in which certain designated cells of hollow units are continuously filled with grout.

8.1.11.2 *Grouted multi-wythe masonry*

A form of grouted masonry construction in which the space between the wythes is solidly or periodically filled with grout.

8.1.12 *Joint Reinforcement*

A prefabricated reinforcement in the form of lattice truss which has been hot dip galvanized after fabrication and is to be laid in the mortar bed joint.

8.1.13 Pier

An isolated vertical member whose horizontal dimension measured at right angles to its thickness is not less than 4 times its thickness and whose height is less than 5 times its length.

8.1.14 *Prism*

An assemblage of masonry units bonded by mortar with or without grout used as a test specimen for determining properties of masonry.

8.1.15 *Reinforced Masonry*

Masonry which is reinforced (as specified in 2) and grouted (if necessary) so that the two materials act together in resisting forces.

8.1.16 *Grouted Cavity Reinforced Masonry*

Masonry with two parallel single-leaf walls spaced at least 50 mm apart, and effectively tied together with wall ties. The intervening cavity contains steel reinforcement and is filled with infill concrete so as to result in common action with masonry under load.

8.1.17 *Pocket type Reinforced Masonry*

Masonry reinforced primarily to resist lateral loading where the main reinforcement is concentrated in vertical pockets formed in the tension face of the masonry and is surrounded by in situ concrete.

8.1.18 *Quetta Bond Reinforced Masonry*

Masonry that is at least one and half units thick, in which vertical pockets containing reinforcement and mortar or concrete infill occur at intervals along its length.

8.1.19 *Specified Compressive Strength of Masonry*

Minimum compressive strength (in MPa) is force per unit of net cross-section area, which is required of the masonry used in construction and upon which the design is based.

8.1.20 *Wall Tie*

A metal fastener, which connects wythes of masonry to each other or to other materials.

8.1.21 *Wythe*

A continuous vertical layer of masonry wall of one unit in thickness.

NOTE — For low strength masonry buildings, wooden runners may also be used as runner.

8.2 General Principles

The general principles given in 8.2.1 to 8.2.9 shall be observed in construction of earthquake resistant buildings.

8.2.1 *Lightness*

Since the earthquake force is a function of mass, the weight of the building shall be as minimum as possible, consistent with structural safety and functional requirements. Roofs and upper storeys of buildings, in particular, should be designed as light as possible.

8.2.2 *Continuity of Construction*

8.2.2.1 As far as possible, the parts of the building should be tied together in such a manner that the building acts as one unit.

8.2.2.2 For parts of buildings between separation or crumple sections to expansion joints, floor slabs shall be continuous throughout as far as possible. Concrete slabs shall be rigidly connected or integrally cast with the support beams.

8.2.2.3 Additions to the structures shall be accompanied by the provision of separation or crumple sections between the new and the existing structures as far as possible, unless positive measures are taken to establish continuity between the existing and the new construction.

8.2.2.4 Alteration to the building structure shall be done by maintaining its structural stability by ensuring proper load path.

8.2.3 *Projecting and Suspended Parts*

8.2.3.1 Projecting parts shall be avoided as far as possible. If the projecting parts cannot be avoided, they shall be properly reinforced and firmly tied to the main structure, and their design shall be in accordance with **5** of Part C/Section 1 of this NBCS.

8.2.3.2 Ceiling plaster shall preferably be avoided. When it is unavoidable, the plaster shall be as thin as possible.

8.2.3.3 Suspended ceiling shall be avoided as far as possible. Where provided they shall be light, adequately framed and secured to which electrical fixtures shall be fully secured.

8.2.4 *Building Configuration*

8.2.4.1 Masonry buildings shall have walls placed uniformly along the two principal plan directions. Buildings with the irregularities listed in **5** of Part C/Section 1 of this NBCS perform poorly during earthquake shaking, and should be avoided. When these irregularities appear in a building, the guidance given in **5** of Part C/Section 1 of this NBCS for the respective irregularity shall be followed. In order to minimize torsion and stress concentration, provisions given in 8.2.4.2 to 8.2.4.4 should be complied with as relevant.

8.2.4.2 The building should have a simple rectangular plan and be symmetrical both with respect to mass and rigidity so that the centre of mass and rigidity of the building coincide with each other in which case no separation sections other than expansion joints are necessary. For provision of expansion joints reference may be made to [C-4(6)].

8.2.4.3 If symmetry of the structure is not possible in plan, elevation or mass, provision shall be made for torsional and other effects due to earthquake forces in the structural design or the parts of different rigidities may be separated through crumple sections. The length of such building between separation sections shall not preferably exceed three times the width.

NOTE — As an alternative to separation section to reduce torsional moments, the centre of rigidity of the building may be brought close or coincident to the centre of mass by adjusting the locations and/or sizes of columns and walls.

8.2.4.4 Buildings having plans with shapes like L, T, E and Y shall preferably be separated into rectangular parts by providing separation sections at appropriate places. Typical examples are shown in Fig. 15.

NOTES

1 The buildings with small lengths of projections forming L, T, E or Y shapes need not be provided with separation section. In each cases the length of the projection may not exceed 15 percent to 20 percent of the total dimension of the building in the direction of the projection (*see* Fig. 16).

2 For buildings with minor asymmetry in plan and elevation, separation sections may be omitted.

8.2.5 *Strength in Various Directions*

The structure shall be designed to have adequate strength against earthquake effects along both the horizontal axes. The design shall also be safe considering the reversible nature of earthquake forces.

8.2.6 *Foundations*

The structure shall not be founded on such soils which shall subside or liquefy during an earthquake, resulting in large differential settlements (*see also* **8.3.3.3**).

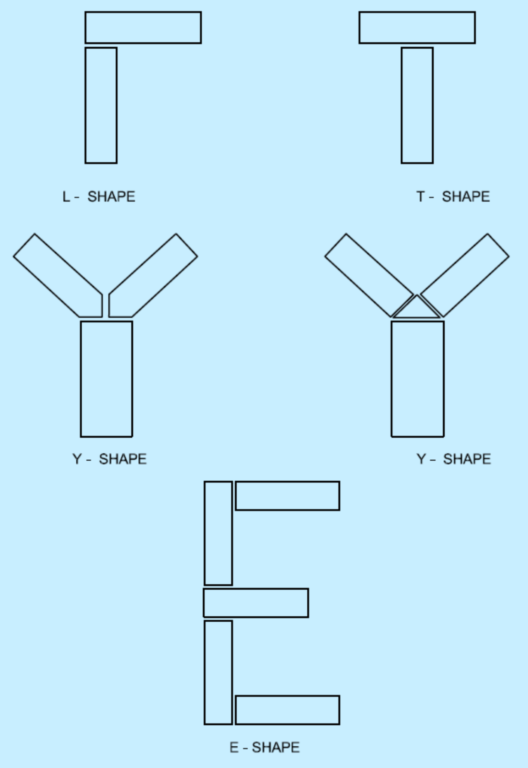


FIG. 15 TYPICAL SHAPES OF BUILDING WITH SEPARATION SECTIONS

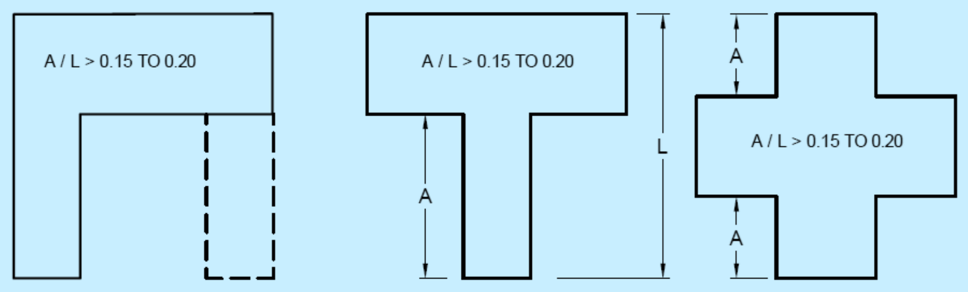


FIG. 16 (A) PLAN IRREGULARITIES

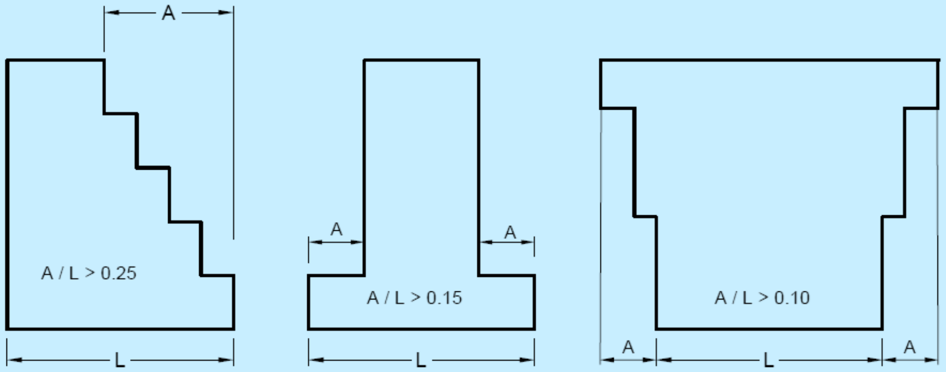


FIG. 16(B) VERTICAL IRREGULARITIES

FIG. 16 PLAN AND VERTICAL IRREGULARITIES

8.2.7 *Ductility*

The main structural elements and their connection shall be designed to have a ductile failure. This shall enable the structure to absorb energy during earthquakes to avoid sudden collapse of the structure. Providing reinforcing steel in masonry at critical sections, as specified in this Section shall not only increase strength and stability but also ductility. The details for achieving ductility in reinforced concrete structures is given in Part C 'Structural Design, Section 5 Structural Concrete' of this NBCS.

8.2.8 *Damage to Non-Structural Parts*

Suitable details shall be worked out to connect the non-structural parts with the structural framing so that the deformation of the structural frame leads to minimum damage of the non-structural elements.

8.2.9 *Fire Safety*

Fire frequently follows an earthquake and therefore, buildings shall be constructed to make them fire resistant in accordance with the provisions of Part F 'Fire and Life Safety' of this NBCS.

8.3 Special Construction Features

8.3.1 *Separation of Adjoining Structures*

8.3.1.1 Separation of adjoining structures or parts of the same structure is required for structures having different total heights or storey heights and different dynamic characteristics. This is to avoid collision during an earthquake.

8.3.1.2 Minimum width of separation gaps as mentioned in **8.3.1.1**, shall be as specified in Table 13. The design seismic coefficient to be used shall be in accordance with **5** of Part C/Section 1 of this NBCS.

8.3.1.3 Where separation is necessary, a complete separation of the parts shall be made except below the plinth level. The plinth beams, foundation beams and footings may be continuous. Where separation sections are provided in a long building, they shall take care of movement owing to temperature changes also.

8.3.2 *Separation or Crumple Section*

8.3.2.1 In case of framed construction, members shall be duplicated on either side of the separation or crumple section. As an alternative, in certain cases, such duplication may not be provided, if the portions on either side can act as cantilevers to take the weight of the building and other relevant loads.

8.3.2.2 Typical details of separation and crumple sections are shown in Fig. 17. For other types of joint details, reference may be made to [C-4(5)].

Table 13 Gap Width for Adjoining Structures

(*Clause* 8.3.1.2)

Sl No.	Buildings Categories for Earthquake Resisting Feature	Gap Width per Storey for Adjoining Masonry Building mm
(1)	(2)	(3)
i)	Frames with shear walls	15
ii)	Category B[1]	10
iii)	Category C[1]	10
iv)	Category D[1]	15
v)	Category E[1]	20

NOTE — Minimum total gap shall be 25 mm. For any other value of A_h the gap width shall be determined proportionately.

[1] *See* Table 14.

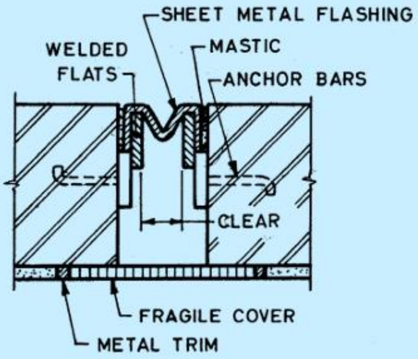

SHEET METAL FLASHING
WELDED FLATS
MASTIC
ANCHOR BARS
CLEAR
FRAGILE COVER
METAL TRIM

FIG.17(A) BRICK WALL

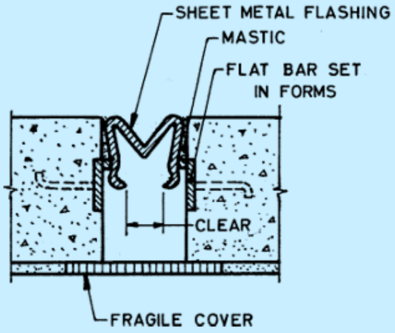

SHEET METAL FLASHING
MASTIC
FLAT BAR SET IN FORMS
CLEAR
FRAGILE COVER

FIG. 17(B) CONCRETE WALLS

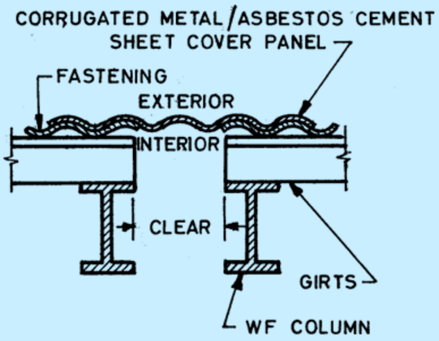

CORRUGATED METAL/ASBESTOS CEMENT SHEET COVER PANEL
FASTENING
EXTERIOR
INTERIOR
CLEAR
GIRTS
WF COLUMN

FIG. 17(C) METAL SLIDING INDUSTRIAL WORK

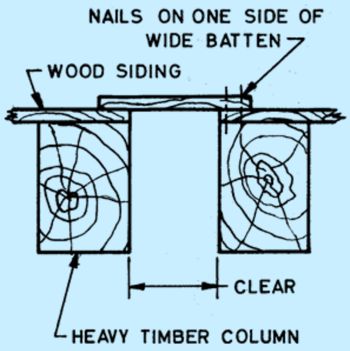

NAILS ON ONE SIDE OF WIDE BATTEN
WOOD SIDING
CLEAR
HEAVY TIMBER COLUMN

FIG. 17(D) WOOD SHEATHING INDUSTRIAL WORK

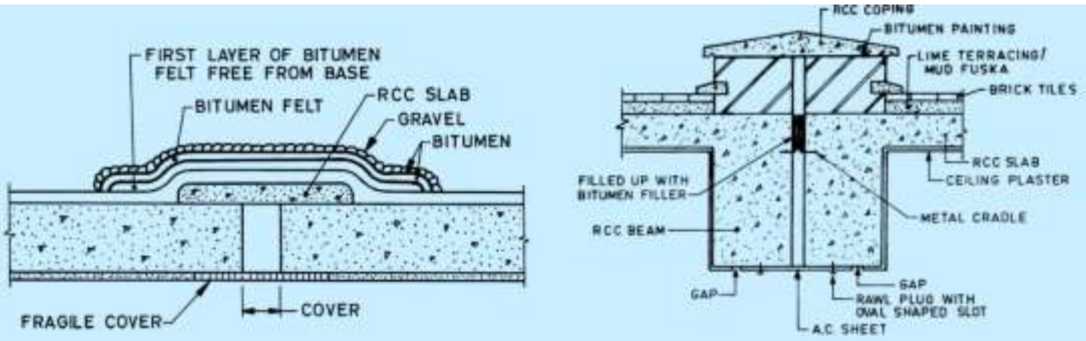

FIRST LAYER OF BITUMEN FELT FREE FROM BASE
BITUMEN FELT
RCC SLAB
GRAVEL
BITUMEN
FRAGILE COVER
COVER
RCC COPING
BITUMEN PAINTING
LIME TERRACING/ MUD FUSKA
BRICK TILES
FILLED UP WITH BITUMEN FILLER
RCC SLAB
CEILING PLASTER
METAL CRADLE
RCC BEAM
GAP
GAP
RAWL PLUG WITH OVAL SHAPED SLOT
A.C SHEET

FIG.17(E) RCC SLAB ON ROOF SURFACE

FIG. 17(F) SEPARATION JOINT DETAILS AT ROOF

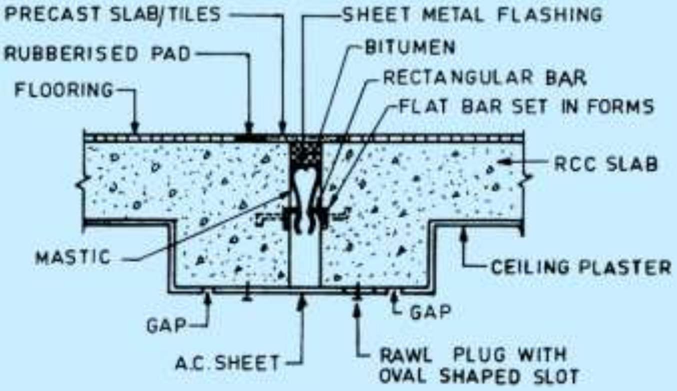

PRECAST SLAB/TILES
SHEET METAL FLASHING
RUBBERISED PAD
BITUMEN
FLOORING
RECTANGULAR BAR
FLAT BAR SET IN FORMS
RCC SLAB
MASTIC
CEILING PLASTER
GAP
GAP
A.C. SHEET
RAWL PLUG WITH OVAL SHAPED SLOT

FIG.17(G) SEPARATION AT FLOOR LEVEL

FIG. 17 TYPICAL DETAILS OF SEPARATION OR CRUMPLE SECTION

8.3.3 *Foundations*

8.3.3.1 For the design of foundations, the provisions of Part C/Section 1 and Section 2 of this NBCS shall generally be followed.

8.3.3.2 The subgrade below the entire area of the building shall preferably be of the same type of the soil. Wherever this is not possible, a suitably located separation or crumple section shall be provided.

8.3.3.3 Loose fine sand, soft silt and expansive clays should be avoided. If unavoidable, the building shall rest either on a rigid raft foundation or on piles taken to a firm stratum. However, for light constructions the following measures may be taken to improve the soil on which the foundation of the building may rest:

a) sand piling; and

b) soil stabilization.

8.3.3.4 *Isolated footings for columns*

All the individual footings or pile caps where used in Type III Soft soils, shall be connected by reinforced concrete ties at least in two directions approximately at right angles to each other. For buildings with no basement, the ties may be placed at or below the plinth level and for buildings with basement they may be placed at the level of basement floor. They shall need to be designed to carry the load of the panel walls also.

NOTE — The ties may not be necessary where structural floor connects the columns at or below the plinth level.

8.3.3.4.1 Where ties are used, their sections shall be designed to carry in tension as well as in compression, an axial load not less than the earthquake force in the direction the tie acting on the heavier of the columns connected, but the sections shall not be less than 200 mm × 200 mm with M20 concrete reinforced with 4 bars of 12 mm diameter plain mild steel bars or 10 mm diameter high strength deformed bars, one at each corner, bound by 8 mm diameter stirrups not more than 150 mm apart.

NOTE — In working out the buckling strength of ties, the lateral support provided by the soil may be taken into account. Calculations show that for such buried ties, lateral buckling is not a problem and the full section of the tie may be taken effective as a short column.

8.3.3.4.2 In the case of reinforced concrete slab, the thickness shall not be less than 1/50th of the clear distance between the footings, but not less than 100 mm in any case. It shall be reinforced with not less than 0.15 percent mild steel bars or 0.12 percent high strength deformed bars in each direction placed symmetrically at top and bottom.

8.3.4 *Roofs and Floors*

8.3.4.1 Flat roof or floor shall not preferably be made of tiles of ordinary bricks supported on steel, timber or reinforced concrete joists, nor they shall be of a type which in the event of an earthquake is likely to be loosened and parts or all of which may fall. If this type of construction cannot be avoided, the joists should be blocked at ends and bridged at intervals such that their spacing is not altered during an earthquake.

8.3.4.1.1 For pitched roofs, corrugated iron or asbestos sheets shall be used in preference to country, Allahabad or Mangalore tiles or other loose roofing units. All roofing materials shall be properly tied to the supporting members. Heavy roofing materials shall generally be avoided.

8.3.4.2 *Pent roofs*

8.3.4.2.1 All roof trusses shall be supported on reinforced concrete or reinforced brick band (*see* **8.5**). The holding down bolts shall have adequate size and length as required for earthquake forces in accordance with **5** of Part C/Section 1 of this NBCS.

Where a trussed roof adjoins a masonry gable, the ends of the purlins shall be carried on and secured to a plate or bearer which shall be adequately bolted to reinforced concrete or reinforced brick band at the top of gable end masonry.

NOTE — Hipped roof in general have shown better structural behaviour during earthquakes than gable ended roofs.

8.3.4.2.2 At tie level all the trusses and the gable end shall be provided with diagonal braces in plan so as to transmit the lateral shear due to earthquake force to the gable walls acting as shear walls at the ends as specified in **8.5**.

8.3.4.3 *Jack arches*

Jack arched roofs or floors, where used shall be provided with mild steel ties in all spans along with diagonal braces in plan to ensure diaphragms actions.

8.3.5 *Staircases*

8.3.5.1 The inter-connection of the stairs with the adjacent floors should be appropriately treated by providing sliding joints at the stairs to eliminate their bracing effect on the floors. Large stair halls shall preferably be separated from the rest of the building by means of separation or crumple sections.

8.3.5.2 Three types of stair construction may be adopted as described below:

a) *Separated staircases* — One end of the staircase rests on a wall and the other end is carried by columns and beams which have no connection with the floors. The gap at the vertical joints between the floor and the staircase may be covered either with a tread plate attached to one side of the joint and sliding on the other side, or covered with some appropriate material which could crumple or fracture during an earthquake without causing structural damage. The supporting members, columns or walls, are isolated from the surrounding floors by means of separation or crumple sections. A typical example is shown in Fig. 18;

b) *Built-in staircase* — When stairs are built monolithically with floors, they can be protected against damage by providing rigid walls at the stair opening. An arrangement, in which the staircase is enclosed by two walls, is given in Fig. 19. In such cases, the joints, as mentioned in respect of separated staircases, shall not be necessary;

The two walls mentioned above, enclosing the staircase, shall extend through the entire height of the stairs and to the building foundations; and

c) *Staircases with sliding joints* — In case it is not possible to provide rigid walls around stair openings for built-in staircase or to adopt the separated staircases, the staircases shall have sliding joints so that they shall not act as diagonal bracing.

8.3.6 *Framing of Thin Load Bearing Walls* (*see* Fig. 20)

Load bearing walls can be made thinner than 200 mm say 150 mm inclusive of plastering on both sides. Reinforced concrete framing columns and collar beams shall be necessary to be constructed to have full bond with the walls. Columns are to be located at all corners and junctions of walls and spaced not more than 1.5 m apart but so located as to frame up the doors and windows. The horizontal bands or ring beams are located at all floors, roof as well as lintel levels of the openings. The sequence of construction between walls and columns shall be first to build the wall up to 4 to 6 courses height leaving toothed gaps (tooth projection being about 40 mm only) for the columns and second to pour M20 (1 : 1½ : 3) concrete to fill the columns against the walls using wood forms only on two sides. The columns steel should be accurately held in position all along. The band concrete should be cast on the wall masonry directly so as to develop full bond with it.

Such construction may be limited to only two storeys maximum in view of its vertical load carrying capacity. The horizontal length of walls between cross walls shall be restricted to 7 m and the storey height to 3 m.

8.3.7 *Reinforcing Details for Hollow Block Masonry*

The following details may be followed in placing the horizontal and vertical steel in hollow block masonry using cement-sand or cement-concrete blocks.

8.3.7.1 *Horizontal band*

U-shaped blocks may be used for construction of horizontal bands at various levels of the storeys as shown in Fig. 21, where the amount of horizontal reinforcement shall be taken 25 percent more than that given in Table 18 and provided by using four bars and 6 mm diameter stirrups. Other continuity details shall be followed, as shown in Fig. 28.

NOTES

1 Detailing of steel around the window openings will be same as for door openings with additional 75 mm band at sill level.

2 Figures are for just explanation purposes and the same shall not be used as design guide.

8.3.7.2 *Vertical reinforcement*

Bars, as specified in Table 19 shall be located inside the cavities of the hollow blocks, one bar in each cavity (*see* Fig. 29). Where more than one bar is planned these can be located in two or three consecutive cavities. The cavities containing bars are to be filled by using micro-concrete 1 : 2 : 3 or cement coarse sand mortar 1 : 3, and properly rodded for compaction. The vertical bars should be spliced by welding or overlapping for developing full tensile strength. For proper bonding, the overlapped bars should be tied together by winding the binding wire over the lapped length. To reduce the number of overlaps, the blocks may be made U-shaped as shown in Fig. 29 which shall avoid lifting and threading of bars into the hollows.

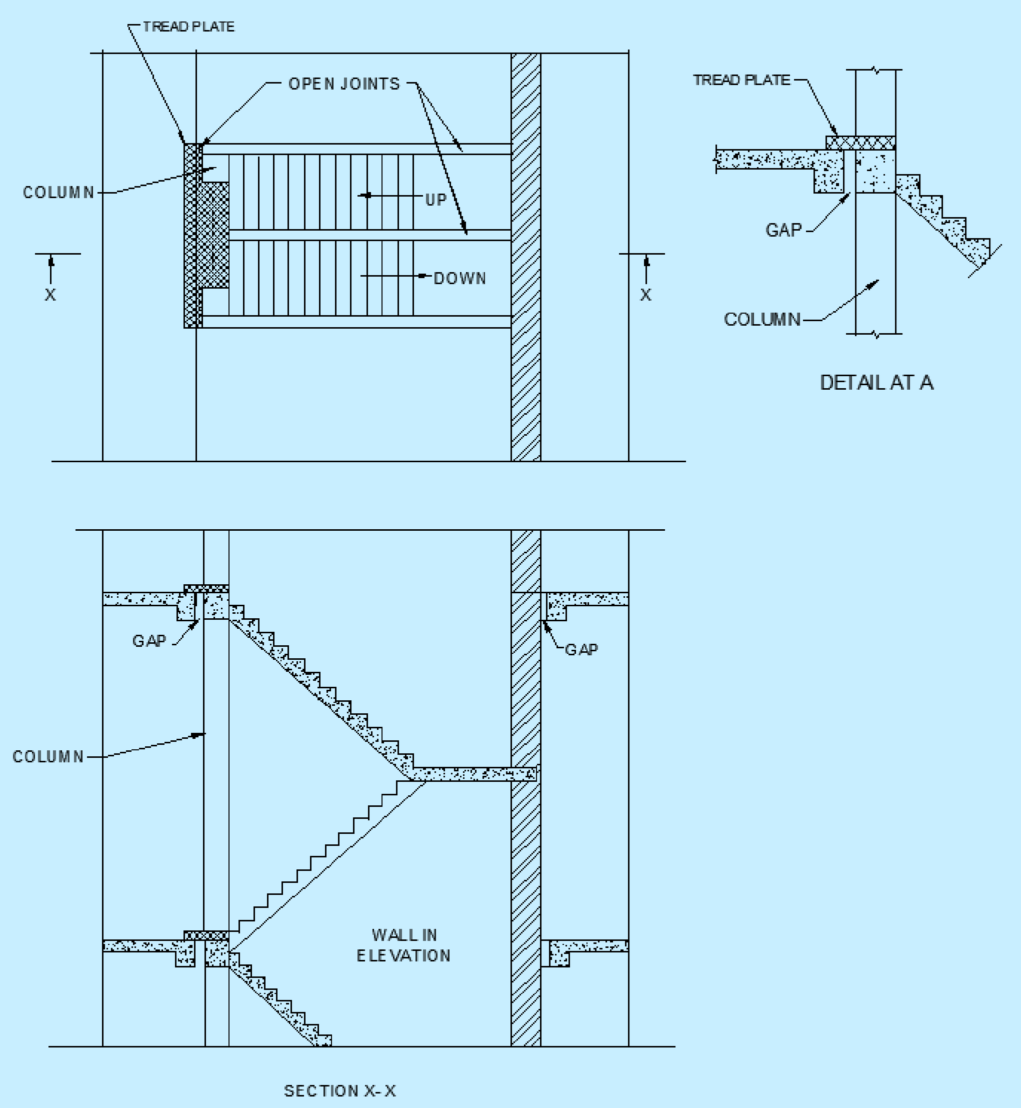

TREAD PLATE
OPEN JOINTS
COLUMN
UP
DOWN
X
X
TREAD PLATE
GAP
COLUMN
DETAIL AT A
GAP
GAP
COLUMN
WALL IN ELEVATION
SECTION X-X

FIG. 18 SEPARATED STAIRCASE

8.4 DESIGN CONSIDERATIONS

8.4.1 *Design Philosophy*

The design approach adopted for masonry buildings is the working stress method at serviceability loads, with structural materials assumed to behave in linear elastic manner. Safety is ensured by restricting stresses in material induced by design loads imposed on the structure as per the load combinations specified in **5** of Part C/Section 1 of this NBCS.

8.4.1.1 *Working stress method*

In the working stress method of design of members, permissible stresses given in Table 14 shall govern the earthquake resistant design of members of the masonry building systems specified in this section.

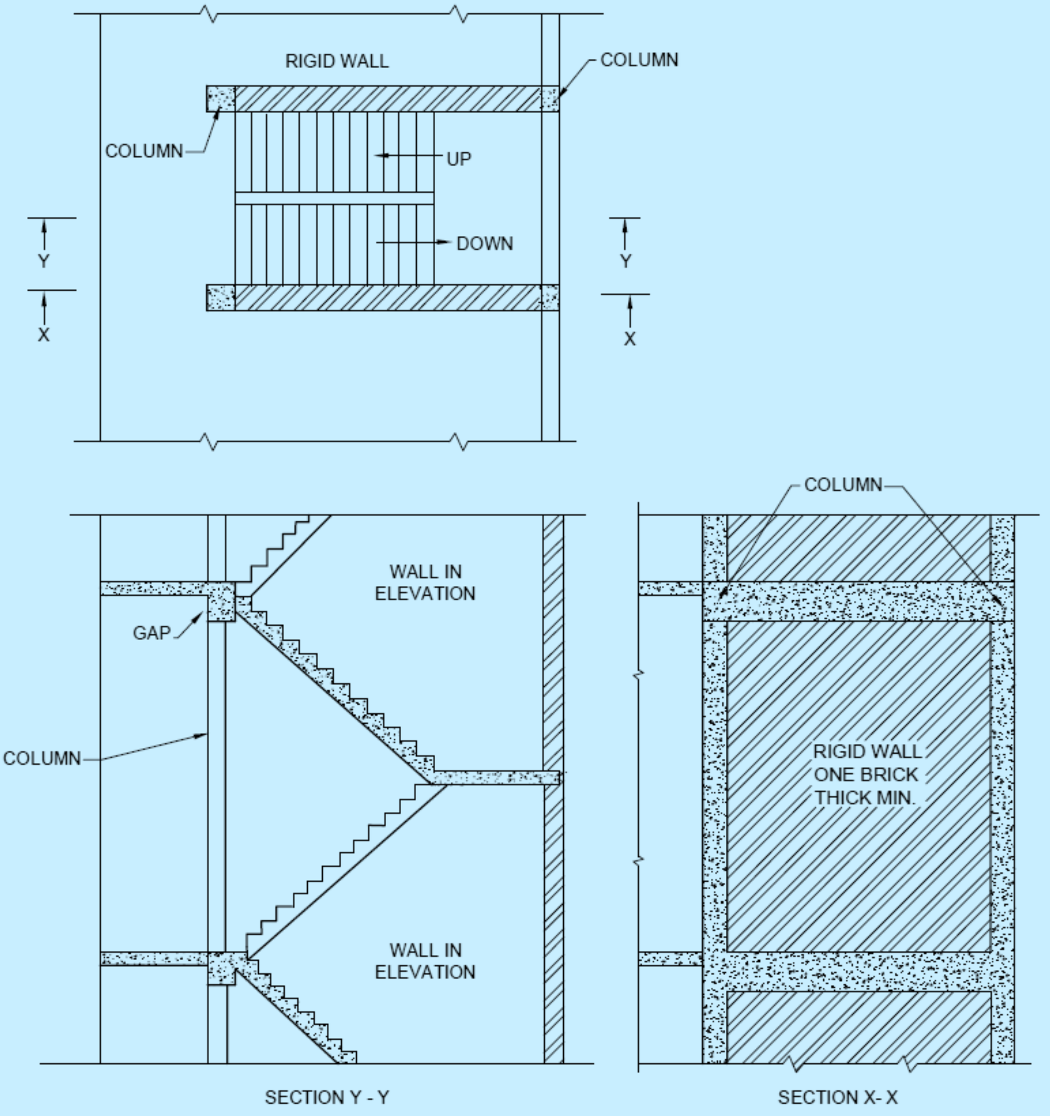
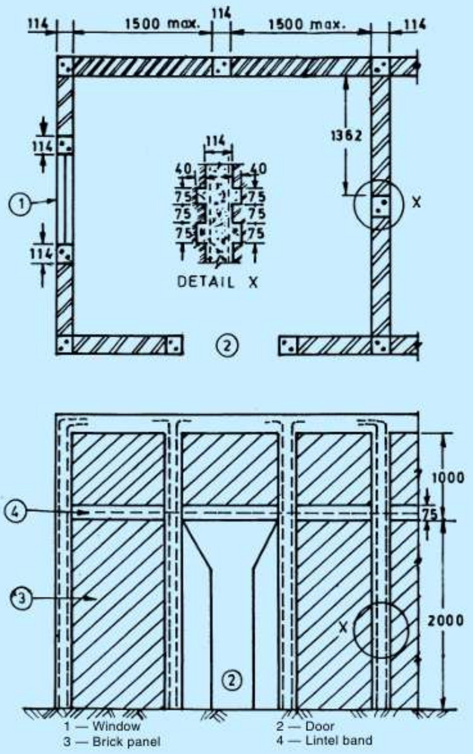

RIGID WALL
COLUMN
COLUMN
UP
DOWN
Y
X
Y
X
COLUMN
WALL IN ELEVATION
GAP
COLUMN
WALL IN ELEVATION
RIGID WALL ONE BRICK THICK MIN.
SECTION Y - Y
SECTION X- X

FIG. 19 RIGIDLY BUILT-IN STAIRCASE


114
1500 max.
114
1500 max.
114
1362
114
①
114
114
40
40
75
75
75
75
75
75
DETAIL X
X
②
④
③
1000
75
X
2000
②
1 — Window
3 — Brick panel
2 — Door
4 — Lintel band

All dimensions in millimeters.

FIG. 20 FRAMING OF THIN LOAD-BEARING BRICK WALLS

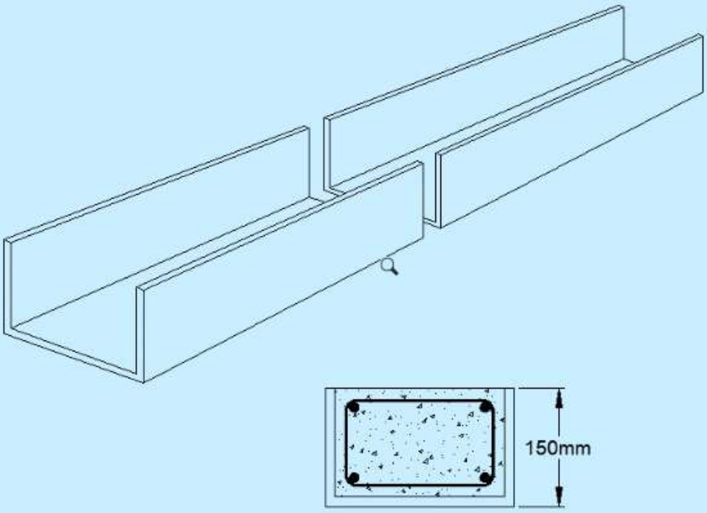


FIG. 21 U - BLOCKS FOR HORIZONTAL BANDS

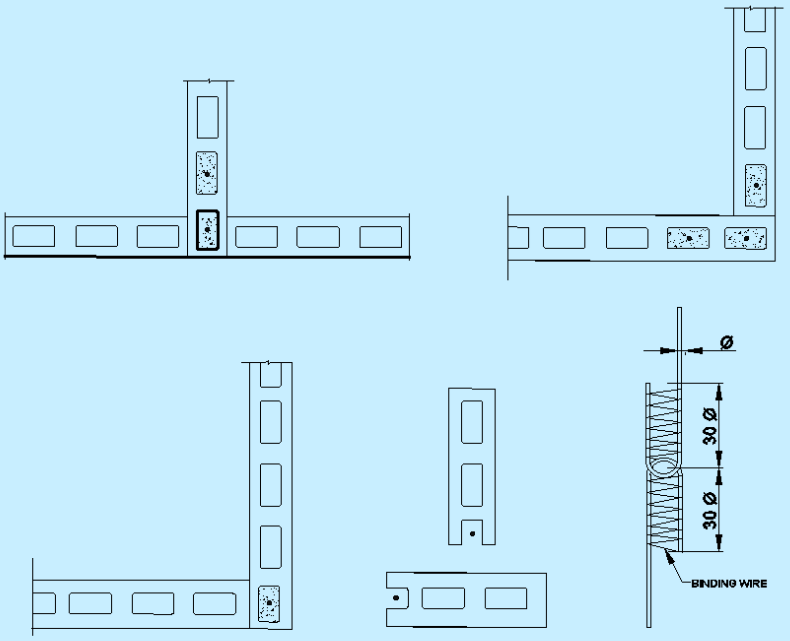


FIG. 22 VERTICAL REINFORCEMENT IN CAVITIES

Table 14 Permissible Stresses in Materials to be Used in the Design of Members of Masonry Buildings

(*Clauses* 8.4.1.1, 11.5 *and* 11.6.1)

Sl No.	**Compression**		**Tension**	**Shear**
	Axial	Axial and Flexural	Axial and Flexural	
(1)	(2)	(3)	(4)	(5)
Masonry Wall with Prescriptive Bands (MWB) Masonry Wall with Prescriptive Bands and Vertical Reinforcements (MWBR)				
i)	5.4.1 and Table 9 apply	Increase in permissible compressive stress permitted as per 5.4.1.4 applies	5.4.2 applies. Masonry walls subjected to in-plane bending and vertical loads shall be designed based on no-tension, permissible shear, and compressive stresses	5.4.3 applies.
Confined Masonry Wall (CMW)				
ii)	Compressive force in confined masonry due to axial load shall not exceed: $P_0 = k_s(0.25 f_m A_m + 0.65 f_s A_t + f_{co} A_c)$	Compressive stress in masonry due to combined action of axial load and bending shall not exceed 1.25 f_a	5.4.2 applies.	Allowable shear stress shall be according to 5.4.3
Reinforced Masonry Wall (RMW)				
iii)	Compressive force due to axial load shall not exceed: $P_0 = k_s(0.25 f_m A_m + 0.65 f_s A_t)$	Compressive stress in masonry due to combined action of axial load and bending shall not exceed 1.25f_a	5.4.2 applies.	For flexural members: a) without web reinforcement: $f_v = 0.083\sqrt{f_m}$ ≤ 0.75MPa

Table 14 (*Concluded*)

Table 14 Permissible Stresses in Materials to be Used in the Design of Members of Masonry Buildings

(*Clauses* 8.4.1.1, 11.5 *and* 11.6.1)

Sl No.	**Compression**		**Tension**	**Shear**
	Axial	Axial and Flexural	Axial and Flexural	
(1)	(2)	(3)	(4)	(5)
				b) with web reinforcement: $f_v = 0.25\sqrt{f_m} \le 0.75\text{MPa}$ For walls, shall be as per **5.4.3**

8.4.2 Bands and Vertical Elements

Masonry buildings, other than those with reinforced masonry walls and confined masonry walls, shall be provided with horizontal bands and vertical reinforcing elements:

a) the horizontal bands shall run along the full perimeter of the external and internal walls, within the full thickness of the walls; and

b) the vertical reinforcing elements shall pass through vertically at all corners and adjoining all openings (door, window, and ventilator).

8.4.2.1 *Types*

Five types of bands are admissible, namely:

a) Gable band (when masonry buildings have gable walls);

b) Roof band;

c) Lintel band;

d) Sill band; and

e) Plinth band.

8.4.2.2 *Geometry*

The width of RC band shall be same as the thickness of the wall. Wall thickness shall be at least 200 mm. A clear cover of 20 mm shall be maintained for the reinforcement.

The vertical thickness of RC Band shall be at least:

a) 75 mm, where two longitudinal bars are specified, one on each face; and

b) 150 mm, where four bars are specified, one at each corner.

8.4.2.3 *Ductile detailing*

The bands shall be made of reinforced concrete of grade not leaner than M25 or reinforced brickwork in cement mortar not leaner than 1 : 3. In coastal areas, the filling mortar with water proofing admixture shall be used.

8.4.3 *Floor Slabs*

The roof and floor slabs in MWBs, MWBR, CMBs and RMBs shall be designed as beam supported slabs as per the provisions of Part C/Section 5 of this NBCS.

8.4.4 *Building Structure Type*

Masonry buildings shall be categorized into four types (Table 15), namely Types B, C, D and E, based on the earthquake and the category of the building and the importance of building I, where I is importance factor applicable to the building. Type E buildings shall not be more than 3 storeys tall.

Table 15 Building Categories of Building for Earthquake Resisting Features

(*Clause* 8.4.4)

Sl No.	**Importance Factor**	**Earthquake Zone**			
		II	**III**	**IV**	**V**
(1)	(2)	(3)	(4)	(5)	(6)
i)	1.0	*B*	*C*	*D*	*E*
ii)	1.5	C	D	*E*	*E*

8.4.4.1 *Slenderness of walls*

The masonry walls shall meet the slenderness limit specified in Table 16.

Table 16 Allowable Effective Height to Effective Thickness Ratios of Unreinforced Masonry Walls

(*Clause* 8.4.4.1)

Sl No.	**Wall**	**Building Structure Type**			
		B	C	D	E
(1)	(2)	(3)	(4)	(5)	(6)
i)	MWB and MWBR	15	15	12	12
ii)	CMW	15	15	15	15
iii)	RMW	15	15	15	15
iv)	URM parapet walls	12	12	6	6

8.4.5 *Footings*

Strip footings under load bearing walls shall be designed as per the provisions of [C-4(8)] in conjunction with Part C/Section 1 of this NBCS.

8.5 Masonry Walls with Prescriptive Bands (MWB), and Masonry Walls with Prescriptive Bands and Vertical Reinforcement (MWBR)

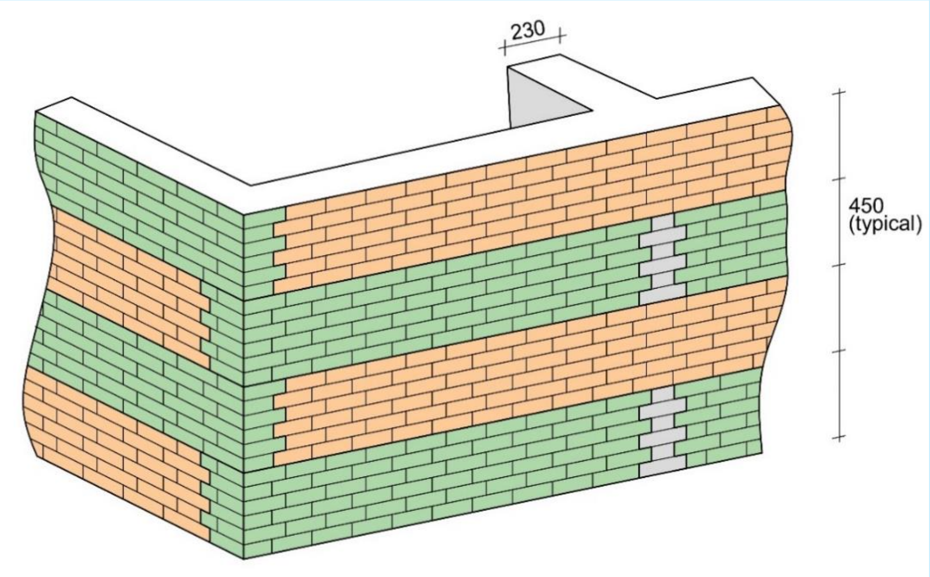
8.5.1 *Masonry Walls*

8.5.1.1 The bearing walls in both directions shall be straight and symmetrical in plan.

8.5.1.2 The wall panels formed between cross walls and floors, or roof shall be checked for their strength in bending as a plate or as a vertical strip subjected to the earthquake force acting on its own mass. This check need not be complied with in walls of 200 mm or larger thickness and of storey height less than 3.5 m

8.5.1.3 *Masonry bond*

For achieving full strength of masonry, the usual bonds specified for masonry should be followed so that the vertical joints are broken properly from course to course. To obtain full bond between perpendicular walls, it is necessary to make a slopping (stepped) joint by making the corners first to a height of 600 mm and then building the wall in between them. Otherwise, the toothed joint should be made in both the walls alternatively in lifts of about 450 mm (Fig. 23).



All dimensions in millimetres.

FIG. 23 ALTERNATING TOOTHED JOINTS IN WALLS AT CORNER AND T-JUNCTION

8.5.2 *Openings in Bearing Walls*

8.5.2.1 Door and window openings reduce the lateral load resistance of walls, and hence, should preferably be small and more centrally located in the wall panels. The guidelines on the size and position of opening are given in Table 17 and Fig. 24.

8.5.2.2 Openings in any storey shall have their top at the same level to accommodate a continuous band over them, including the lintels throughout the building. In addition, openings in different storeys in a masonry wall shall be vertically aligned, and not staggered.

8.5.2.3 Where openings do not comply with the guidelines of Table 17, they shall be strengthened by providing reinforced concrete or reinforcing the brickwork (Fig. 25) with high strength deformed bars of 8 mm diameter but the quantity of steel shall be increased at the jambs to comply with **8.5.3.9**, if so required.

8.5.2.4 If a window or ventilator is to be projected out, the projection shall be in reinforced masonry or concrete and well anchored.

8.5.2.5 If an opening is tall (from bottom to almost top of a storey, thus dividing the wall into two portions), the adjoining portions shall be reinforced with horizontal reinforcement of 6 mm diameter bars at not more than 450 mm intervals, one on inner and one on outer face, properly tied to vertical steel at jambs, corners or junction of walls, where used.

8.5.2.6 The use of arches to span over the openings is a source of weakness and shall be avoided. When compelled to use, steel ties shall be provided.

8.5.3 *Earthquake Strengthening Arrangements*

8.5.3.1 All masonry buildings shall be strengthened by the methods specified for different types of buildings, as listed in Table 18, and detailed in subsequent clauses. Fig. 26 and Fig. 27 show, schematically, the overall strengthening arrangements to be adopted for types D and E buildings, which consist of horizontal bands of reinforcement at critical levels, vertical reinforcing bars at corners, junctions of walls and jambs of openings.

In four-storey buildings of type B, the requirements of vertical steel may be checked through an earthquake analysis using a design horizontal acceleration coefficient equal to 4 times that given in **5** of Part C/Section 1 of this NBCS. If this analysis shows that vertical steel is not required, the designer may take the decision accordingly.

Table 17 Size and Position of Openings in Bearing Walls

(*Clauses* 8.5.2.1, 8.5.2.3 *and* Fig. 24)

Sl No.	**Position of Opening**	**Details of Opening**		
		B	**C**	**D, E**
(1)	(2)	(3)	(4)	(5)
i)	Minimum Distance b_5 (mm) from inside corner of outside wall	0	230	450
ii)	Total length of openings shall be such that the ratio $(b_1 + b_2 + b_3)/l_1$ or $(b_6 + b_7)/l_2$ does not exceed:			
	a) 1-storeyed building	0.60	0.55	0.50
	b) 2-storeyed building	0.50	0.46	0.42
	c) 3- or 4-storeyed building	0.42	0.37	0.33
iii)	Minimum width b_4 (mm) of pier between consecutive openings	340	450	560
iv)	Minimum vertical distance h_3 (mm) between two openings (one above the other)	600	600	600
v)	Maximum Width b_8 (mm) of opening of ventilator	900	900	900

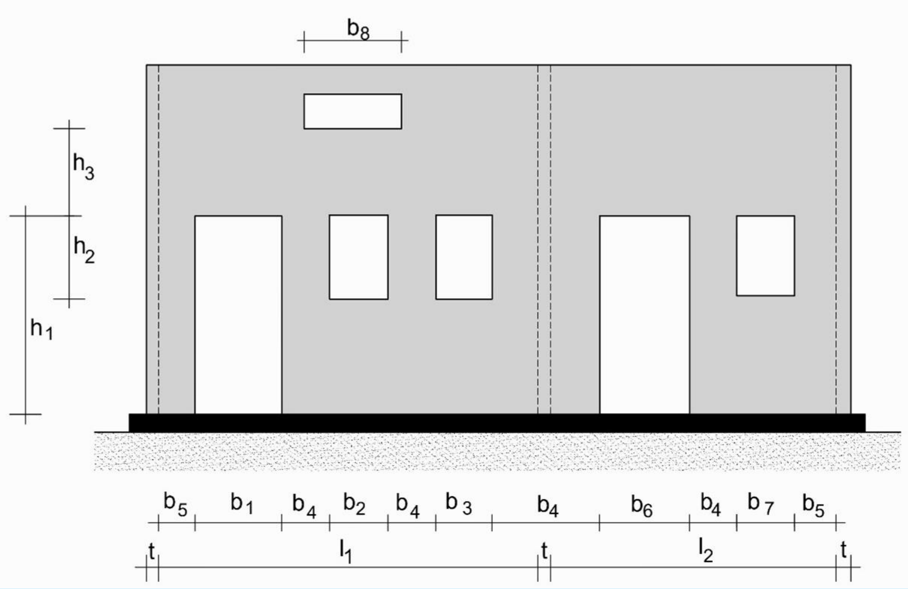


FIG. 24 DIMENSIONS OF OPENINGS AND PIERS FOR RECOMMENDATIONS IN TABLE 17

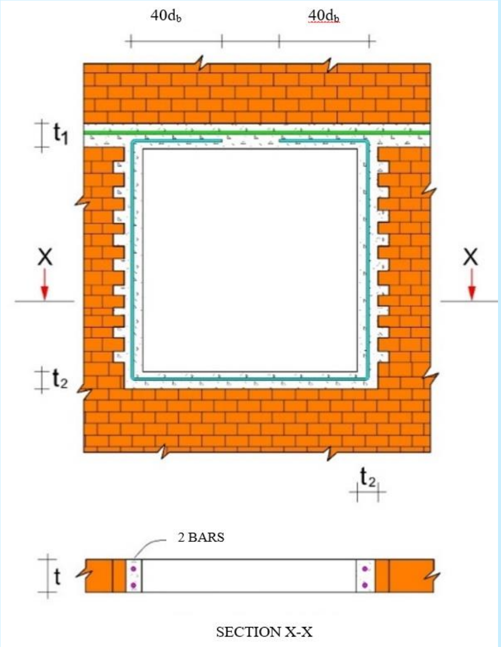


FIG. 25 STRENGTHENING MASONRY AROUND AN OPENING

Table 18 Measures Recommended in Masonry Buildings Made with Rectangular Masonry Units

(*Clauses* 8.3.7.1, 8.5.3.1 *and* 8.6.2.3)

Sl No. (1)	Structure Type (2)	Number of Storeys (3)	Measures to be Provided in all Storeys (4)
i)	B	1 to 3	a, b, c, f, g
		4	a, b, c, d, f, g
ii)	C	1 and 2	a, b, c, f, g
		3 and 4	a, b, c, d, e, f, g
iii)	D	1 and 2	a, b, c, d, e, f, g
		3 and 4	a, b, c, d, e, f, g, h
iv)	E	1 to 3	a, b, c, d, e, f, g, h

where

a = masonry mortar (as per **5.4.6**);

b = lintel band (as per **8.5.3.2**);

c = roof band and gable band where necessary (as per **8.5.3.3** and **8.5.3.4**, respectively);

d = vertical steel at corners and junctions of walls (as per **8.5.3.8**);

e = vertical steel at jambs of openings (as per **8.5.3.9**);

f = bracing in plan at tie level of roofs;

g = plinth band where necessary (as per **8.5.3.6**); and

h = dowel bars (as per **8.5.3.7**).

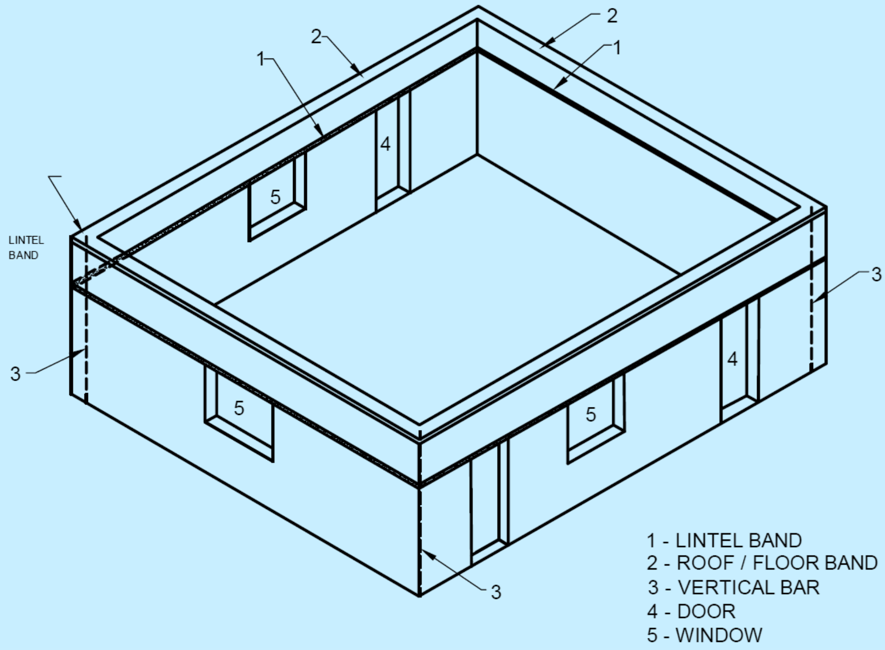

2
1
2
1
4
5
LINTEL BAND
3
3
4
5
5
3
1 - LINTEL BAND
2 - ROOF / FLOOR BAND
3 - VERTICAL BAR
4 - DOOR
5 - WINDOW

FIG. 26 OVERALL ARRANGEMENT OF REINFORCING MASONRY BUILDINGS

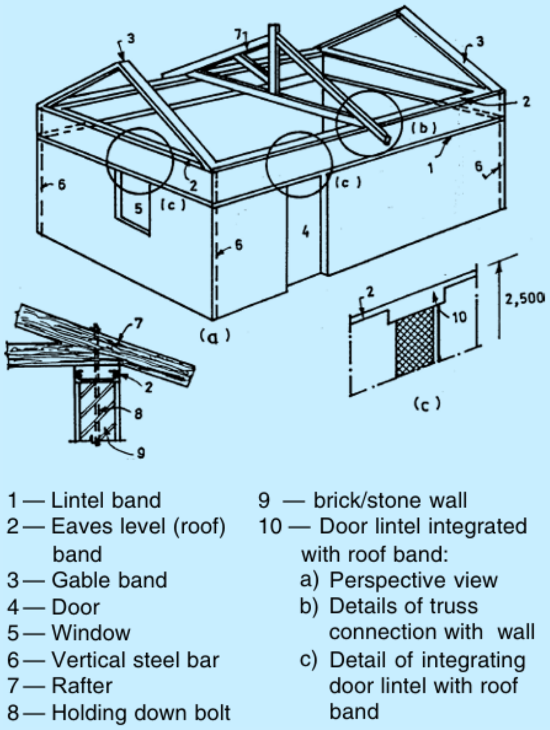

3
7
3
2
(b)
1
6
6
2
5
(c)
(c)
6
4
(a)
2
10
2,500
(c)
7
2
8
9
1 — Lintel band
2 — Eaves level (roof) band
3 — Gable band
4 — Door
5 — Window
6 — Vertical steel bar
7 — Rafter
8 — Holding down bolt
9 — brick/stone wall
10 — Door lintel integrated with roof band:
a) Perspective view
b) Details of truss connection with wall
c) Detail of integrating door lintel with roof band

FIG. 27 OVERALL ARRANGEMENT OF REINFORCING MASONRY BUILDING HAVING PITCHED ROOF

8.5.3.2 Lintel band shall be provided at the lintel level on all load bearing internal, external longitudinal and cross walls, as per **8.5.3.5**. This band provided in panel or partition walls improves their stability during strong earthquake shaking.

8.5.3.3 Roof band shall be provided immediately below the roof or floors. The specifications of the band are given in **8.5.3.5**. Such a band need not be provided underneath reinforced concrete or brick-work slabs resting on bearing walls, provided that the slabs are continuous over the intermediate wall up to the crumple sections, if any, and cover the width of end walls, fully or at least three-fourths of the wall thickness.

8.5.3.4 Gable band is provided at the top of gable masonry below the purlins. The specifications of the band are given in **8.5.3.5**. This band shall be made continuous with the roof band at the eaves level.

8.5.3.5 *Section and reinforcement of band*

8.5.3.5.1 The band shall be as per **8.4.2**.

8.5.3.5.2 The bands shall be of the full width of the wall not less than 75 mm in depth and reinforced with longitudinal steel (Table 19). The longitudinal steel bars shall be held in position by steel links or stirrups 6 mm diameter spaced 150 mm apart. With respect to Table 19:

a) span of wall shall be the distance between centrelines of its cross walls or buttresses. For spans greater than 8 m intermediate pilasters or buttresses shall be provided or the adequacy of such long-span walls shall be ascertained through detailed analysis and full-scale test.

b) the numbers and diameter of bars given above pertain to high strength deformed bars.

c) the geometry of the bands shall be as per **8.4.2.2**.

d) concrete used in the bands shall be as per **8.3.4**.

e) the longitudinal steel bars shall be held in position by steel links or stirrups 6 mm diameter spaced at maximum 150 mm apart.

8.5.3.5.3 In reinforced brickwork, the thickness of joints containing steel bars shall be increased to have at least a minimum mortar cover of 10 mm around the bar. In bands of reinforced brickwork, the area of steel provided should be at least equal to that specified in Table 19.

8.5.3.5.4 For full integrity of walls at corners and junctions of walls and effective horizontal bending resistance of bands continuity of reinforcement is essential. The details as shown in Fig. 28 are recommended.

Table 19 Recommended Longitudinal Steel in Reinforced Concrete Bands

(*Clauses* 8.3.7.2, 8.5.3.5.2 *and* 8.5.3.5.3)

Sl No.	Span	Building Structure Type							
		B		C		D		E	
		Number of bars	Diameter	Number of bars	Diameter	Number of bars	Diameter	Number of bars	Diameter
	m		mm		mm		mm		mm
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
i)	5 or less	2	8	2	8	2	8	2	10
ii)	6	2	8	2	8	2	10	2	12
iii)	7	2	8	2	10	2	12	4	10
iv)	8	2	10	2	12	4	10	4	12

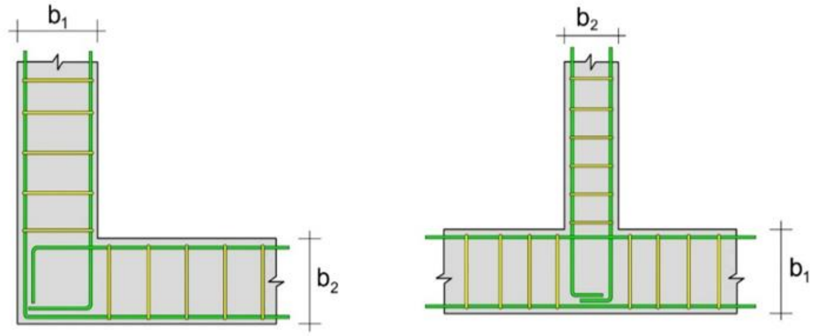
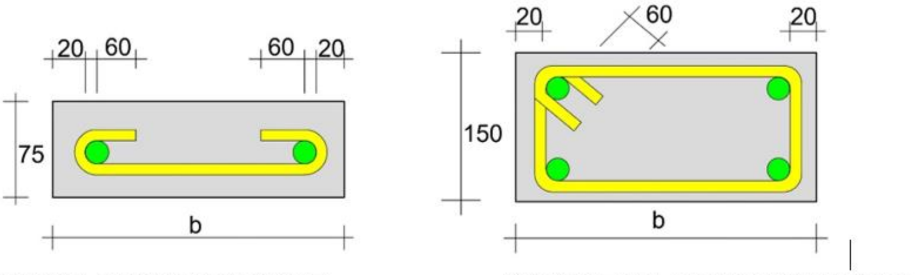


FIG. 28(A) DETAILS AT CORNER JOINT

FIG. 28(B) DETAILS AT T-JUNCTION



28(C) DETAILS AT BAND WITH 2 BARS

28(D) DETAILS AT BAND WITH 4 BARS

FIG. 28 REINFORCEMENT AND BENDING DETAIL IN RC BAND

8.5.3.6 Plinths band is provided at plinth level of walls on top of the foundation wall. This is to be provided where strip footings of masonry (other than reinforced concrete or reinforced masonry) are used and the soil is either soft or uneven in its properties. Where used, its section may be kept the same as in **8.5.3.5**. This band shall serve as damp proof course as well.

8.5.3.7 In Type D and E buildings, to further enhance the box action of walls, steel dowel bars may be used at corners and T-junctions of walls at the sill level of windows to length of 900 mm from the inside corner in each wall. Such dowel may be in the form of U stirrups 8 mm diameter. Where used, such bars must be laid in 1 : 3 cement sand mortar with a minimum clear cover of 10 mm on all sides to minimize corrosion.

8.5.3.8 *Vertical reinforcement*

Vertical steel at corners and junctions of walls, which are up to 340 mm (1½ brick) thick, shall be provided as specified in Table 20. For walls thicker than 340 mm, the area of the bars shall be proportionately increased. With respect to Table 20:

a) the diameters given above are for reinforcing steels of grade Fe415 or higher; and

b) typical details of providing vertical steel in brickwork masonry with rectangular solid units at corners and T-junctions are shown in Fig. 29. The vertical bars shall be covered with concrete of grade M20 or 1 : 3 mortar in suitably created pockets around the bars (Fig. 29). This shall ensure their safety from corrosion and good bond with masonry.

Table 20 Diameter (mm) of Single Vertical Steel Reinforcement in Masonry Walls with Rectangular Masonry Units

(*Clause* 8.5.3.8, 8.5.3.9 *and* 8.6.2.3)

Sl No.	Number of Storeys	Storey	Buildings Structure Type			
			Type B	Type C	Type D	Type E
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	1	—	Nil	Nil	10	12
ii)	2	Top	Nil	Nil	10	12
		Bottom	Nil	Nil	12	16
iii)	3	Top	Nil	10	10	12
		Middle	Nil	10	12	16
		Bottom	Nil	12	12	16
iv)	4	Top	10	10	10	Not permitted
		Third	10	10	12	
		Second	10	12	16	
		Bottom	12	12	20	

8.5.3.8.1 The vertical reinforcement shall be properly embedded in the plinth masonry of foundations and roof slab or roof band to develop its tensile strength in bond. It shall pass through the lintel bands and floor slabs or floor level bands in all storeys.

8.5.3.8.2 Bars in different storeys shall be lapped as per the requirements of Part C/Section 5 of this NBCS.

8.5.3.9 Vertical reinforcement of jambs of window and door openings shall be provided as per Table 20. It may start from the foundation of floor and terminate in lintel band (Fig. 29).

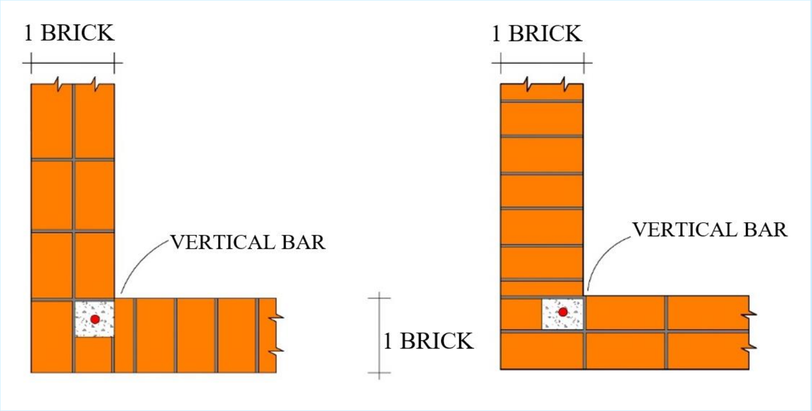


FIG. 29(A) SINGLE BRICK WALL CORNER JOINT DETAIL

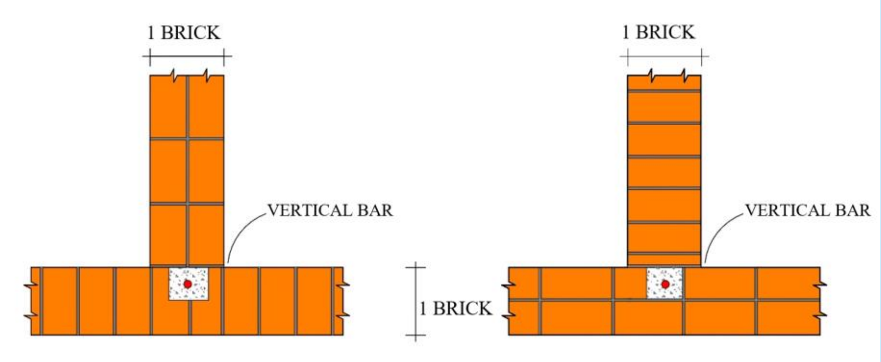


FIG. 29(B) SINGLE BRICK WALL T-JOINT DETAIL

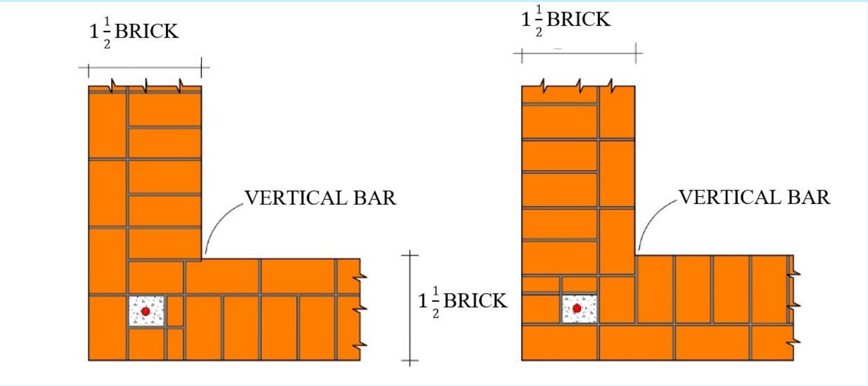


FIG. 29(C) 1½ BRICK WALL CORNER JOINT DETAIL

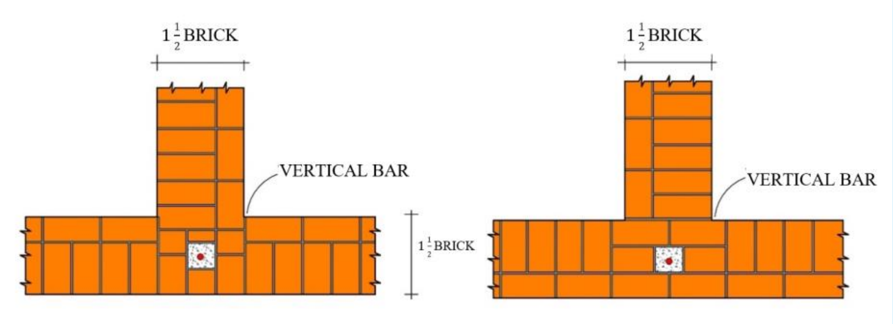


FIG. 29(D) 1½ BRICK WALL T-JOINT DETAIL

FIG. 29 TYPICAL DETAILS OF PROVIDING VERTICAL STEEL BARS IN BRICK MASONRY

8.6 Floors/Roofs with Small Precast Components

8.6.1 *Types of Precast Floors/Roofs*

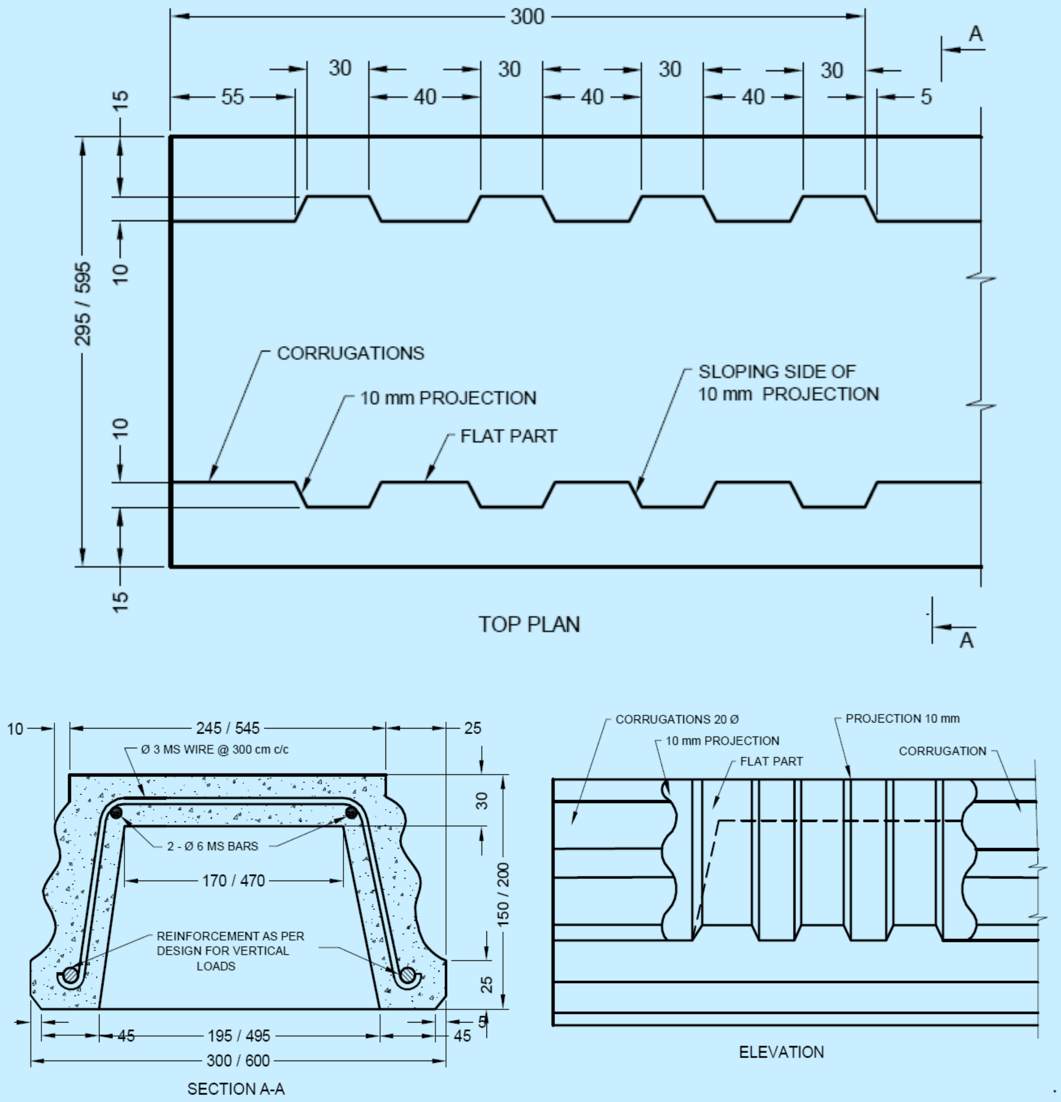
Earthquake resistance measures for floors and roofs with small precast components, as covered in this Section, have been dealt with as typical examples.

8.6.1.1 *Precast reinforced concrete unit roof/floor*

The unit is a precast reinforced concrete component, channel (inverted trough) shaped in section (*see* Fig. 30). The nominal width of the unit varies from 300 mm to 600 mm, its height from 150 mm to 200 mm and a minimum flange thickness of 30 mm. Length of unit shall vary according to room dimensions, but the maximum length is restricted to 4.2 m from stiffness considerations. Horizontal corrugations are provided on the two longitudinal faces of the units so that the structural roof/floor acts monolithic after concrete grouted in the joints between the units attains strength (*see* Fig. 31).

8.6.1.2 *Precast reinforced concrete cored unit roof/floor*

The unit is a reinforced concrete component having a nominal width of 300 to 600 mm and thickness of 130 to 150 mm having two circular hollows 90 mm diameter, throughout the length of the unit (*see* Fig. 32). The minimum flange/web thickness of the unit shall be 20 mm. Length of unit varies according to room dimensions, but the maximum length shall be restricted to 4.2 m from stiffness considerations. Horizontal corrugations are provided on the two longitudinal faces of the units so that the structural roof/floor acts monolithic after concrete grouted in the joints between the units attains strength (*see* Fig. 33).


300
55
30
40
30
40
30
40
30
5
A
15
10
295 / 595
10
15
CORRUGATIONS
10 mm PROJECTION
FLAT PART
SLOPING SIDE OF 10 mm PROJECTION
TOP PLAN
A
10
245 / 545
25
Ø 3 MS WIRE @ 300 cm c/c
2 - Ø 6 MS BARS
170 / 470
REINFORCEMENT AS PER DESIGN FOR VERTICAL LOADS
30
150 / 200
25
45
195 / 495
45
5
300 / 600
SECTION A-A
CORRUGATIONS 20 Ø
10 mm PROJECTION
FLAT PART
PROJECTION 10 mm
CORRUGATION
ELEVATION

All dimensions in millimetres

FIG. 30 CHANNEL UNITS

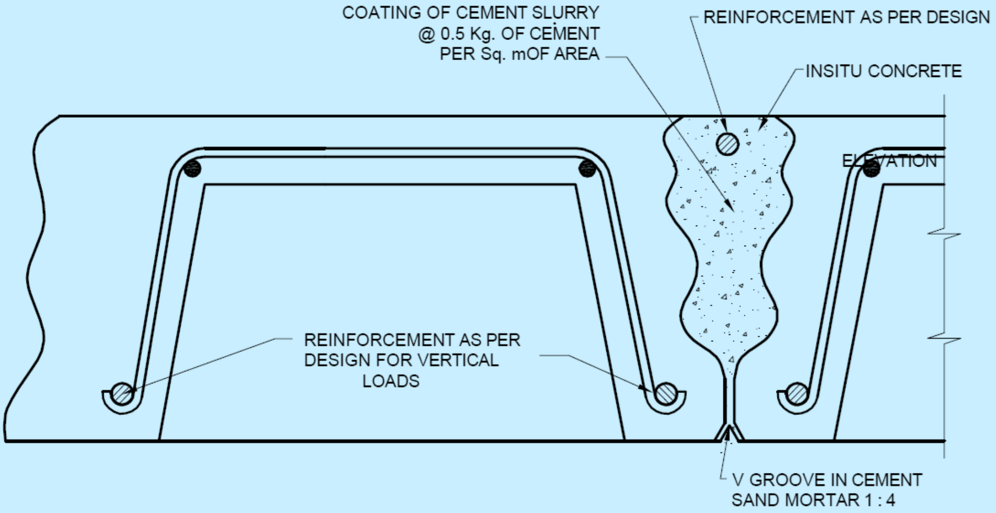
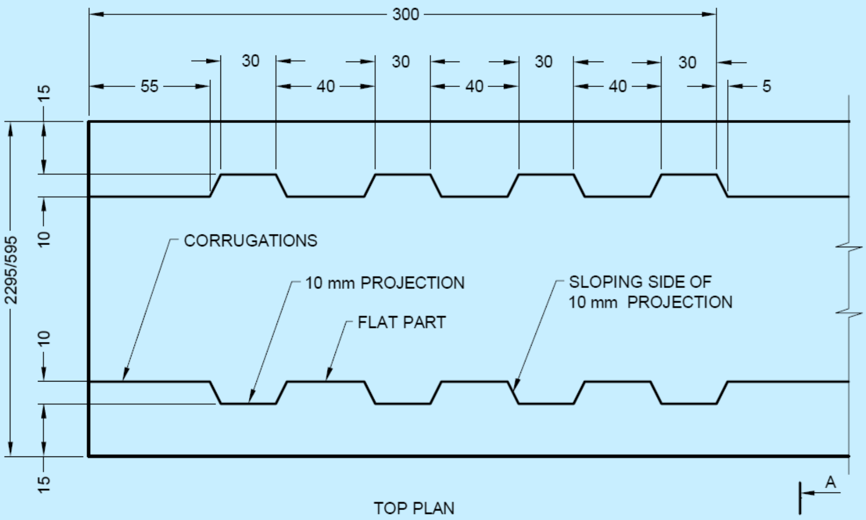
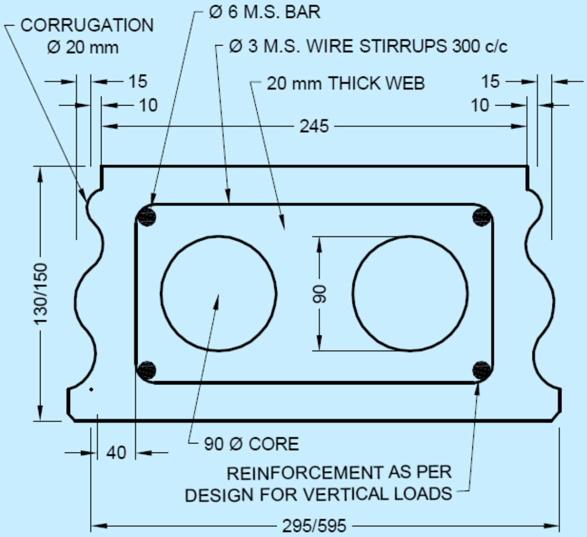

COATING OF CEMENT SLURRY @ 0.5 Kg. OF CEMENT PER Sq. mOF AREA
REINFORCEMENT AS PER DESIGN
INSITU CONCRETE
ELEVATION
REINFORCEMENT AS PER DESIGN FOR VERTICAL LOADS
V GROOVE IN CEMENT SAND MORTAR 1 : 4

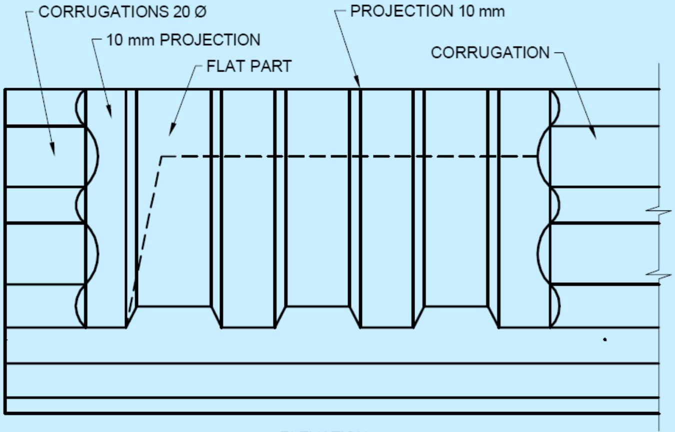
FIG. 31 CHANNEL UNITS


300
55
30
40
30
40
30
40
30
5
15
10
10
15
2295/595
CORRUGATIONS
10 mm PROJECTION
FLAT PART
SLOPING SIDE OF 10 mm PROJECTION
A

TOP PLAN


CORRUGATION Ø 20 mm
Ø 6 M.S. BAR
Ø 3 M.S. WIRE STIRRUPS 300 c/c
15
10
20 mm THICK WEB
15
10
245
130/150
90
40
90 Ø CORE
REINFORCEMENT AS PER DESIGN FOR VERTICAL LOADS
295/595

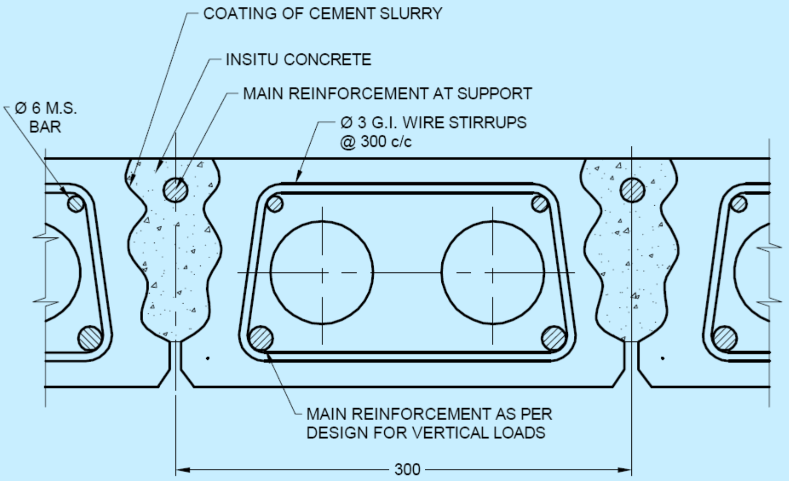
SECTION A - A


CORRUGATIONS 20 Ø
10 mm PROJECTION
FLAT PART
PROJECTION 10 mm
CORRUGATION

ELEVATION

All dimensions in millimetres

FIG. 32 CORE UNITS


COATING OF CEMENT SLURRY
INSITU CONCRETE
MAIN REINFORCEMENT AT SUPPORT
Ø 6 M.S. BAR
Ø 3 G.I. WIRE STIRRUPS @ 300 c/c
MAIN REINFORCEMENT AS PER DESIGN FOR VERTICAL LOADS
300

All dimensions in millimeteres.

FIG. 33 CORED, UNIT FLOOR

8.6.1.3 *Precast reinforced concrete plank and joist scheme for roof/floor*

The scheme consists of precast reinforced concrete planks supported on partially precast reinforced concrete joists. The reinforced concrete planks are 300 mm wide and the length varies according to the spacing of the joists, but it shall not exceed 1.5 m (*see* Fig. 34). To provide monolithic property to the roof/floor and to have T-beam effect with the joists, the planks shall be made partially 30 mm thick and the partially 60 mm thick and *in-situ* concrete shall be filled in the depressed portions to complete the roof/floor structurally (*see* Fig. 35).

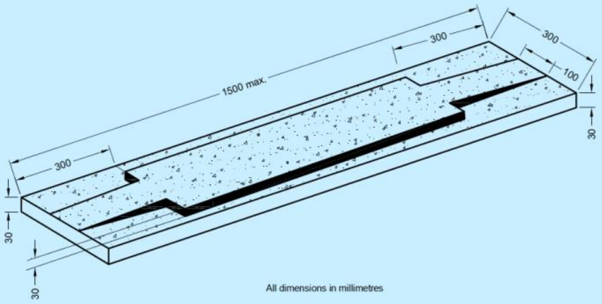
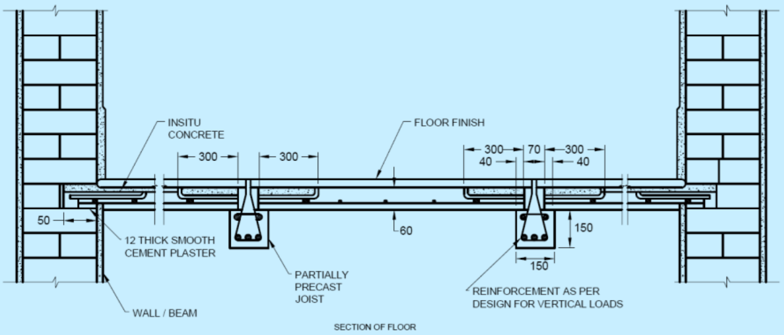

1500 max.
300
300
300
100
30
30
30
All dimensions in millimetres

FIG. 34 PRECAST REINFORCED PLANK

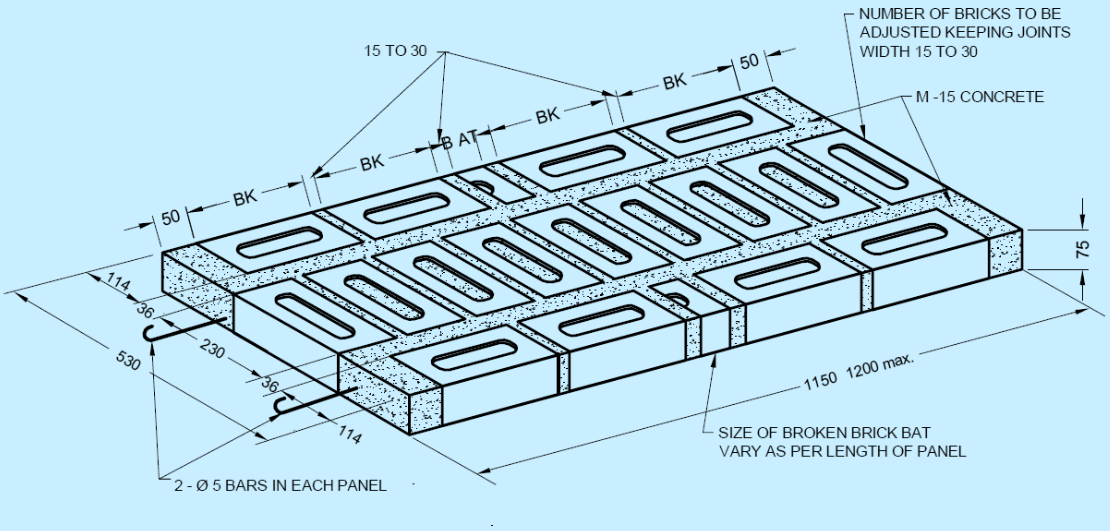

INSITU CONCRETE
FLOOR FINISH
300
300
300
70
300
40
40
50
60
150
150
12 THICK SMOOTH CEMENT PLASTER
PARTIALLY PRECAST JOIST
REINFORCEMENT AS PER DESIGN FOR VERTICAL LOADS
WALL / BEAM
SECTION OF FLOOR

All dimensions in millimeteres.

FIG. 35 PRECAST REINFORCED PLANK FLOOR

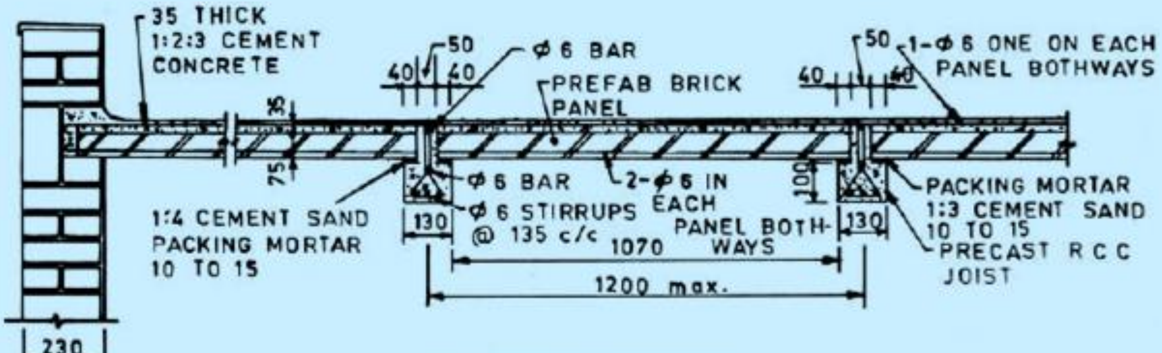
8.6.1.4 *Prefabricated brick panel system for roof/floor*

It consists of prefabricated reinforced brick panels (*see* Fig. 36) supported on Precast reinforced concrete joists with nominal reinforced 35 mm thick structural deck concrete over the brick panels and joists (*see* Fig. 37). The width of the brick panels shall be 530 mm for panels made of bricks of conventional size and 450 mm for panels made of bricks of modular size. The thickness of the panels shall be 75 mm or 90 mm, respectively depending upon whether conventional or modular bricks are used. The length of the panels shall vary depending upon the spacing of the joists, but the maximum length shall not exceed 1.2 m.


NUMBER OF BRICKS TO BE ADJUSTED KEEPING JOINTS WIDTH 15 TO 30
15 TO 30
50
BK
BK
BK
B AT
BK
BK
50
M -15 CONCRETE
75
114
36
230
36
114
530
1150
1200 max.
SIZE OF BROKEN BRICK BAT VARY AS PER LENGTH OF PANEL
2 - Ø 5 BARS IN EACH PANEL

All dimensions in millimeteres.

FIG. 36 PREFAB BRICK PANEL

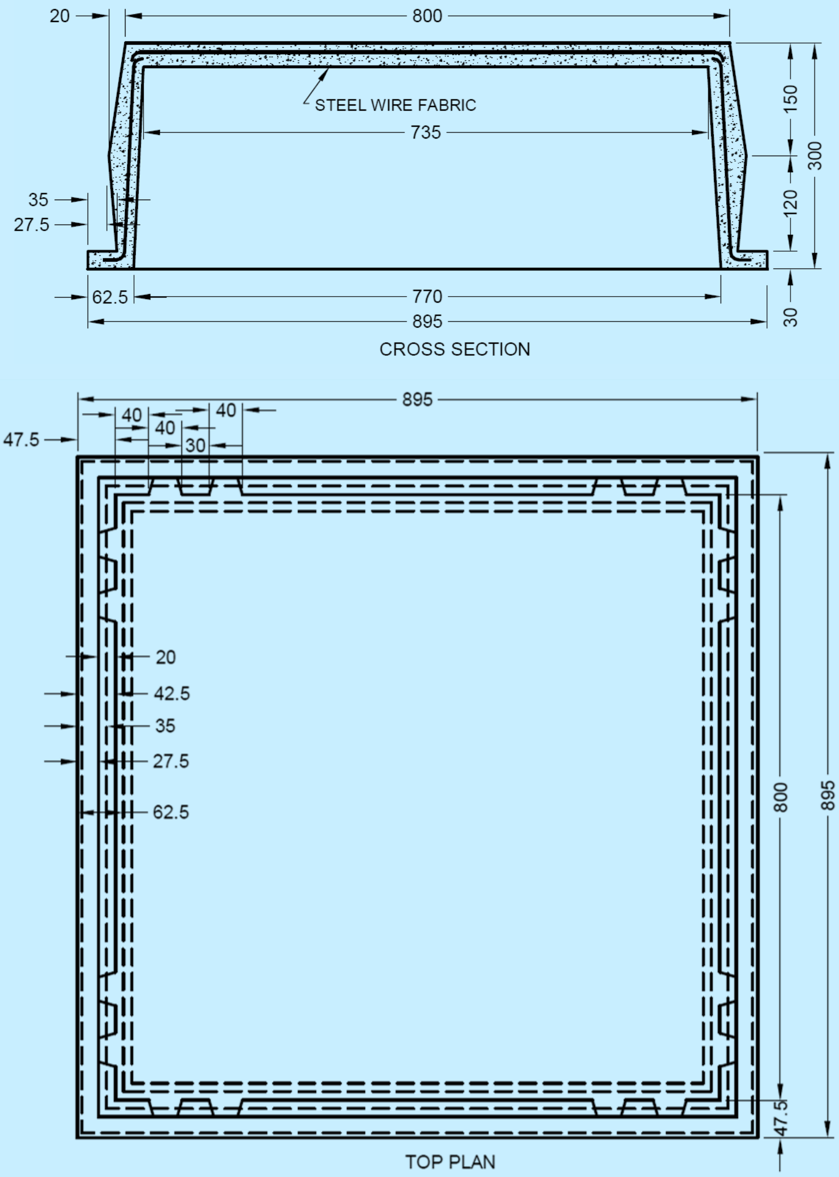

35 THICK 1:2:3 CEMENT CONCRETE
50
40
40
Φ 6 BAR
PREFAB BRICK PANEL
50
1-Φ 6 ONE ON EACH PANEL BOTHWAYS
40
40
35
75
Φ 6 BAR
Φ 6 STIRRUPS @ 135 c/c
2-Φ 6 IN EACH PANEL BOTH-WAYS
100
1:4 CEMENT SAND PACKING MORTAR 10 TO 15
130
1070
130
1200 max.
PACKING MORTAR 1:3 CEMENT SAND 10 TO 15
PRECAST R C C JOIST
230

All dimensions in millimetres.

FIG. 37 BRICK PANEL FLOOR

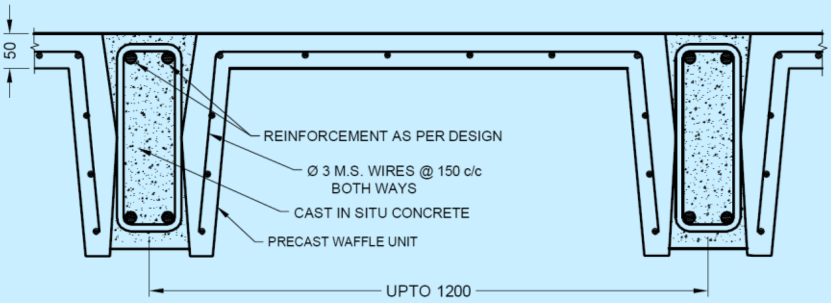
8.6.1.5 *Precast reinforced concrete waffle unit roof/floor*

Waffle units are of the shape of inverted troughs, square or rectangular in plan, having lateral dimensions up to 1.2 m and depth depending upon the span of the roof/floor to be covered (*see* Fig. 38 and Fig. 39). The minimum thickness of flange/web shall be 35 mm. Horizontal projections may be provided on all the four external faces of the unit and the unit shall be so shaped that it shall act monolithic with *in-situ* concrete to ensure load transfer. Vertical castellation, called shear keys, shall be provided on all the four external faces of the precast units to enable them to transfer horizontal shear force from one unit to adjacent unit through *in-situ* concrete filled in the joints between the units. The waffle units shall be laid in a grid pattern with gaps between two adjacent units, and reinforcement, as per design, and structural concrete shall be provided in the gaps between the units in both the directions. The scheme is suitable for two way spanning roofs and floors of buildings having large spans.


20
800
STEEL WIRE FABRIC
735
150
300
120
35
27.5
62.5
770
895
30
CROSS SECTION
895
40
40
40
30
47.5
20
42.5
35
27.5
62.5
800
895
47.5
TOP PLAN

All dimensions in millimeteres.

Fig. 38 Waffle Units


50
REINFORCEMENT AS PER DESIGN
Ø 3 M.S. WIRES @ 150 c/c
BOTH WAYS
CAST IN SITU CONCRETE
PRECAST WAFFLE UNIT
UPTO 1200

All dimensions in millimeteres.

Fig. 39 Waffle Unit Floor

8.6.2 *Seismic Resistance Measures*

8.6.2.1 All floors and roofs to be constructed with small precast components shall be strengthened as specified for various categories of buildings in Table 21. The strengthening measures are detailed in **8.6.2.3** and **8.6.2.8**.

8.6.2.2 Vertical castellation, called shear keys, shall be provided on the longitudinal faces of the channel, cored and waffle units to enable them to transfer horizontal shear force from one unit to the adjacent unit through the *in-situ* concrete filled in the joints between the units. The minimum percentage of area of shear keys as calculated below, on each face of the unit, shall be 15.

Shear keys shall have a minimum width of 40 mm at its root with the body of the component and shall be to the full height of the component and preferably at uniform spacing. Percentage of area of shear keys shall be calculated as:

$$\frac{\text{No. of shear keys on one face of the component } \times 40}{\text{Length of the face of the component, in mm}} \times 100$$

Table 21 Strengthening Measures for Floors/Roofs with Small Precast Components

(*Clauses* 8.6.2.1, 8.6.2.4, 8.6.2.5, 8.6.2.6, 8.6.2.7 *and* 8.6.2.8)

Sl No.	Building Category	Number of Storeys	Strengthening to be Provided in Floor/Roof with			
			Channel/Cored Unit	R.C. Planks and Joists	Brick Panels and Joists	Waffle Units
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	B	1 to 34	aa, c	aa, c	aa, d	aa
ii)	C	1 and 2	a, ba, b, c	aa, c	aa, d	aa, e
		3 and 4				
iii)	D	1 to 4	a, b c	a, c	a, d	a, c, e
iv)	E	1 to 3	a, b, c	a, c	a, d	a, c, e

NOTES

1 Tie beam as per **8.6.2.3**;

2 Reinforcing bars of precast unit and tied to tie beam reinforcement as per **8.6.2.4**;

3 Reinforced deck concrete as per **8.6.2.5**;

4 Reinforced deck concrete as per **8.6.2.6**; and

5 Reinforced bars in joint between precast waffle units tied to tie beam reinforcement as per **8.6.2.7**.

8.6.2.3 Tie beam (*see* Table 20) is a beam provided all round the floor or roof to bind together all the precast components to make it a diaphragm. The beams shall be to the full width of the supporting wall or beam less the bearing of the precast components. The depth of the beam shall be equal to the depth of the precast components plus the thickness of structural deck concrete, where used over the components. The beam shall be made of cement concrete of grade not leaner than M15 and shall be reinforced as indicated in Table 18. If depth of tie is more than 75 mm, equivalent reinforcement shall be provided with one bar of minimum diameter 8 mm at each corner. Tie beams shall be provided on all longitudinal and cross walls. Typical details of the beams are shown in Fig. 40 to Fig. 44.

NOTE — Adequate edge support say 60 mm, shall be provided to precast element on the wall so as to avert its slippage during seismic ground motion.

8.6.2.4 Top reinforcement in the channel or cored units (*see* Table 21) shall be projected out at both the ends for anchorage length and tied to tie beam reinforcement.

8.6.2.5 Structural deck concrete (*see* Table 21) of grade not leaner than M15 shall be provided over precast components or act monolithic. Wherever, deck concrete is to be provided, the top surface of the components shall be finished rough. Cement slurry with 0.5 kg of cement/m^2 of the surface area shall be applied over the components immediately before laying the deck concrete and the concrete shall be compacted using plate vibrators. The minimum thickness of deck concrete shall be 35 mm or 40 mm reinforced with 6 mm diameter bars and 150 mm apart both ways and anchored into the tie beam placed all round. The maximum size of coarse aggregate used in deck concrete shall not exceed 12 mm.

NOTE — Under conditions of economic constraints, the deck concrete itself could serve as floor finish. The concrete is laid in one operation (*see* Fig. 44) without joints.

8.6.2.6 The deck concrete normally used over the brick panel with joist floor shall be reinforced with 6 mm diameter bars spaced 150 mm apart both ways (*see* Table 21).

8.6.2.7 For floors/roofs with precast waffle units, two 16 mm diameter high strength deformed bars shall be provided as top reinforcement in the joints between waffle units, in addition to reinforcement required for taking bending moment for vertical loads. This reinforcement (*see* Table 21) shall be fixed to tie beam reinforcement.

8.6.2.8 In case of floors/roofs with precast components other than those indicated in Table 21, the buildings shall be analysed for maximum expected seismic forces and the floor/roof shall be designed to act as diaphragm and take care of the resulting forces.

8.7 Timber Construction

8.7.1 Timber has higher strength per unit weight and is, therefore, very suitable for earthquake resistant construction. Materials, design and construction in timber shall generally conform to good practice [C-4(9)].

8.7.2 Timber (with masonry in-fill) construction shall generally be restricted to two storeys with or without the attic floor.

8.7.3 In timber (with masonry in-fill) construction attention shall be paid to fire safety against electric short circuiting, kitchen fire, etc.

8.7.4 The superstructure of timber buildings shall be made rigid against deformations by adopting suitable construction details at the junctions of the framing members and in wall panels as given in **8.7.6** to **8.7.10** so that the construction as a whole behaves as one unit against earthquake forces.

8.7.5 *Foundations*

8.7.5.1 Timber construction shall preferably start above the plinth level, the portion below shall be in masonry or concrete.

8.7.5.2 The superstructure may be connected with the foundation in one of the two ways as given below:

a) The superstructure may simply rest on the plinth masonry, or in the case of small buildings of one storey having plan area less than about 50 m^2, it may rest on firm plane ground so that the building is free to slide laterally during ground motion; and

NOTES

1 Past experience has shown that superstructure of the buildings not fixed with the foundation escaped collapse even in a severe earthquake although they were shifted sideways.

2 Where fittings for water supply or water borne sanitation from the house are to be installed, proper attention should be given to permit movement so as to avoid fracture of damage to pipes.

b) The superstructure may be rigidly fixed into the plinth masonry or concrete foundation as given in Fig. 45 or in case of small building having plan area less than 50 m^2, it may be fixed to vertical poles embedded into the ground. In each case the building is likely to move along with its foundation. Therefore, the superstructure shall be designed to carry the resulting earthquake shears.

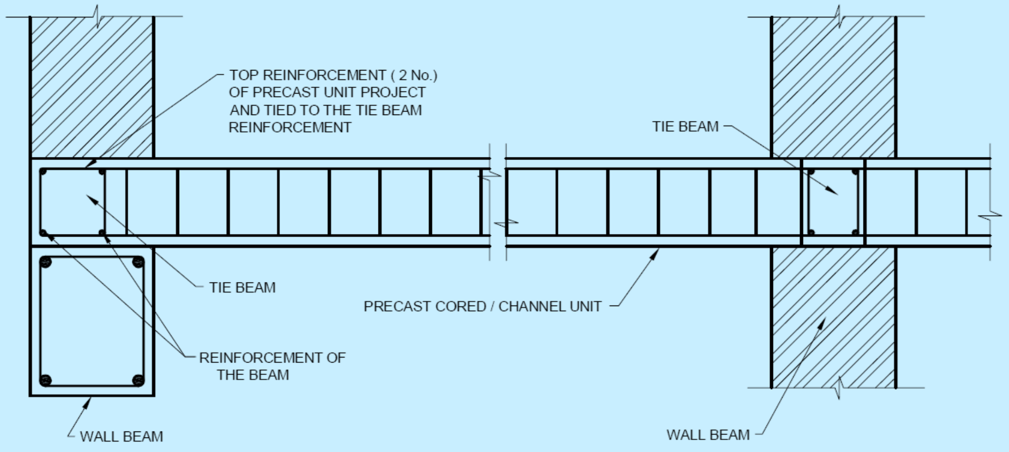

TOP REINFORCEMENT (2 No.) OF PRECAST UNIT PROJECT AND TIED TO THE TIE BEAM REINFORCEMENT
TIE BEAM
TIE BEAM
PRECAST CORED / CHANNEL UNIT
REINFORCEMENT OF THE BEAM
WALL BEAM
WALL BEAM

FIG. 40 CONNECTION OF PRECAST CORED/CHANNEL UNIT WITH TIE BEAM

8.7.6 *Types of Framing*

The types of construction usually adopted in timber building are as follows:

a) Stud wall construction; and

b) Brick nogged timber frame construction.

8.7.7 *Stud Wall Construction*

8.7.7.1 The stud wall construction consists of timber studs and corner posts framed into sills, top plates and wall plates. Horizontal struts and diagonal braces are used to stiffen the frame against lateral loads. The wall covering may consist of *EKRA*, timber or like. Typical details of stud walls are shown in Fig. 46. Minimum sizes and spacing of various members used are specified in **8.7.7.2** to **8.7.7.10**.

8.7.7.2 The timber studs for use in load bearing walls shall have a minimum finished size of 40 mm × 90 mm and their spacing shall not exceed those given in Table 22.

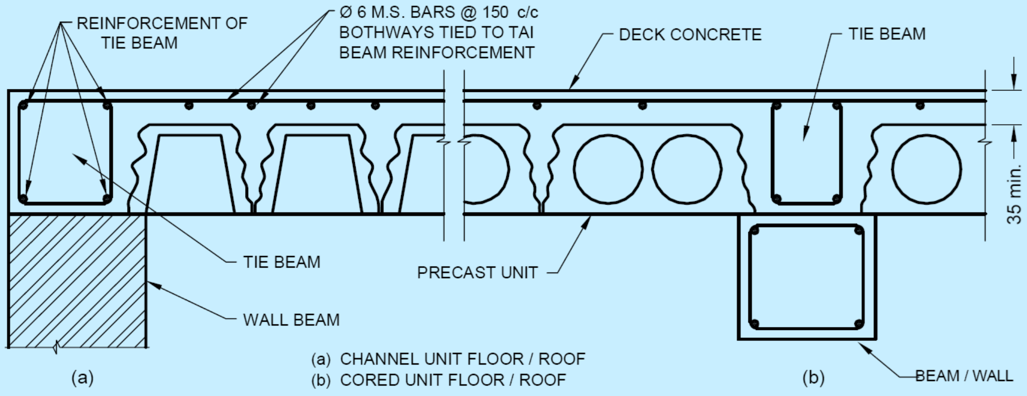
8.7.7.3 The timber studs in non-load bearing walls shall not be less than 40 mm × 70 mm in finished cross section. Their spacing shall not exceed 1 m.

8.7.7.4 There shall be at least one diagonal brace for every 1.6 m × 1 m area of load bearing walls. Their minimum finished sizes shall be in accordance with Table 23.

8.7.7.5 The horizontal struts shall be spaced not more than 1 m apart. They shall have a minimum size of 30 mm × 40 mm for all locations.

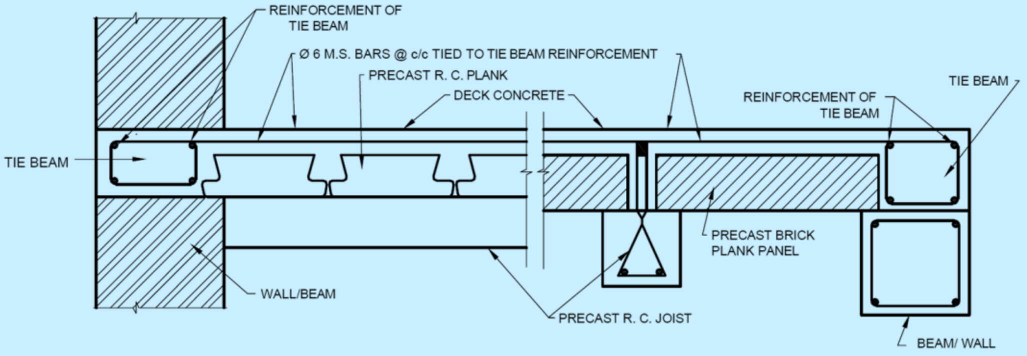
8.7.7.6 The finished sizes of the sill, the wall plate and top plate shall not be less than the size of the studs used in the wall.

8.7.7.7 The corner posts shall consist of three timbers, two being equal in size to the studs used in the walls meeting at the corner and the third timber being of a size to fit so as to make a rectangular section (*see* Fig. 46).


REINFORCEMENT OF TIE BEAM
Ø 6 M.S. BARS @ 150 c/c BOTHWAYS TIED TO TAI BEAM REINFORCEMENT
DECK CONCRETE
TIE BEAM
35 min.
TIE BEAM
PRECAST UNIT
WALL BEAM
(a)
(a) CHANNEL UNIT FLOOR / ROOF
(b) CORED UNIT FLOOR / ROOF
(b)
BEAM / WALL

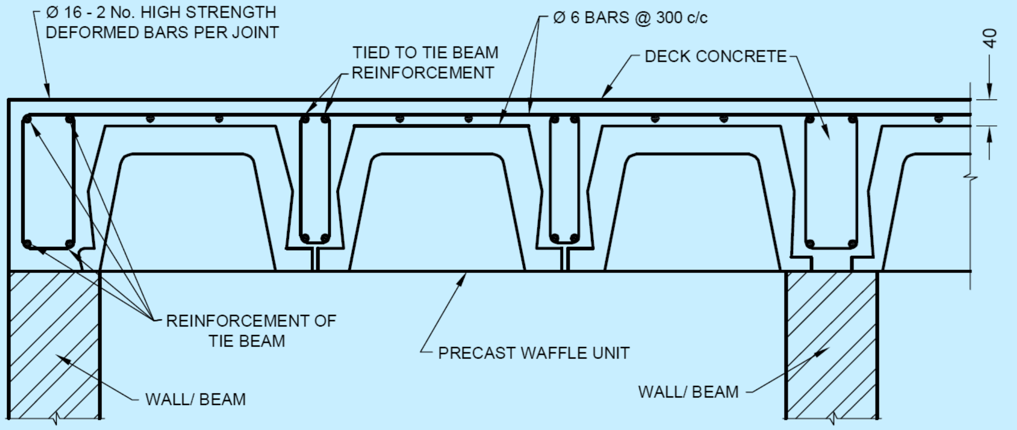
All dimensions in millimetres.

FIG. 41 CONNECTION OF CHANNEL/CORED UNIT FLOOR / ROOF "(WITH DECK CONCRETE) WITH THE BEAM


REINFORCEMENT OF TIE BEAM
Ø 6 M.S. BARS @ c/c TIED TO TIE BEAM REINFORCEMENT
PRECAST R. C. PLANK
DECK CONCRETE
REINFORCEMENT OF TIE BEAM
TIE BEAM
TIE BEAM
PRECAST BRICK PLANK PANEL
WALL/BEAM
PRECAST R. C. JOIST
BEAM/ WALL

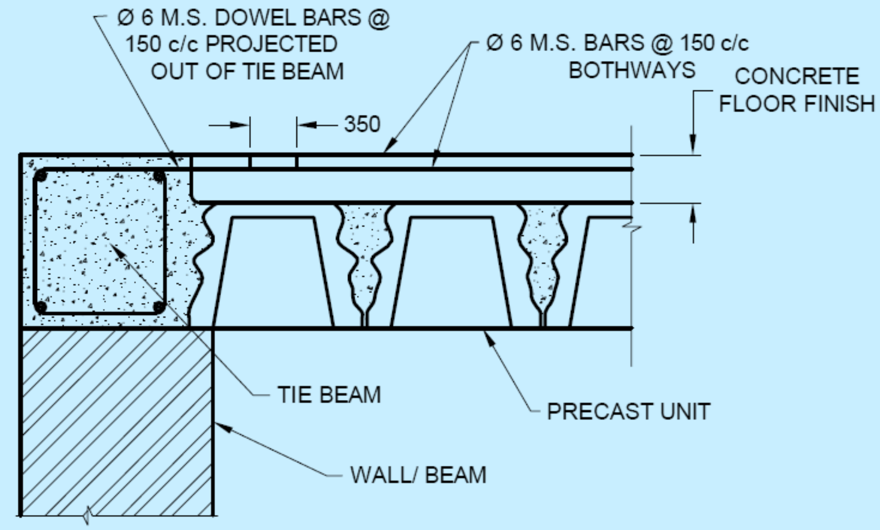
All dimensions in millimetres.

FIG. 42 CONNECTION OF PRECAST REINFORCED CONCRETE PLANK AND PRECAST BRICK PANEL FLOOR/ROOF (WITH DECK CONCRETE) WITH TIE BEAM


Ø 16 - 2 No. HIGH STRENGTH DEFORMED BARS PER JOINT
Ø 6 BARS @ 300 c/c
TIED TO TIE BEAM REINFORCEMENT
DECK CONCRETE
40
REINFORCEMENT OF TIE BEAM
PRECAST WAFFLE UNIT
WALL/ BEAM
WALL/ BEAM

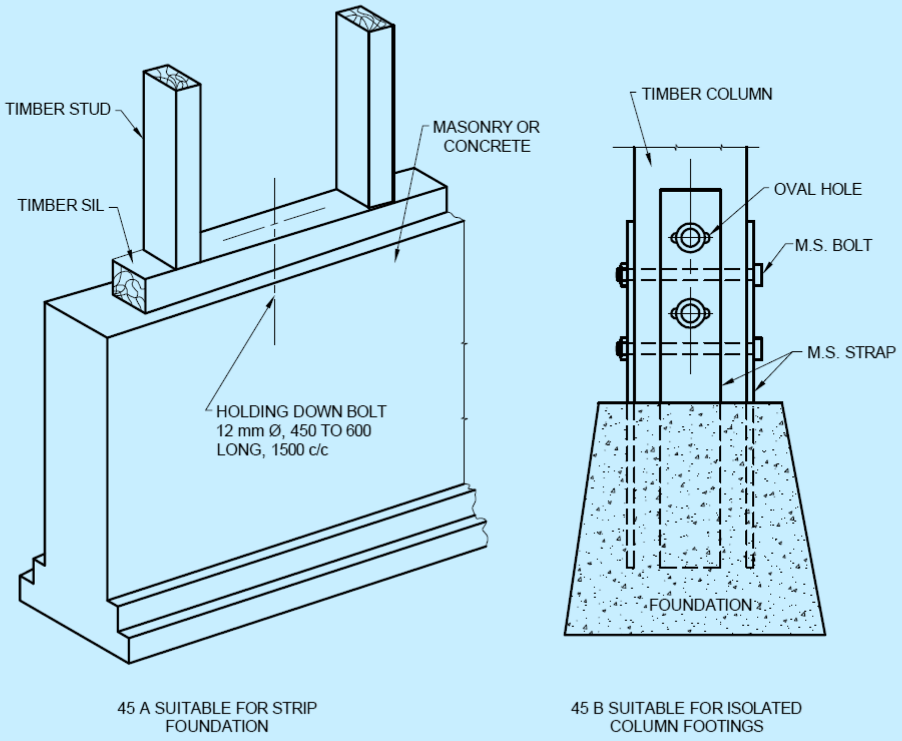
All dimensions in millimetres.

FIG. 43 CONNECTION OF PRECAST WAFFLE UNIT FLOOR/ROOF (WITH DECK CONCRETE) WITH TIE BEAM


Ø 6 M.S. DOWEL BARS @ 150 c/c PROJECTED OUT OF TIE BEAM
Ø 6 M.S. BARS @ 150 c/c BOTHWAYS
CONCRETE FLOOR FINISH
350
TIE BEAM
PRECAST UNIT
WALL/ BEAM

All dimensions in millimetres.

FIG. 44 PROVISION OF REINFORCEMENT IN CONCRETE FLOOR FINISH TIE BEAM


TIMBER STUD
TIMBER SIL
MASONRY OR CONCRETE
HOLDING DOWN BOLT 12 mm Ø, 450 TO 600 LONG, 1500 c/c
TIMBER COLUMN
OVAL HOLE
M.S. BOLT
M.S. STRAP
FOUNDATION
45 A SUITABLE FOR STRIP FOUNDATION
45 B SUITABLE FOR ISOLATED COLUMN FOOTINGS

All dimensions in millimetres.

FIG. 45 DETAILS OF CONNECTION OF COLUMN WITH FOUNDATION

Table 22 Maximum Spacing of 40 mm × 90 mm Finished Size Studs in Stud Wall Construction

(*Clauses* 8.7.7.2)

Sl No.	Group of Timber (Grade I[1])	Single Storeyed or First Floor of the Double Storeyed Buildings		Ground Floor of Double Storeyed Buildings	
		Exterior Wall mm	Interior Wall mm	Exterior Wall mm	Interior Wall mm
(1)	(2)	(3)	(4)	(5)	(6)
i)	Group A, B	1000	800	500	400
ii)	Group C	1000	1000	500	500

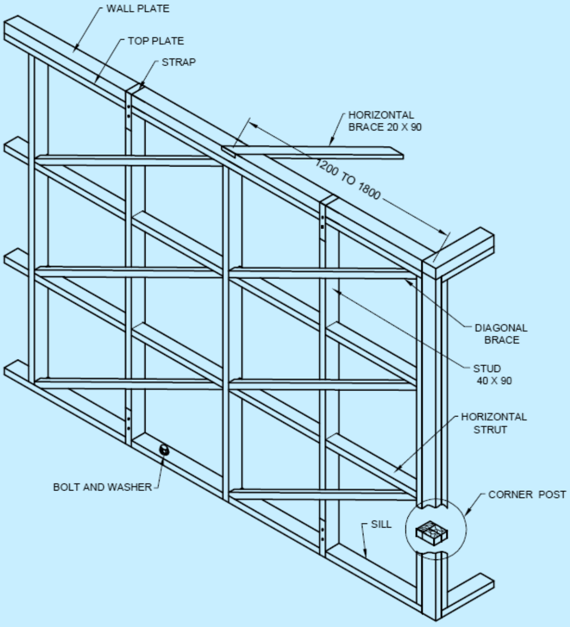
[1] Grade I timbers as defined in Table 5 of [C-4(9)].

Table 23 Minimum Finished Sizes of Diagonal Braces

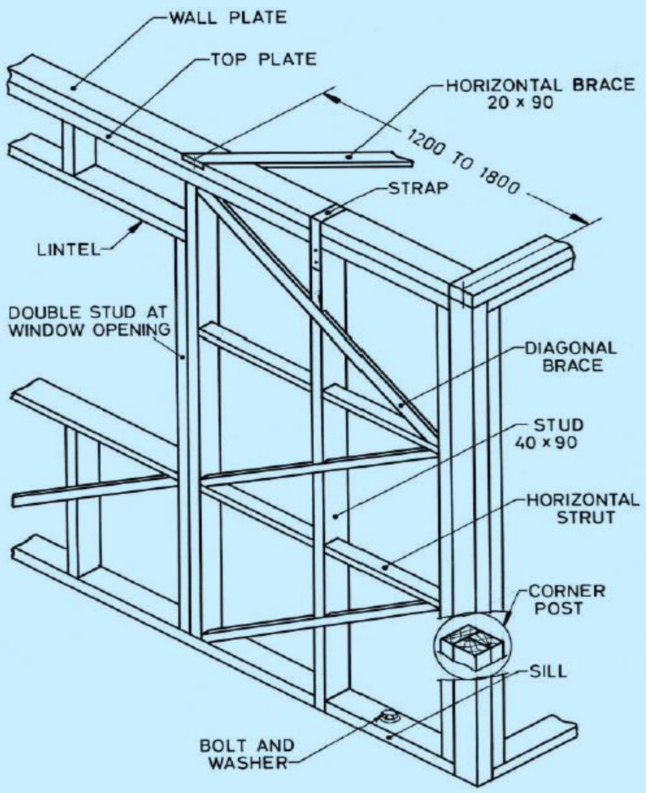
(*Clauses* 8.7.7.4, 8.7.8.2 *and* 8.7.8.4)

Sl No.	Building Category	Group of Timber (Grade I[1])	Single Storeyed or First Floor of Double Storeyed Buildings		Ground Floor of Double Storeyed Building	
			Exterior Wall mm × mm	Interior Wall mm × mm	Exterior Wall mm × mm	Interior Wall mm × mm
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	B, C	All	20 × 40	20 × 40	20 × 40	20 × 40
ii)	D and E	Group A and Group B	20 × 40	20 × 40	20 × 40	30 × 40
		Group C	20 × 40	30 × 40	30 × 40	30 × 40

[1] Grade I timber as defined in Table 5 of [C-4(9)].


WALL PLATE
TOP PLATE
STRAP
HORIZONTAL BRACE 20 X 90
1200 TO 1800
DIAGONAL BRACE
STUD 40 X 90
HORIZONTAL STRUT
CORNER POST
SILL
BOLT AND WASHER

46 A Timber Framing in Stud Wall Construction Without Opening in Wall



46 B TIMBER FRAMING IN STUD WALL CONSTRUCTION WITH OPENING IN WALL

All dimensions in millimetres.

FIG. 46 STUD WALL CONSTRUCTION

8.7.7.8 The diagonal braces shall be connected at their ends with the stud wall members by means of wire nails having 6 gauge (4.88 mm diameter) and 100 mm length. Their minimum number shall be 4 nails for 20 mm × 40 mm braces and 6 nails for 30 mm × 40 mm braces. The far end of nails may be clutched as far as possible.

8.7.7.9 Horizontal bracing shall be provided at corners of T-junctions of walls at sill, first floor and eaves levels. The bracing members shall have a minimum finished size of 20 mm × 90 mm and shall be connected by means of wire nails to the wall plates at a distance between 1.2 m and 1.8 m measured from the junction of the walls. There shall be a minimum number of six nails of 6 gauge (4.88 mm diameter) and 10 cm length with clutching as far ends.

8.7.7.10 Unsheathed studding shall not be used adjacent to the wall of another building. The studding shall be sheathed with close jointed 20 mm or thicker boards.

8.7.8 *Brick Nogged Timber Frame Construction*

8.7.8.1 The brick nogged timber frame consists of intermediate verticals, columns, sills, wall plates, horizontal nogging members and diagonal braces framed into each other and the space between framing members filled with tight-fitting brick masonry in stretcher bond. Typical details of brick nogged timber frame construction are shown in Fig. 47. Minimum sizes and spacing of various elements used are specified in **8.7.8.2** to **8.7.8.9**.

8.7.8.2 The vertical framing members in brick nogged load bearing walls shall have minimum finished sizes as specified in Table 23.

8.7.8.3 The minimum finished size of the vertical members in non-load bearing walls shall be 40 mm × 100 mm spaced not more than 1.5 m apart.

8.7.8.4 The sizes of diagonal bracing members shall be the same as in Table 23.

8.7.8.5 The horizontal framing members in brick-nogged construction shall be spaced not more than 1 m apart. Their minimum finished sizes shall be in accordance with Table 24 and Table 25.

8.7.8.6 The finished sizes of the sill, wall plate and top plate shall be not less than the size of the vertical members used in the wall.

8.7.8.7 Corner posts shall consist of three vertical timbers as described in **8.7.7.7**.

8.7.8.8 The diagonal braces shall be connected of their ends with the other members of the wall by means of wire nails as specified in **8.7.7.8**.

8.7.8.9 Horizontal bracing members of corners of T-junctions of wall shall be as specified in **8.7.7.9**.

Table 24 Minimum Finished Sizes of Vertical in Brick Nogged Timber Frame Construction

(*Clause* 8.7.8.5)

Sl No.	Spacing	Group of Timber (Grade I[1])	Single Storeyed or First Floor of Double Storeyed Buildings		Ground Floor of Double Storeyed Buildings	
			Exterior Wall	Interior Wall	Exterior Wall	Interior Wall
	m		mm × mm	mm × mm	mm × mm	mm × mm
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	1	Group A, B	50 × 100	50 × 100	50 × 100	50 × 100
		Group C	50 × 100	70 × 100	70 × 100	90 × 100
ii)	1.5	Group A, B	50 × 100	70 × 100	70 × 100	80 × 100
		Group C	70 × 100	80 × 100	80 × 100	100 × 100

---

[1] Grade I timber as defined in Table 5 of [C-4(9)].

Table 25 Minimum Finished Size of Horizontal Nogging Members

(*Clause* 8.7.8.5)

Sl No.	Spacing of Verticals	Size
(1)	(2)	(3)
i)	1.5	70 × 100
ii)	1	50 × 100

8.7.9 *Notching and Cutting*

8.7.9.1 Timber framing frequently requires notching and cutting of the vertical members. The notching or cutting should in general be limited to 20 mm in depth unless steel strips are provided to strengthen the notched face of the members. Such steel strips, where necessary shall be at least 1.5 mm thick and 35 mm wide extending at least 150 mm beyond each side of the notch or cut and attached to the vertical member by means of bolts or screws at each end.

8.7.9.2 The top plate, the wall plate or the sill of a wall may be notched or cut, if reinforcing strip of iron is provided as specified in **8.7.9.1**. In case the member is notched or cut not to exceed 40 mm in depth, such reinforcing strip may be placed along the notched edge only. Where the notch or cut is more than 40 mm in depth or the member is completely cut through, such reinforcing strips shall be placed on both edges of the member. The details of notching and cutting are shown in Fig. 48.

8.7.9.3 Joints in timber shall preferably be bound by metallic fasteners.

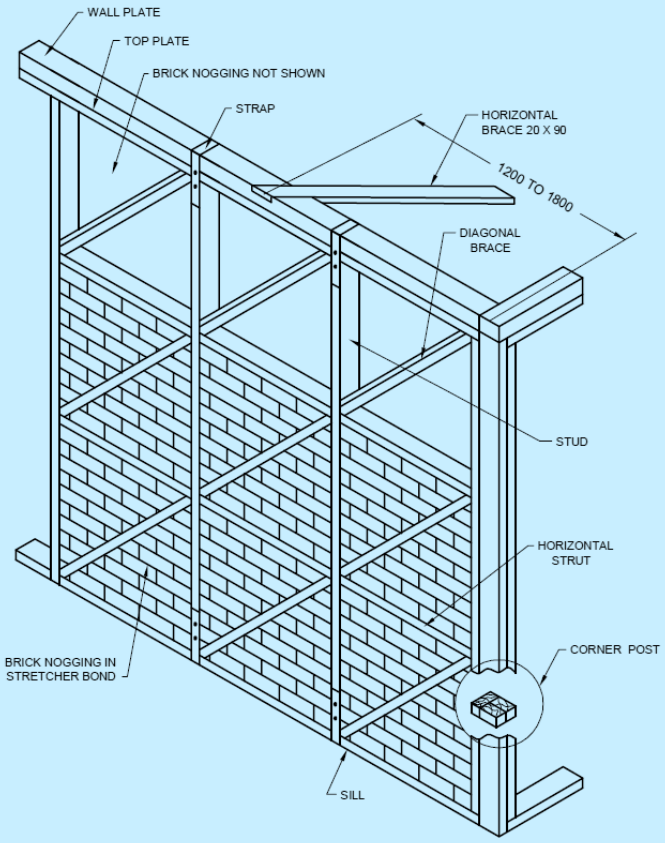
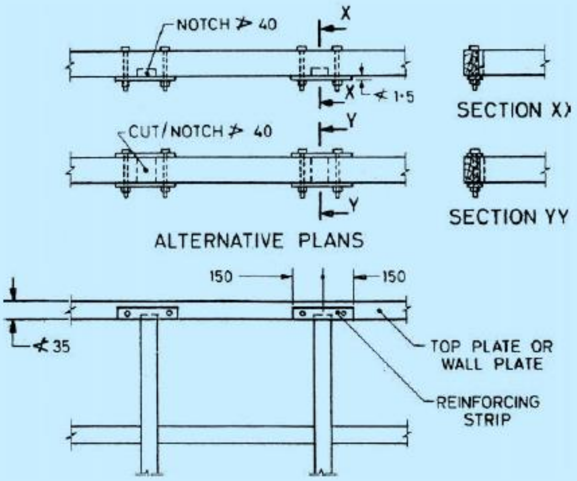

WALL PLATE
TOP PLATE
BRICK NOGGING NOT SHOWN
STRAP
HORIZONTAL BRACE 20 X 90
1200 TO 1800
DIAGONAL BRACE
STUD
HORIZONTAL STRUT
CORNER POST
BRICK NOGGING IN STRETCHER BOND
SILL

FIG. 47 BRICK NOGGED TIMER FRAME CONSTRUCTION


NOTCH ≯ 40
X
X
≮ 1·5
SECTION X
CUT/NOTCH ≯ 40
Y
Y
SECTION YY
ALTERNATIVE PLANS
150
150
≮ 35
TOP PLATE OR WALL PLATE
REINFORCING STRIP

All dimensions in millimetres.

FIG. 48 NOTCHING AND CUTTING

8.7.10 *Bridging and Blocking*

8.7.10.1 All wooden joists shall have at least one row of cross bridging for every 3.5 m length of span. The cross-section of the bridging member shall be a minimum of 40 mm × 70 mm and the member shall be screwed or nailed to the joists.

8.7.10.2 All spaces between joists shall be blocked at all bearing with solid blocks not less than 40 mm thick and the full depth of the joists. The block shall be screwed or nailed to the joists as well as to the bearings.

9 CONFINED MASONRY WALLS (CMW)

9.1 Design Considerations

9.1.1 *General*

The provisions given in 9.1.2 to 9.1.6 apply in addition to those specified in 4.

9.1.2 *Structural Integrity*

Intersecting walls shall be joined together to resist the effect of gravity and lateral loads. The walls shall be adequately connected to elements which provide lateral support, such as floors and roofs.

9.1.3 *Building Configuration*

A regular building configuration is one of the key requirements for satisfactory earthquake performance. The following recommendations related to building plan shape shall be followed:

a) The building's length-to-width ratio in plan shall not exceed 4 and storey height shall be less than 4 m;

b) The walls shall be built in a symmetrical manner with regard to the horizontal axes through the centre of the building plan. Some walls shall be placed on the perimeter also to increase resistance of the building to twisting (torsion) during an earthquake;

c) There shall be at least two lines of walls in each orthogonal direction of the building plan, and the walls along each line shall extend over at least 50 percent of the building dimension in the direction considered at each storey level (Fig. 49);

d) The walls shall be continuous up to the full building height. There shall be no vertical offsets in the walls along the building height;

e) The openings (doors and windows) shall be placed in the same position on each floor;

f) The total cross-sectional area of all walls in two adjacent floors shall not be different by more than 30 percent; and

g) The structural system in a building shall be the same in all storeys and in both principal plan directions.

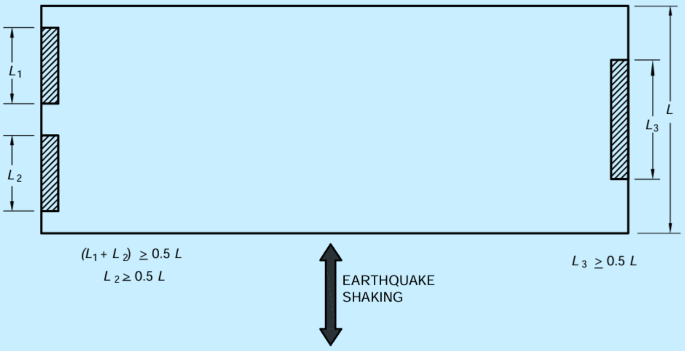


FIG. 49 AT LEAST TWO PARALLEL LINES OF WALLS ARE REQUIRED IN EACH PLAN DIRECTION

9.1.4 *Minimum Design Dimensions and Placements of Confining Elements*

Requirements regarding spacing of tie-columns and tie-beams are presented in Fig. 50. Minimum dimension of tie-column and tie-beam shall be 150 mm along the wall direction and as much as the thickness of the wall in the direction perpendicular to it.

9.1.4.1 *Placement of reinforced concrete tie-columns and tie-beams*

Tie-columns should be provided at:

a) intersections of walls;

b) intermediate locations in longer walls, where spacing shall not exceed lesser than 1.5 h (where h is the clear wall height between floors) or 4 m; and

c) free ends of wall panels that provide lateral load resistance to the building (Fig. 51).

Also, reinforced concrete tie-beams must be provided at the top of each wall and spacing between tie-beams should be preferably less than 4 m.

9.1.4.2 *Horizontal lintel bands*

When the unsupported height of the wall h is greater than 2.5 m, a continuous horizontal lintel band shall be provided over the openings. A continuous horizontal band is not essential for $h < 2.5$ m, but a lintel beam shall be provided above the openings.

9.1.5 *Minimum Dimensions of Masonry Walls*

The following shall be applicable:

a) the wall thickness (t) shall not be less than 110 mm; and

b) the maximum wall height-to-thickness (h/t) ratio shall not exceed 25, where h is the height between floors.

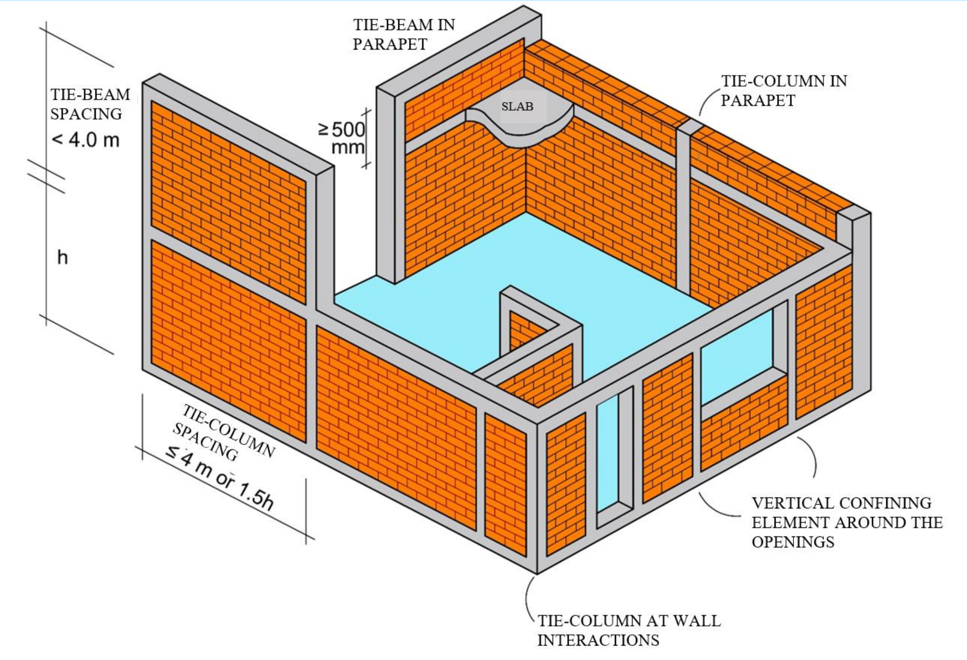

TIE-BEAM IN PARAPET
TIE-COLUMN IN PARAPET
SLAB
≥500 mm
TIE-BEAM SPACING < 4.0 m
h
TIE-COLUMN SPACING ≤4 m or 1.5h
VERTICAL CONFINING ELEMENT AROUND THE OPENINGS
TIE-COLUMN AT WALL INTERACTIONS

FIG. 50 REQUIREMENTS REGARDING CONFINING ELEMENTS

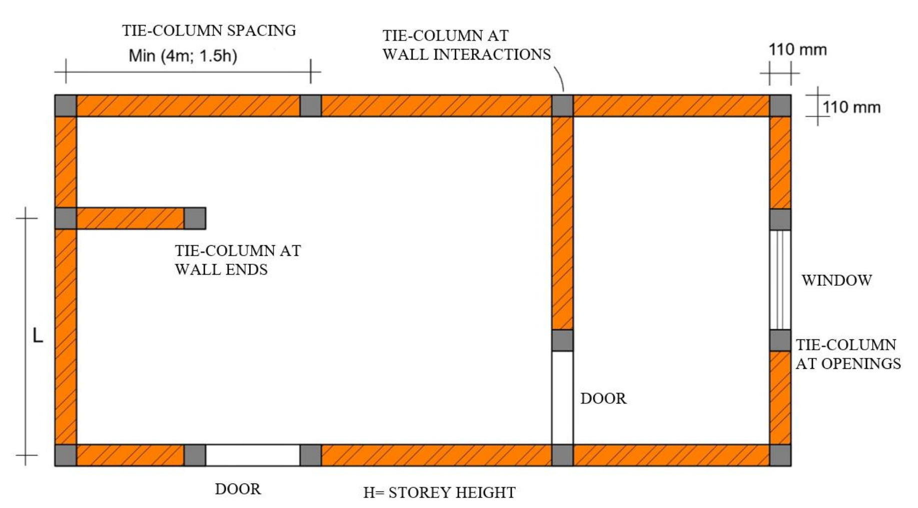


FIG. 51 TYPICAL PLAN ILLUSTRATING THE PLACEMENT OF RC TIE COLUMNS

9.1.5.1 *Aspect Ratio of Confined Masonry Walls*

The height-to-width ratio of a wall that is a part of the lateral force-resisting system shall be less than or equal to 2.

9.1.5.2 *Parapets*

RC tie-columns and tie-beams shall extend to the top of the parapet Fig. 51. When a parapet is not confined by tie-beams, its height shall not be more than 3 times its thickness. For parapet walls with top tie-beams, the height shall not be more than 1.2 m.

9.1.5.3 *Gable Walls*

The top of gable shall be confined with reinforced concrete tie-beams, and tie-columns located at the middle of the gable wall shall be extended from the lower floor to the top of gable wall (whenever applicable), as shown in Fig. 52(A) Alternatively, a gable portion of the wall can be made of timber or other light-weight material that is continuous Fig. 52(B).

9.1.6 *Walls with Openings*

9.1.6.1 *Size of opening*

The presence of large openings may have a negative effect on earthquake performance of confined masonry buildings, especially if openings are not confined. A large opening has a total area greater than 10 percent of the wall panel area, while a small opening has a total area less than or equal to 10 percent of the wall panel area.

9.1.6.2 *Walls with large openings*

The following three approaches shall be followed in walls with large openings:

a) when reinforced concrete tie-columns are not provided at the ends of an opening, the panel shall not be considered as confined and its contribution to earthquake resistance of the building shall be disregarded but shall be strengthened [*see* Fig. 53(A)];

b) when reinforced concrete tie-columns are provided at the opening, and the confined masonry panels are considered to contribute to earthquake resistance of the building, the aspect ratio *H*/*L* of these panels shall be less than 2.0 [Fig. 53(B)]. Better performance can be achieved by providing both sill and lintel bands below and above the openings, respectively; and

c) if total area of openings is greater than 25 percent, both openings and masonry piers shall be confined with horizontal and vertical confining elements [Fig. 53(C)].

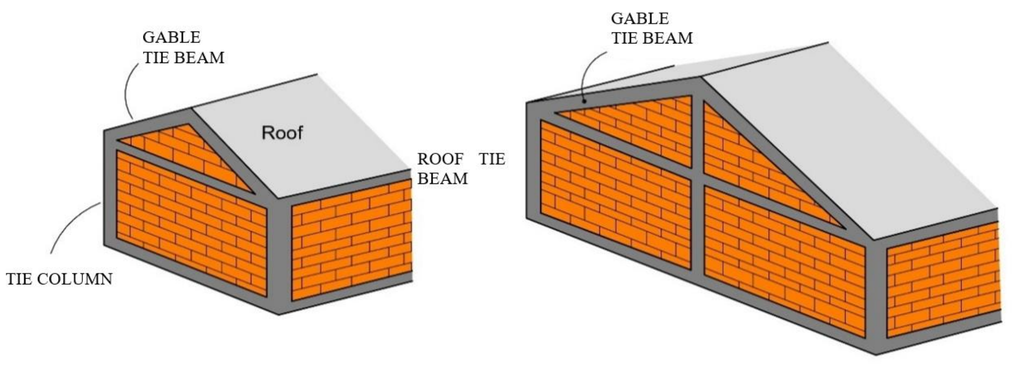


FIG. 52(A) CONFINING ELEMENTS

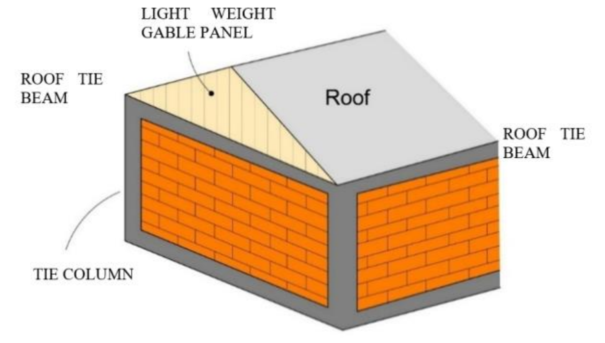


FIG. 52(B) LIGHT-WEIGHT GABLE PANELS

FIG. 52 TYPES OF GABLE WALLS

9.1.6.3 *Walls with small and single openings*

The following three approaches shall be followed in walls with small openings:

a) when the opening is located outside the diagonals Fig. 54(a), it shall be ignored, and the entire wall cross-sectional area considered for earthquake resistance;

b) when an opening is located at the intersection of the panel diagonals [Fig. 54(b)], the panel cross-sectional area (A_T) considered for earthquake resistance should exclude the opening length; and

c) when an opening is located close to one end of the panel, the panel cross-sectional area (A_T) considered in earthquake resistance shall use the larger pier length [Fig. 54(c)].

9.2 Structural Design

9.2.1 *Design Criteria*

Design of structural elements shall be performed as per the working stress method.

9.2.2 *Structural Design as per Working Stress Method*

9.2.2.1 *Load combinations*

The working stress method shall be employed for the structural design of SEs of confined masonry buildings for the load combinations specified in **5** of Part C/Section 1 of this NBCS.

9.2.2.2 *Transformed section properties*

Confined masonry wall panel shall be treated as a composite structural element which consists of a masonry wall and reinforced concrete tie-columns, and designed as a transformed section. Modular ratio (m) shall be taken as the ratio of elastic modulus for concrete and masonry. The modulus of elasticity of concrete can be taken as per

Part C/Section 5 of this NBCS and modulus of elasticity of masonry as per **5.4.6**. Transformed section properties of a confined masonry panel used in design are illustrated in Fig. 55.

9.2.2.3 *Permissible compressive force*

Compressive force in confined masonry due to axial load shall not exceed that given by:

$$P_o = (0.25\,f_m\,A_m + f_{cc}\,A_c + 0.65\,A_s\,f_s)\,k_s,$$

where

A_c = cross-sectional area of concrete excluding reinforcing steel;

A_m = net area of masonry;

A_s = area of steel;

f_{cc} = permissible stress in concrete in direct compression as per Part C/Section 5 of this NBCS;

f_m = compressive strength of masonry as per **5.4.5**;

f_s = permissible steel tensile stress as per Part C/Section 5 of this NBCS; and

k_s = stress reduction factor as per Table 10.

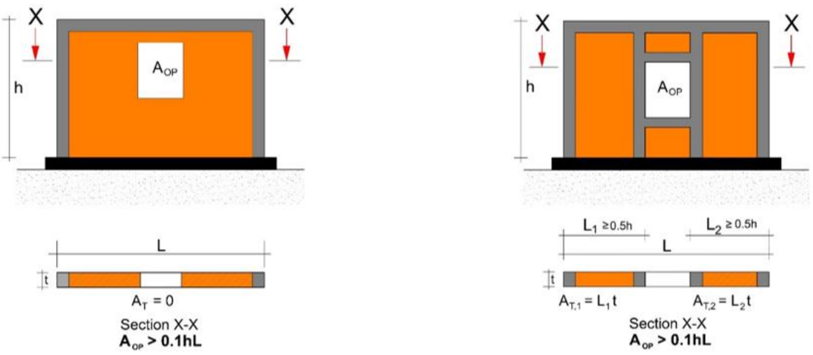

X
X
h
A_OP
L
t
A_T = 0
Section X-X
A_OP > 0.1hL
X
X
h
A_OP
L_1 ≥0.5h
L_2 ≥ 0.5h
L
t
A_T,1 = L_1t
A_T,2 = L_2t
Section X-X
A_OP > 0.1hL

FIG. 53(A) UNCONFINED PANEL

FIG. 53(B) PANEL WITH TIE COLUMNS

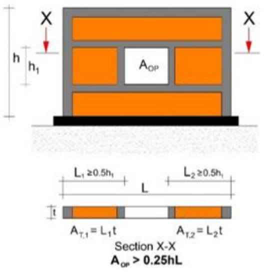

X
X
h
h_1
A_OP
L_1 ≥0.5h_1
L_2 ≥0.5h_1
L
t
A_T,1 = L_1t
A_T,2 = L_2t
Section X-X
A_OP > 0.25hL

FIG. 53(C) PANEL WITH HORIZONTAL BANDS

FIG. 53 MASONRY WALLS WITH LARGE OPENING

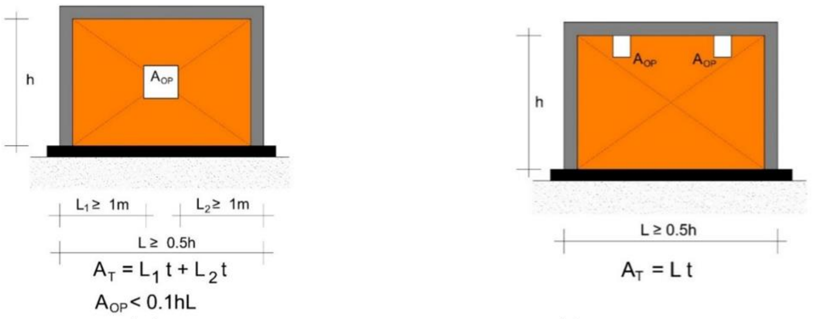

h
AOP
L1 ≥ 1m
L2 ≥ 1m
L ≥ 0.5h
AT = L1 t + L2 t
AOP < 0.1hL
AOP
AOP
h
L ≥ 0.5h
AT = L t

FIG. 54(A) OPENING ALONG DIAGONAL

FIG. 54(B) OPENING OFF THE DIAGONAL

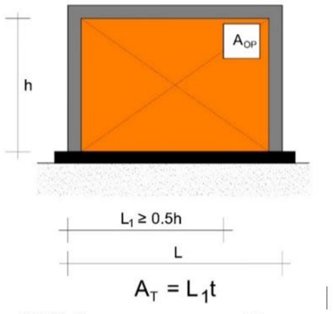
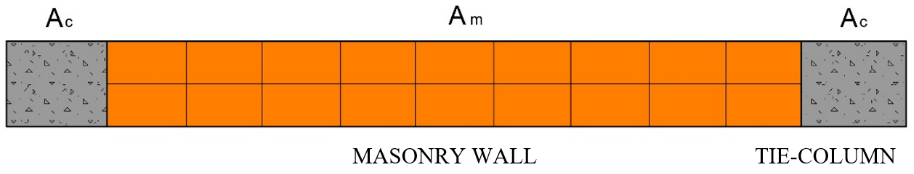
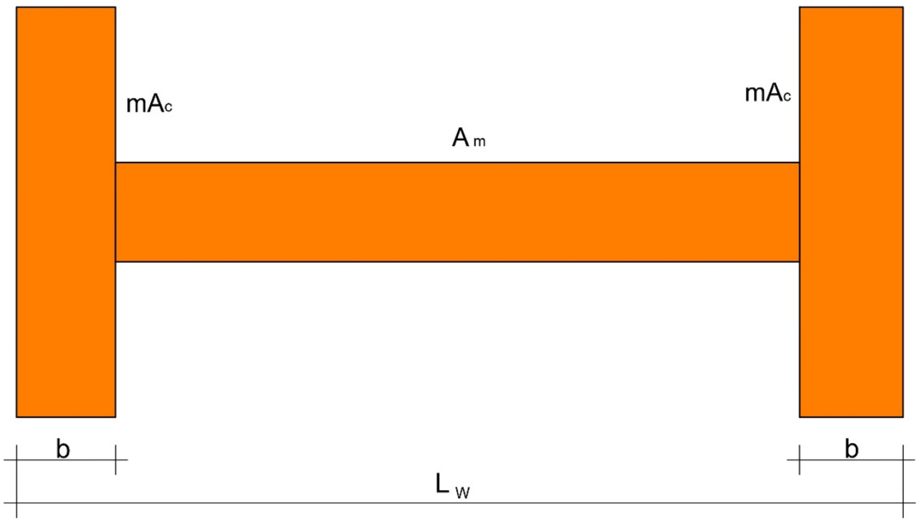

h
AOP
L1 ≥ 0.5h
L
AT = L1t

FIG. 54(C) OPENING ALONG THE DIAGONAL

FIG. 54 CONFINED MASONRY WALL PANEL WITH SMALL OPENING


Ac
Am
Ac
MASONRY WALL
TIE-COLUMN

55A) MASONRY WALL


mAc
mAc
Am
b
b
LW

55B) WALL TO BE CONSIDERED IN DESIGN

FIG. 55 TRANSFORMED SECTION PROPERTIES OF A CONFINED MASONRY PANEL

Table 26 Maximum Allowable Shear Stress τ_{cm} of Confined Masonry

(*Clause* 9.2.2.6)

Sl No. (1)	$\left(\frac{M}{Vd}\right)$ (2)	f_t (MPa) (3)	τ_{cm} (MPa) (4)
i)	< 1	$\frac{1}{36}\left(4-\frac{M}{Vl_w}\right)$	$0.4\text{-}0.2\left(\frac{M}{Vl_w}\right)$
ii)	> 1	$0.083\sqrt{f_m}$	0.4

9.2.2.4 *Combined permissible axial and flexural compressive stress*

For walls subjected to combined axial load and flexure, the compressive stress in masonry due to combined action of axial load and bending shall not exceed 1.25 f_a and compressive stress in masonry due to axial load only shall not exceed f_a.

9.2.2.5 *Permissible tensile stress*

Provisions of **5.4.2** shall apply.

9.2.2.6 *Permissible shear stress*

The permissible shear stress τ_{cm} for confined masonry walls shall be as per Table 26. If there is tension in any part of a section of masonry, the area under tension shall be ignored while estimating the shear stress demand on the cross-section.

When designing buildings as per the working stress method, the load combinations given in Table 27 shall be used. These combinations are provided considering short-term effects. When assessing the long-term effects due to creep, the dead load, and that part of imposed load likely to be permanent alone shall be used.

Table 27 Load Combinations to be Considered in Design of Buildings as per Working Stress Method

(*Clause* 9.2.2.6)

Sl No. (1)	Combination Case (2)	Serviceability Load Combination (3)
i)	1	DL + IL
ii)	2	DL + EL
iii)	3	DL + 0.8 IL + 0.8 EL

9.2.2.7 *Design assumptions*

The following assumptions shall be made in design of confined masonry wall panels subjected to axial and/or flexural loads:

a) masonry behaves like a homogeneous material;

b) strain distribution across the cross-section of the wall varies linearly;

c) tensile stresses are resisted only by reinforcing steel (masonry and concrete tensile resistance is ignored);

d) bond is perfect between steel reinforcement and adjacent concrete;

e) maximum compressive strains in masonry (ε_m) and concrete (ε_c) shall be taken equal to 0.004 0 and 0.003 0, respectively; and the stress-strain curve of masonry is linear, unless a more accurate relation is determined by experimental study of masonry prisms.

9.2.2.8 *Stress-strain curves for concrete, masonry and steel*

The relationship between the compressive stress distribution in concrete and the strain in concrete may be assumed to be rectangle, trapezoid, parabola, or any other shape which results in prediction of strength in substantial agreement with the results of test. An acceptable stress-strain curve is given in Part C/Section 5 of this NBCS. But the ultimate strain in concrete shall be taken as 0.003 0 in place of 0.003 5. For design purposes, the compressive strength of concrete in the structure shall be assumed to be 0.67 times the characteristic strength. The partial safety factor γ_m of 1.5 shall be applied in addition to this.

The stresses in the reinforcement are derived from representative stress-strain curve for the type of steel used. Typical curves are given in Part C/Section 5 of this NBCS. For design purposes, the partial safety factor γ_m of 1.15 shall be applied.

The relation between the compressive stress-strain in masonry may be assumed to be rectangle, trapezoid, parabola, or any other shape which results in prediction of strength in substantial agreement with the results of test. An acceptable stress-strain curve is given in Fig. 56. For design purposes the partial safety factor γ_m of 2.0 shall be applied.

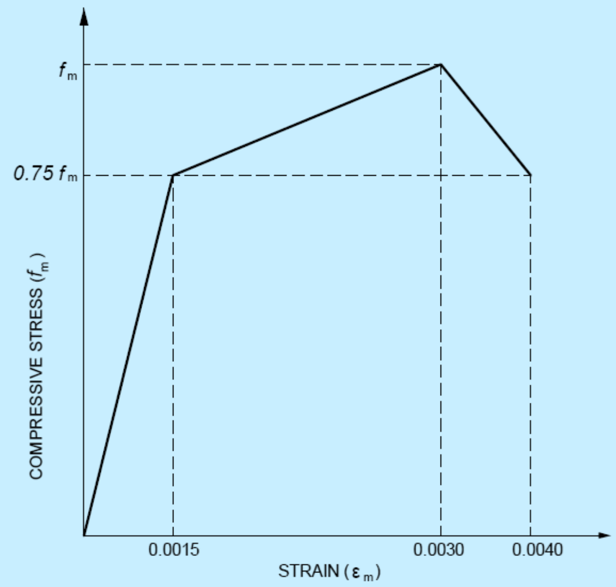


FIG. 56 ACCEPTABLE STRESS-STRAIN CURVE OF MASONRY

9.2.2.9 *Axial load resistance*

Axial load resistance of a confined masonry wall (*P*u) shall be determined considering the contribution of masonry and longitudinal steel reinforcement in tie-columns assuming that the steel has yielded in compression, that is:

$$P_u = (0.4\,f_m\,A_m + 0.45\,f_{ck}\,A_c + 0.75\,f_y\,A_s)\,k_s,$$

where

f_m = compressive strength of masonry;

A_m = net area of masonry;

f_{ck} = characteristic cube compressive strength of concrete;

A_c = cross-sectional area of concrete excluding reinforcing steel;

f_y = characteristic yield strength of the reinforcing steel;

A_s = area of steel; and

k_s = stress reduction factor as in Table 10.

9.2.2.10 *Design of confined masonry walls for combined axial load and out-of-plane bending*

Confined masonry walls need to be designed for combined effects of axial load and out-of-plane bending (bending perpendicular to the wall surface). Bending moments may be due to eccentric gravity loads or lateral loads acting perpendicular to wall plane (wind and earthquake). Generally, confined masonry walls have sufficient resistance against earthquake force acting in out-of-plane direction if slenderness limits in **9.4.1** are satisfied. For out-of-plane forces, only one-way bending may be considered, that is, bending in the vertical direction as shown in Fig. 57.

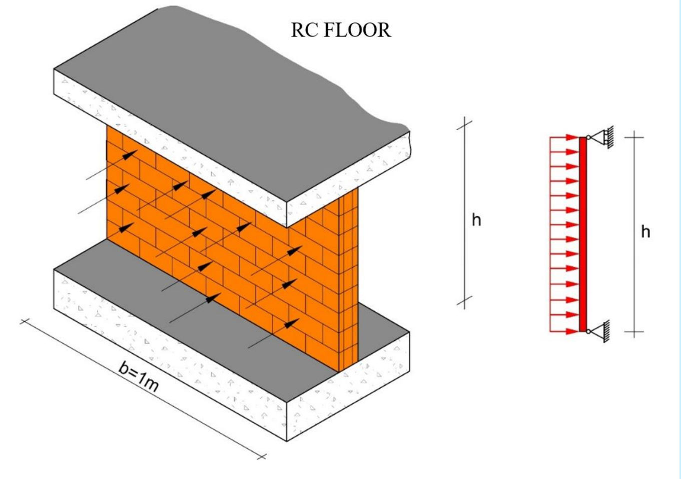


FIG. 57 UNIT LENGTH B OF MASONRY WALL CONSIDERED FOR OUT-OF-PLANE BENDING IN VERTICAL DIRECTION

The interaction of compression due to axial stresses and bending stresses should be within the following limits:

$$\frac{P}{P_u} + \frac{M}{M_u} \leq 1.0$$

Design bending moment demand M due to design wind pressure p_d [as per Part C/Section 1 of this NBCS] acting out-of-plane over unit length b can be calculated as follows:

$$M = \frac{p_d h^2}{8}$$

where h is floor-to-floor height. The axial resistance P_u shall be calculated as per **9.2.2.9** by ignoring the contribution of concrete and reinforcement in tie-column and considering the net area of masonry per unit length $A_m^{'}$. The moment of resistance M_u per unit length shall be estimated for bending about horizontal axis normal to the length of wall as follows:

$$M_u = \left(\frac{f_t}{\gamma_m} + \frac{P}{A_m^{'}} \right) S_m^{'}$$

where axial load P should not exceed self-weight of the unit length of panel plus $0.15A_m^{'}$ (in MPa),

where

f_t = flexural tensile strength normal to bed joints;

$$= \begin{cases} 0.3 \text{ MPa} & \text{Grade M1 or better Mortar} \\ 0.2 \text{ MPa} & \text{Grade M2 Mortar} \end{cases}$$

A'_{m} = net area of masonry per unit length (mm^2); and

S'_{m} = section modulus per unit length (mm^3).

9.2.2.11 *Moment resistance of confined masonry walls due to combined axial load and in-plane bending*

a) *General approach* — Moment resistance M_u for a section of a confined masonry wall subjected to the design axial load P shall be determined from equilibrium of internal forces acting on the section, by following the assumptions stated in **9.2.2.7**; and

b) *Simplified axial load and bending moment interaction diagram* — For walls with longitudinal bars placed symmetrically in tie-columns, the following equations define a simplified axial load-bending moment interaction diagram (Fig. 58):

$$M_{\mathrm{u}} = \begin{cases} 0.3Pd + M_{\mathrm{uf}} & \text{Points A-B :: } 0 \leq P < (P_{\mathrm{u}}/3) \\ 0.10Pd + M_{\mathrm{uf}} & \text{Point B :: } P = (P_{\mathrm{u}}/3) \\ \dfrac{2}{3}(0.05Pd + 1.5M_{\mathrm{uf}}) & \text{Point C :: } P = (P_{\mathrm{u}}/3) \\ \left(1 - \dfrac{P}{P_{\mathrm{u}}}\right)(0.15Pd + 1.5M_{\mathrm{uf}}) & \text{Points A-B :: } P > (P_{\mathrm{u}}/3) \end{cases}$$

where

M_{f} = $0.87 f_{\mathrm{y}} A_{\mathrm{s}} (l_{\mathrm{w}} - b)$ is the moment resistance corresponding to pure bending load condition, and d the effective depth of the wall section.

c) *Alternate method* — The P-M interaction curve for the confined masonry section can also be determined by sectional analysis method employed in reinforced concrete members.

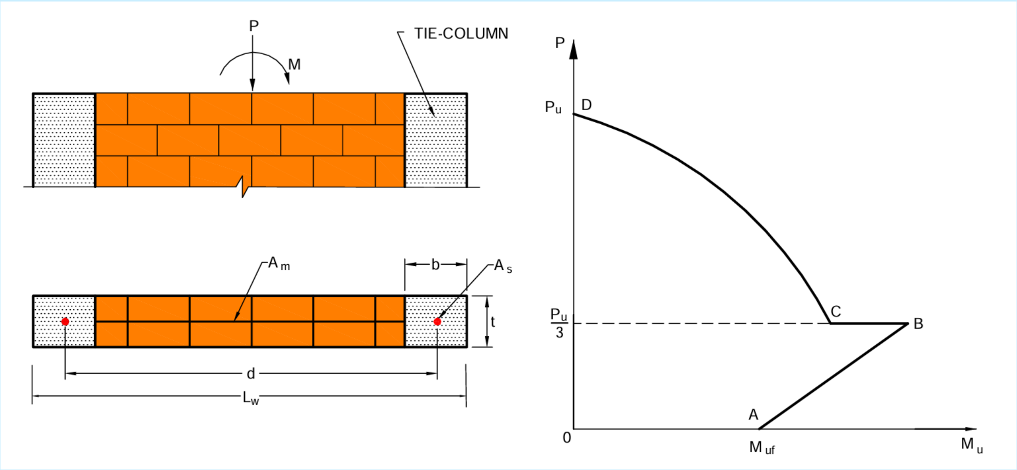


FIG. 58 SIMPLIFIED INTERACTION DIAGRAM FOR DESIGN OF CONFINED MASONRY WALLS

9.2.2.12 *Design for shear*

Shear resistance of a confined masonry wall is due to combined contribution of masonry and horizontal wall reinforcement. Although reinforced concrete tie-columns contribute to shear resistance of a confined masonry wall, their contribution shall be ignored in the design of confined masonry structure.

a) *Masonry shear resistance*

1) *Empirical expression method* — Shear strength of masonry wall may be estimated by any of the following methods:

Shear resistance V_u provided by masonry wall shall be determined as:

$$V_u = 0.8(0.5 v_m A_T + 0.4 P_d) f \leq 1.5 v_m A_T$$

where

A_T = area of cross-section of confined masonry wall including tie-columns;

f = corrected factor for the aspect ratio H/L of the wall;

$$= \begin{cases} 1.55 & \left(\frac{H}{L}\right) \leq 0.2 \\ 1.70 - 0.7\left(\frac{H}{L}\right) & 0.2 < \left(\frac{H}{L}\right) \leq 1.0 \\ 1.00 & 1.0 < \left(\frac{H}{L}\right) \end{cases} ;$$

P_d = design compressive axial load which shall include permanent loads only and with the partial safety factor of 1.0;

v_m = masonry shear strength; and

$= 0.16\sqrt{f_m} \leq 0.6$ MPa.

2) *Test method* — Shear resistance V_u of masonry wall shall be determined as:

$$V_u = v_m A_T$$

where, v_m can be obtained from the standard test method for diagonal tension (shear) in masonry assemblages as given hereunder:

i) When shear strength v_m of masonry is to be established by tests, it shall be done in advance of the construction, using masonry specimens built of similar materials under the same conditions with the same bonding arrangement as for the structure. In making the specimens, moisture content of the units at the time of laying, the consistency of the mortar, the thickness of mortar joints and workmanship shall be the same as will be used in the structure.

The walls specimens (Fig. 59) shall have a length at least two and a half times the length of the masonry unit in one direction and adequate number of courses in perpendicular direction so that the specimen has approximately square shape. The sides of the specimen may not be less than 600 mm. The walls specimens shall be tested by loading them in compression along one diagonal. Tests shall be conducted on at least three specimens constructed with the same size and type of masonry units, mortar, and workmanship.

Specimens shall be tested after 28 days and two steel loading shoes (Fig. 59) shall be used to apply the machine load to the specimen. For the distribution of the applied load P_s, the ratio of the length of bearing, l_b and the width or height of specimen must be equal to or greater than 0.2. The load shall be applied at the rate of 50 kN/min to 100 kN/min and the load at failure shall be recorded. Load shall be applied at a uniform rate so that the maximum load is reached in not less than 1 min and not more than 2 min. Minimum thickness of steel plate used for loading shoe shall be 12 mm.

ii) The shear stress strength v_m of the specimen as:

$$v_m = \frac{P_s}{A_{sn}\sqrt{2}}$$

where

A_{sn} = net area (mm^2) of the wall specimen;

$= \left(\frac{w_s + n_s}{2}\right) t_s$;

P_s = applied design axial load (N);

h_s = height (mm);

t_s = total thickness (mm) of the wall specimen; and

w_s = width (mm).

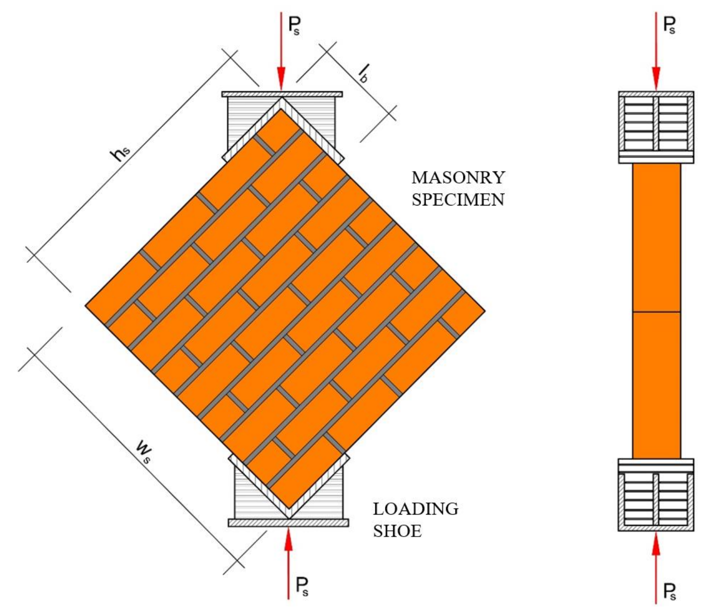


FIG. 59 WALL SPECIMEN FOR DIAGONAL COMPRESSION TEST

b) *Alternate method* (*Strut-and-Tie method*)

The Strut-and-Tie method can be used for determining the shear capacity of confined masonry walls. This method provides a rational and consistent design approach by idealizing complex structural members with an appropriate simplified truss model. According to this procedure, based on the knowledge of direction of principal stresses, load paths are drawn through the wall in form of a truss which is analyzed for the design loads. A possible strut-and-tie model for the confined masonry wall based on its load resisting mechanism is illustrated in Fig. 60; the broken and solid lines represent the strut and tie, respectively. If the opening distribution is irregular or complex in elevation, strut and tie method can be used to estimate the in-plane resistance of the confined masonry wall.

The basic prerequisites for the strut-and-tie model are as follows:

a) The equilibrium of forces at nodes should be maintained for a given set of loads;

b) Tension in concrete and masonry is neglected and adequate detailing of anchorage shall be provided for tie reinforcement;

c) The member forces in the struts and ties are uniaxial which shall not exceed the corresponding member strength at every section; and

d) Sufficient ductility shall be available to make the transition from elastic to plastic behaviour which will enable redistribution of internal forces in the members.

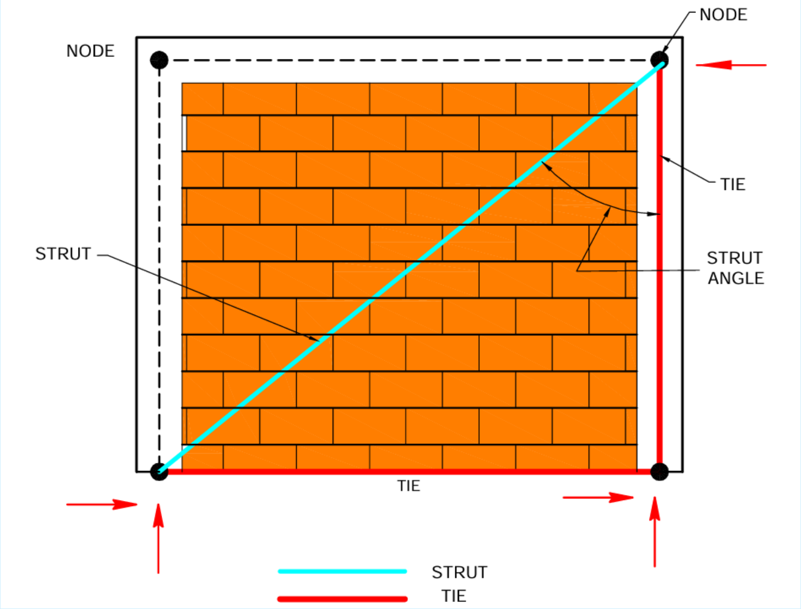


FIG. 60 STRUT-AND-TIE MODEL OF CONFINED MASONRY WALLS

9.2.2.13 *Design of tie-columns and tie-beams*

a) *Minimum amount of longitudinal reinforcement*

Longitudinal reinforcement in tie-columns and tie-beams shall be proportioned to resist the corresponding vertical and horizontal components of the compression strut that develops in masonry when resisting combined gravity and lateral loads. The total area of reinforcement shall be not less than 0.8 percent of the gross cross-section area of the column. For a 2-storey height, the minimum area of reinforcement can be 0.6 percent;

b) *Minimum amount of transverse reinforcement* (*Ties*)

Tie-columns and tie-beams shall have transverse reinforcement in the form of closed stirrups (ties) with the minimum total cross-sectional area A_{sc} (mm^2) of stirrup legs effective in shear equal to:

$$A_{sc} = 0.001\,2\, s h_c,$$

where

s = tie spacing, in mm; and

h_c = Dimension, in mm of tie-column or tie-beam in the wall plane.

c) *Spacing of transverse reinforcement*

Tie spacing shall not exceed the lesser of 200 mm and $1.5t$.

9.2.3 *Foundations and Plinth Construction*

The foundation shall be constructed in a similar manner as for traditional masonry construction. Either a brick masonry footing or an RC strip footing can be used. An RC plinth band shall be constructed on top of the foundation. A plinth band shall be provided to fully confine wall panels along their bases and prevent excessive wall damage due to building settlement in soft soil areas. Note that the longitudinal reinforcement shall be extended from an RC tie-column into the plinth band, and whenever possible, into the foundation.

9.3 Earthquake Resistant Design

9.3.1 *Basis*

Building shall be designed for earthquake forces determined as per **5** of Part C/Section 1 of this NBCS. Also, the load combinations shall be as per Part C/Section 1 of this NBCS.

9.3.2 *Methods of Earthquake Analysis*

9.3.2.1 *General considerations*

9.3.2.1.1 For determining internal forces and moments acting on confined masonry walls, the building may be analyzed for estimating the effects of earthquake shaking using either the simplified method or the earthquake analysis methods specified in **5** of Part C/Section 1 of this NBCS. The simplified method can be used for buildings up to three storeys high, provided that the requirements stipulated in **9.3.2.2** have been met.

The effect of openings shall be considered in lateral stiffness and strength calculations. The structure shall be modelled to adequately simulate the behaviour of its critical structural elements. Modulus of elasticity E_m and shear modulus G_m of masonry shall be used to reflect the axial and shear stiffness expected in the structure.

9.3.2.1.2 Design forces and moments shall be obtained from the analysis using design loads and the corresponding load combinations specified in **5** of Part C/Section 1 of this NBCS. A confined masonry wall shall be designed for the effects of gravity loads, and the effects of lateral loads, including shear force, in-plane bending, and out-of-plane bending moments. When the simplified method is used, design for lateral loads may be limited to the effects of shear force.

9.3.2.2 *Applicability of the simplified method*

9.3.2.2.1 The simplified method is based on an idealized distribution of lateral earthquake forces in regular load bearing wall buildings with rigid diaphragms. The method compares the shear capacity of all walls at the base of the building and the earthquake base shear force determined from **5** of Part C/Section 1 of this NBCS. It is suitable for verifying adequacy of regular buildings with symmetrical wall layout and predominant shear behaviour. The method does not consider torsional effects, arising from eccentricity between centre of mass and centre of resistance. Due to its assumptions, application of this method is restricted to buildings with a height not exceeding three storeys.

9.3.2.2.2 The design can be simplified further for small buildings by applying the concept of wall index, as per procedure in **9.3.2.3**, which can be used for the design of buildings with the total ground plan area not exceeding 200 m^2 and the height not exceeding two storeys or 7 m.

9.3.2.3 *Wall index method*

9.3.2.3.1 Wall Index (WI), also known as wall density, shall be used as an indicator of earthquake load-resisting capacity of earthquake resistant design of low-rise buildings with regular plan shape and elevation. The design according to the simplified method shall be deemed satisfactory provided that the actual wall index (WI_{floor}) per floor in each direction of the building plan is greater than or equal to the required Wall Index (WI_{req}) for specific building.

Wall index WI_{floor} at the ground floor shall be taken as ratio of the sum of cross-sectional areas of all confined masonry walls at that level in the considered direction of earthquake shaking, given by:

$$WI_{Floor} = \frac{A_W}{A_p}$$

where

A_w = cross-sectional area of all confined walls in one direction at the ground floor level; the cross-sectional area of a confined masonry wall is the product of its length (including the reinforced concrete tie-columns and the masonry wall) and thickness; and

A_p = plan area of the floor diaphragm (floor slab) at the ground floor level; the area of any cutouts (openings) in the floor slab shall be deducted in the calculation of A_p.

Parameters for wall index calculations are illustrated in Fig. 61. The wall index shall be estimated along each principal plan direction (X and Y) of the building. Only confined masonry walls aligned in the direction under consideration (shown shaded in Fig. 61) shall be considered in the A_w calculations for the specific direction.

9.3.2.3.2 The required wall index WI_{req} in buildings in different earthquake zones shall be taken as per Table 28 or estimated as follows:

$$WI_{\mathrm{req}} \geq \left(\frac{1.5 A_{\mathrm{h}} w}{v_{\mathrm{m}} / \gamma_{\mathrm{m}}}\right),$$

where

A_{h} = design horizontal acceleration coefficient determined as per **5** of Part C/Section 1 of this NBCS for different zones;

n = number of floor levels in a building;

v_{m} = masonry shear strength as per **9.2.2.12**;

γ_{m} = partial safety factor for masonry as per **9.2.2.8**; and

w = average floor weight, including the self-weight of floor slab, floor finish, walls and 25 percent of the imposed load.

9.3.2.4 *Earthquake analysis methods*

Earthquake analysis of confined masonry buildings of four-storey or higher and buildings up to three-storey high that do not meet requirements for the application of simplified method shall be analysed by the method specified in **5** of Part C/Section 1 of this NBCS. Lateral load effects induced by earthquake shall be determined based on the relative stiffness of walls and wall segments, by considering the effect of both shear and flexure in stiffness calculations. The analysis model shall consider stiffness of floor and roof systems, and any other restraints that may influence wall rotations.

9.3.3 *Other Prescriptive Requirements*

9.3.3.1 *Wall spacing*

The maximum spacing of transverse walls in buildings with flexible diaphragms shall not exceed 4 m. For spacing more than 4 m, the tie-beam at roof level should have a width of $L/20$.

9.3.3.2 *Spacing of transverse reinforcement (ties) in tie-columns*

In earthquake zones IV and above reduced tie spacing ($s/2$) shall be provided of the transverse reinforcement at the ends of tie-columns, where s is the spacing of transverse reinforcement specified *in* 9.2.2.13(c) as shown in Fig. 62. The length over which the reduced tie spacing is required shall not exceed the largest of ($2h_c$), ($2t$) and ($h_o/6$), where h_c is the depth of the tie-column, h_o the clear height of tie-column between floors, and t the width of the tie-column.

9.4 General Requirements

9.4.1 *Reinforcement Detailing*

9.4.1.1 *Concrete cover*

a) The minimum concrete cover to ties (transverse reinforcement) in tie-columns and tie-beams shall not be less than 20 mm; and

b) When horizontal wall reinforcement is provided, the minimum clear distance between a horizontal bar and the exterior wall surface shall not be less than 20 mm.

9.4.1.2 *Bar size and number in tie-columns and tie-beams*

Longitudinal reinforcement in tie-columns and tie-beams shall consist of a minimum of 4 reinforcing bars with the minimum 10 mm diameter.

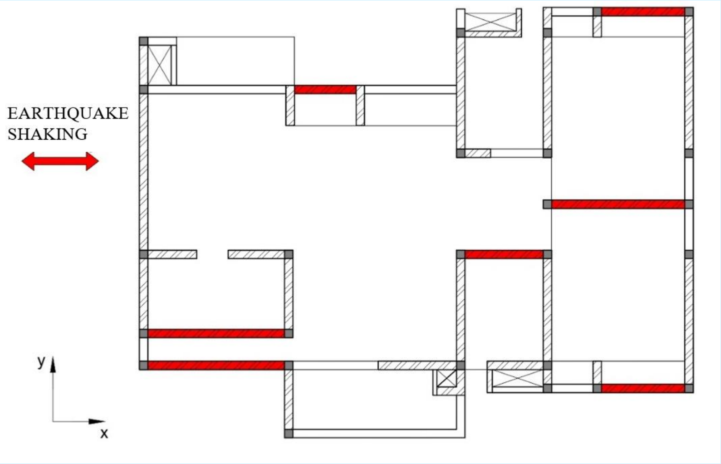


FIG. 61(A) X-DIRECTION

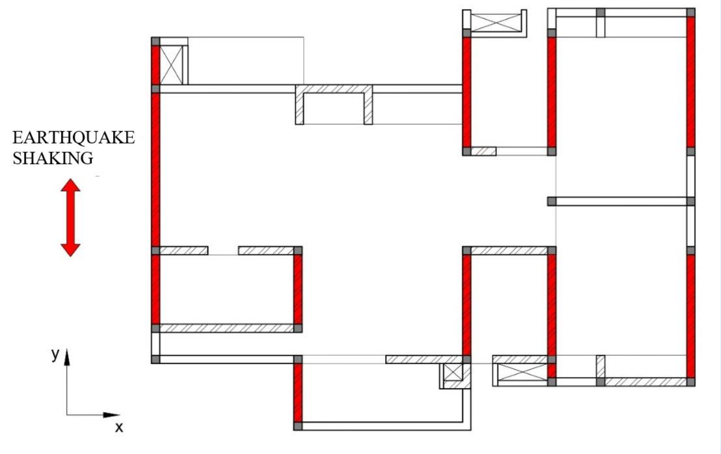


FIG. 61(B) Y-DIRECTION

FIG. 61 WALLS TO BE CONSIDERED IN ESTIMATION OF WALL INDEX ALONG PRINCIPAL PLAN DIRECTIONS OF A BUILDING

Table 28 WI$_{req}$ for Different Earthquake Zones

(*Clause* 9.3.2.3.2)

Sl No.	Earthquake Zone	II	III	IV	V
(1)	(2)	(3)	(4)	(5)	(6)
i)	WI_{req} (percent)	0.7	1.1	1.6	2.4

9.4.1.3 *Ties in tie-columns and tie-beams*

Minimum 6 mm diameter bars shall be used for ties in tie-columns and tie-beams (Fig. 63). Ties shall have 135° hooked ends. Hooks shall be staggered as shown in Fig. 63.

9.4.1.4 *Anchorage of longitudinal bars*

a) Longitudinal reinforcement in tie-columns and tie-beams shall be anchored to develop the full specified steel yield stress. Longitudinal bars in tie-columns and tie-beams shall have a 90° hooked anchorage at intersections. The lap length of the hook tails shall be the largest of 20 times the bar diameter or 500 mm (Fig. 64); and

b) Tie-column longitudinal bars at the roof level shall be bent by 90° and lapped with the tie-beam longitudinal reinforcement (Fig. 65).

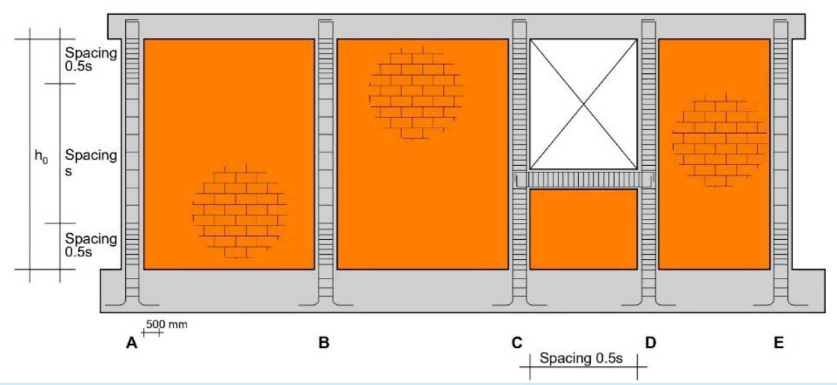


FIG. 62 TIE-COLUMN TRANSVERSE REINFORCEMENT REQUIREMENTS IN EARTHQUAKE ZONES IV AND ABOVE

9.4.1.5 *Lap Splices for longitudinal reinforcement*

Lap splices for longitudinal reinforcement should be at least 40 times the bar diameter. Longitudinal reinforcing bars shall be spliced within the middle third of the column height or beam span. The splices shall be staggered so that not more than 2 bars are spliced at any one location.

9.4.1.6 *Tie-column-to-tie-beam joints*

Continuity of longitudinal tie-beam reinforcement through the joint must be ensured. An example of a continuous longitudinal reinforcement is shown in Fig. 66. First tie at the ends of tie-columns (top and bottom) shall be placed as close to the joint as possible. When tie-beam depth exceeds 300 mm, vertical reinforcement in an RC tie-column must be confined by the ties, below and above the joint. An additional U-shaped stirrup shall be placed in the tie-beam at mid-height (Fig. 67).

Reinforced concrete tie-columns shall be provided at the openings as shown in Fig. 54(B) and Fig. 54(C). A nominal reinforcement around openings as detailed in Fig. 53 shall be provided. When reinforced concrete tie-columns are not provided at the ends of an opening then they should be strengthened as per good practice of [C-4(10)] or minimum two vertical bars of 10 mm diameter with 6 mm ties at 150 mm spacing should be provided.

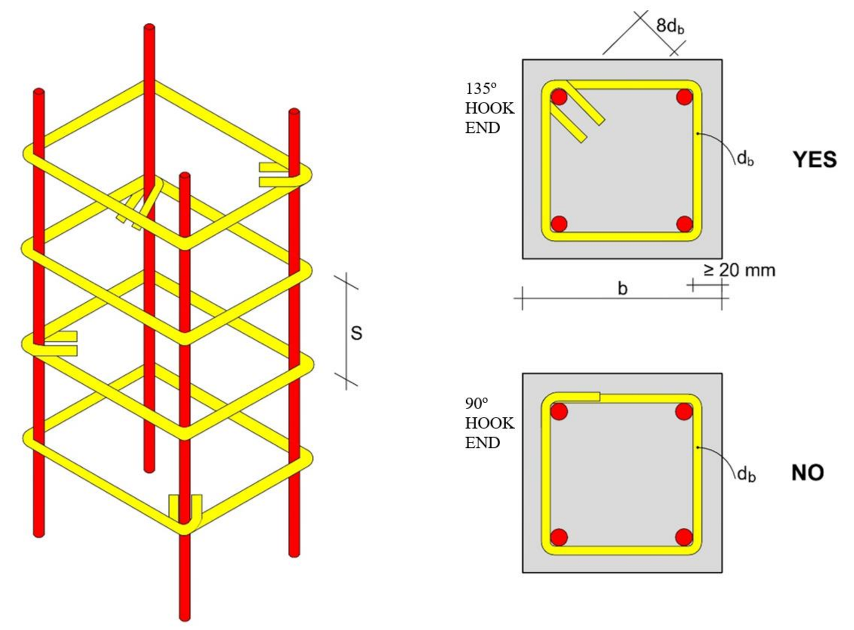


FIG. 63 LAYOUT AND DETAILING OF TIE-COLUMNS AND TIE-BEAMS

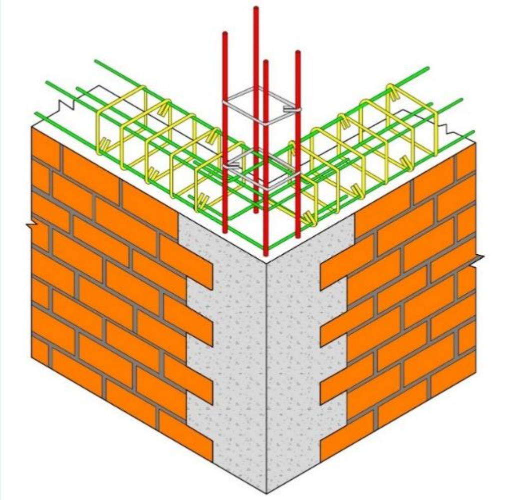


Fig. 64(A) Wall Intersection

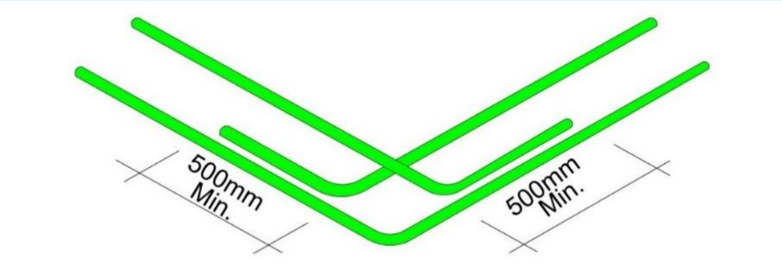

500mm
Min.
500mm
Min.

Fig. 64(B) Hooked Anchorage of Longitudinal Reinforcement at Wall Intersections

Fig. 64 Tie-Beam Construction

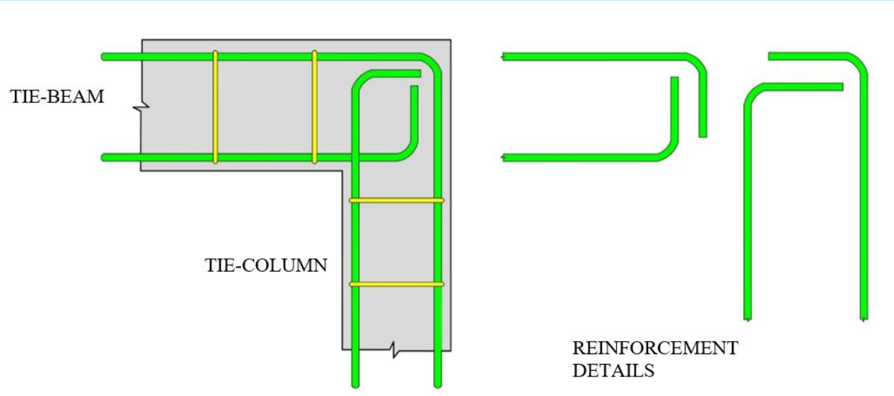

TIE-BEAM
TIE-COLUMN
REINFORCEMENT
DETAILS

Fig. 65 Anchorage of Longitudinal Reinforcement of Tie-Column and Tie-Beam

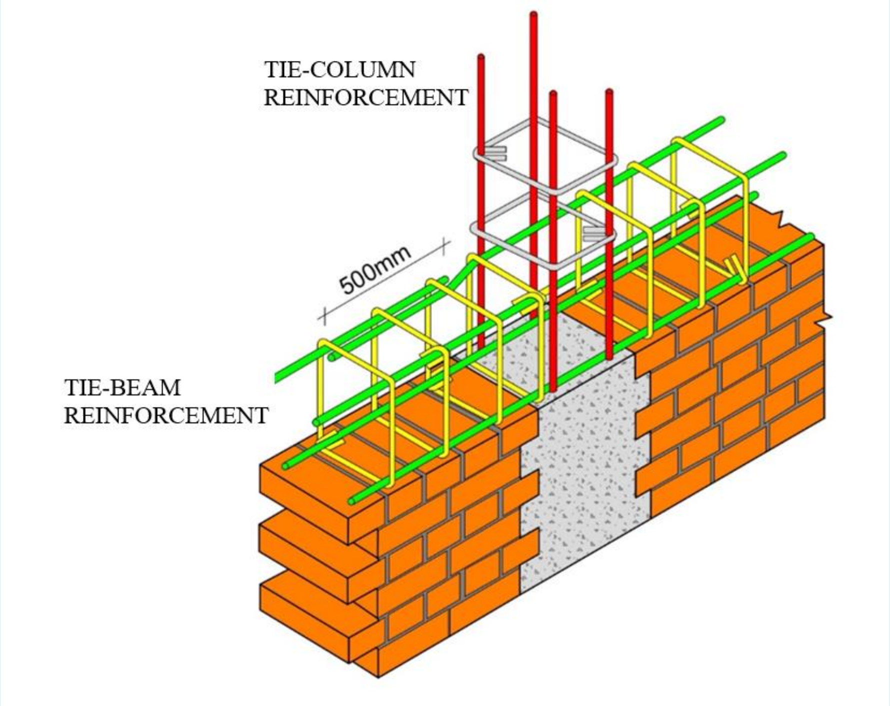


FIG. 66 CONTINUITY OF TIE-BEAM REINFORCEMENT THROUGH JOINT

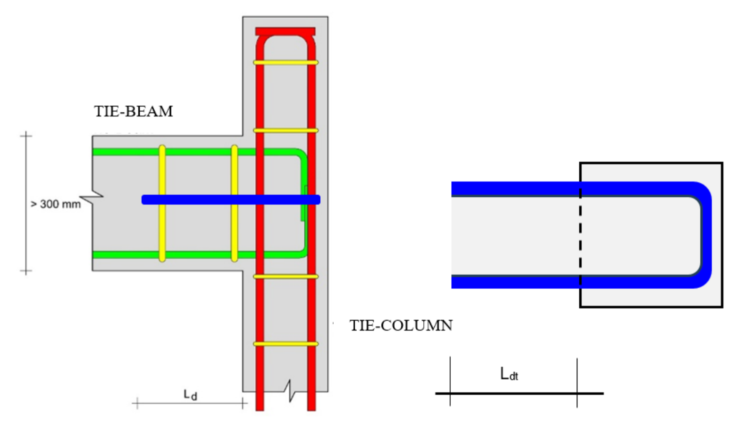


FIG. 67 ADDITIONAL CONFINEMENT OF VERTICAL REINFORCEMENT IN TIE-BEAMS AND TIE-COLUMNS IN EXTERIOR JOINT

9.4.2 *Construction*

Construction of confined masonry buildings shall satisfy the conditions specified hereunder.

9.4.2.1 *Masonry wall construction*

a) *General* — During construction, in addition to the requirements of the sections above, the following shall be complied:

   1) all intersecting walls shall be connected, unless measures to assure stability and good performance are taken;

   2) surfaces of construction joints shall be clean and rough. The joint shall be moistened before construction when clay units are used;

   3) fulfill the requirements of excellent masonry work, Flemish bond or English bond in brickwork shall be adopted; and

4) dring construction, necessary caution to assure wall stability at the job, shall be taken, possible horizontal pressure and loads, including wind and earthquake shall be considered.

b) *Masonry units*

The shape and dimension of masonry units, construction practices, including methods of positioning of reinforcement, placing and compacting of grout, as well as design and detailing shall be, such as to promote homogeneity of structural members, development of the bond between the grout to both reinforcement and masonry units and avoidance of corrosion of reinforcement.

c) *Mortar joint thickness*

Joint mortar shall totally cover the horizontal and vertical sides of the masonry unit. Joint thickness shall be the minimum to get a uniform layer of mortar and good alignment of the units. If industrialized units are used, the thickness of the horizontal joints shall not exceed 12 mm if horizontal reinforcement is placed in the joints, and 10 mm without horizontal reinforcement. Minimum thickness shall be 6 mm.

d) *Toothing*

The vertical interface of masonry with adjacent tie-columns shall be detailed to transfer shear forces. It shall be accepted to indent the masonry (referred to as toothing) or else, to place steel dowels or horizontal reinforcement as shown in Fig. 68.

Toothed edges shall be left on each side of the wall at the interface with the tie-columns. Toothing length shall be equal to one-quarter of the masonry unit length, but not less than 50 mm, as shown in Fig. 68(A). When hand-made bricks are used, it is desirable to cut the brick edges, as shown in Fig. 68(B). It is important to clean the surfaces of 'toothed' masonry units before the concrete has been poured. Horizontal reinforcement anchored into RC tie-columns, also known as dowels, can be used as an alternative no toothing, as shown in Fig. 68(C). The dowels are not necessary when toothed edges are used. 6 mm diameter bars shall be preferably used as dowels.

9.4.2.2 *Reinforcement*

Reinforcement shall be tightly secured before casting.

9.4.2.3 *Concrete*

Casting of tie-columns shall be cast after the masonry wall or the corresponding part has been constructed. The masonry around the tie-columns shall be saturated before the concrete has been poured.

9.4.2.4 *Piping and ducts*

Piping and ducts shall be installed without damaging the masonry. If solid or grouted hollow units are used, grooves in the wall shall be permitted to embed piping and ducts, but the following shall be satisfied:

a) Groove depth shall not exceed one fourth the thickness of the masonry wall ($t/4$);

b) Groove shall be vertical; and

c) Groove shall not be longer than one half the free height of the wall ($H/2$). If hollow units are used, pipes or ducts shall not be placed in cells with reinforcement. Cells with pipes and ducts shall be grouted.

It shall not be permitted to place piping and ducts in tie-columns with a structural function, whether external or internal.

10 REINFORCED MASONRY WALLS (RMW)

10.1 General

The requirements for structural design aspect of reinforced load bearing/walls, constructed with solid or perforated burnt clay bricks, sand-lime bricks, stones, concrete blocks, lime-based blocks or burnt clay hollow blocks shall be specified hereunder related to the materials to be used, the permissible stresses and methods of design.

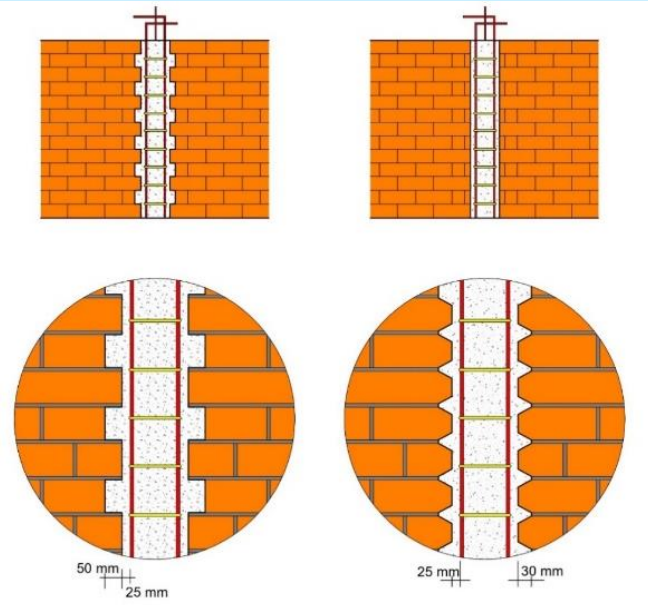


FIG. 68(A) FULL TOOTHING FIG. 68(B) PARTIAL TOOTHING

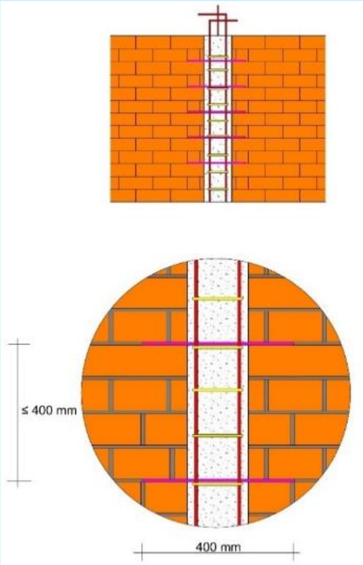


FIG. 68(C) NO TOOTHING

FIG. 68 REINFORCEMENT DETAILS OF TOOTHING IN CONFINED MASONRY WALLS

10.2 Design Considerations

10.2.1 *General*

Design considerations shall be as per geometrical requirements of 4 along with the following provisions.

10.2.2 *Structural Continuity*

Intersecting structural elements intended to act as a unit shall be joined together to resist the design forces. Walls shall be joined together to all floors, roofs or other elements which provide lateral support for the wall. Where floors or roofs are designed to transmit horizontal forces to walls, the anchorages to the walls shall be designed to resist the horizontal forces.

10.2.3 *Effective Span*

10.2.3.1 Effective span of simply supported or continuous members shall be taken as the smaller of the following:

a) Distance between centers of supports; and

b) Clear distance between supports plus an effective depth d.

10.2.3.2 Effective span of a cantilever shall be taken as greater of:

a) distance between the end of cantilever and;

b) centre of its support; and

c) face of support plus half its effective depth.

10.2.4 *Slenderness Ratio*

10.2.4.1 *Wall*

The slenderness ratio (ratio of effective height h_{eff} to effective thickness t_{ef}) shall not exceed 27 for vertically loaded reinforced masonry walls in their plane. For reinforced masonry members, such as walls subjected to out-of-plane bending and for spandrel masonry beams that are a part of wall subjected to bending in the plane of the wall, the maximum effective span to effective depth ratio shall be as given in Table 29.

10.2.4.2 *Columns*

For a column, slenderness ratio shall be taken to be the greater of the ratios of effective heights to the respective effective thickness in the two principal directions. Slenderness ratio for a load bearing unreinforced column shall not exceed 15 whereas for reinforced column the slenderness ratio should be limited to 20.

10.2.5 *Minimum Design Dimensions*

10.2.5.1 *Minimum thickness of load bearing walls columns*

The nominal thickness of masonry bearing walls in building shall not be less than 230 mm.

10.2.5.2 *Parapet wall*

Parapet walls shall be at least 200 mm thick and height shall not exceed 3 times the thickness. The parapet wall shall not be thinner than the wall below. The tie-columns shall be extended into the parapet wall and terminated at the top of the parapet in a tie-beam.

10.2.6 *Eccentricity in Columns*

Columns shall be designed for a minimum eccentricity of 10 percent of side dimension for each axis in addition to applied loads.

10.3 Requirements Governing Reinforcement and Detailing

10.3.1 *General*

This section provides requirements for the working (allowable) stress design of masonry structure neglecting the contribution of tensile strength of masonry.

Table 29 Maximum Ratio Of Effective Span to Effective Depth For Walls Subjected to Out-Of-Plane Bending

(*Clause* 10.2.4.1)

Sl No.	Boundary Conditions	Maximum Permissible Ratios	
		Effective Span to Effective Thickness (l_{ef}/t_{ef}) of Wall Subjected to Out-of-Plane Bending	Effective Span to Effective Depth (l_{ef}/d) of Beam Part of Wall Subjected to In-Plane Bending
(1)	(2)	(3)	(4)
i)	Simply supported	35	20
ii)	Continuous	45	26
iii)	Spanning in 2 directions	45	—
iv)	Cantilevered	18	7

10.3.1.1 Members are designed for composite action. Stresses shall be computed using transformed area concept of linear elastic analysis as follows:

$$A_t = A_b + m\,A_s$$

where

A_t = total transformed cross-sectional area of the member;

A_b = cross sectional area of brick;

m = modular ratio of steel reinforcement and brick; and

A_s = cross sectional area of reinforcement.

10.3.1.2 Stiffness calculation shall be based on un-cracked section properties.

10.3.2 *Steel reinforcement-allowable stresses*

10.3.2.1 *Tension*

Tensile stress in reinforcement shall not exceed the following:

a) 140 MPa in case of Mild Steel (MS) bars of diameter $\leq$ 20 mm and 130 MPa in case of MS bars of diameter > 20 mm; and

b) $0.55f_y$ in case high strength bars, where f_y is the characteristic strength of steel.

10.3.2.2 *Compression*

Compressive stress in reinforcement shall not exceed the following:

a) 130 MPa in case of MS bars; and

b) 190 MPa in case high strength bars.

10.3.3 *Size of Reinforcement*

a) The maximum size of reinforcement used in masonry shall be 25 mm diameter bars and minimum size shall not be less than 8 mm; and

b) The diameter of reinforcement shall not exceed one-half the least clear dimension of the cell, bond beam, or collar joint in which it is placed.

10.3.4 *Spacing of Reinforcement*

a) In beams, clear distance between parallel bars shall not be less than the diameter of the bars, or less than 25 mm; and

b) In columns and pilasters, clear distance between vertical bars shall not be less than 1.5 times the bar diameter, nor less than 35 mm.

10.3.5 *Anchorage*

10.3.5.1 *Development length of bars*

The development length L_{dtm} shall be taken as:

$$L_{\mathrm{dtm}} = \begin{cases} 0.25 d_{\mathrm{b}} F_{\mathrm{s}} \geq 300\ \mathrm{mm} & \text{Fe415, Fe500 and Fe550} \\ 0.40 d_{\mathrm{b}} F_{\mathrm{s}} \geq 300\ \mathrm{mm} & \text{Fe250} \end{cases}$$

where

d_{b} = nominal diameter of bar (mm); and

F_{s} = permissible tensile/compressive stress in steel (MPa).

10.3.5.2 For MS bars, L_d shall be increased by 60 percent.

10.3.5.3 *Standard hooks*

a) Standard hooks shall be formed by one of the following methods (Fig. 69):

1) 180° turn plus extension of at least 4 bar diameters but not less than 64 mm at free end of bar;

2) A 90° turn plus extension of at least 10 bar diameters at free end of bar; and

3) For stirrup and tie anchorage only a 90° or a 135° turn plus an extension of at least 5 bar diameters at the free end of the bar.

b) The diameter of bend, measured to the inside of the bar other than stirrups and ties, shall not be less than 5 bar diameters for 6 mm through 20 mm diameter bars. For 25 mm bars, a minimum bend diameter of 6 times bar diameters shall be used;

c) Inside diameter of bend for 12 mm diameter or smaller stirrups and ties shall not be less than 4 bar diameters. Inside diameter of bend for 16 mm diameter or larger stirrups and ties shall not be less than that given in (b); and

d) Hooks shall not be permitted in the tension portion of any beam, except at the ends of simple or cantilever beams or at the freely supported ends of continuous or restrained beams.

10.3.5.4 *Anchorage of reinforcement*

a) Deformed bars may be used without end anchorages provided development length requirement is satisfied. Hooks should normally be provided for plain bars in tension;

b) Bends and hooks shall conform to the requirements of Part C/Section 5 of this NBCS, and the following anchorage values shall be used:

1) *Bend* — The anchorage value of bend shall be taken as 4 times the diameter of the bar for each 45° bend subject to a maximum of 16 times the diameter of the bar,

2) *Hook* — The anchorage value of a standard U-type hook shall be equal to 16 times the diameter of the bar, and of the 135° hook end equal to 12 times diameter of the bar; and

c) For transverse reinforcement complete development length and anchorage shall be deemed to have been provided when the bar is provided with standard hook as described in **10.3.5.2**.

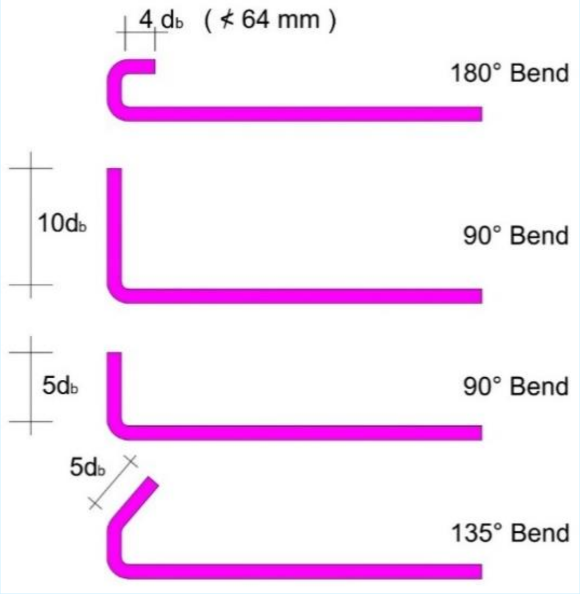


Fig. 69 Standard Hook of a Reinforcing Bar

10.3.6 *Lap Splices*

10.3.6.1 Where splices are provided in the reinforcing bars, they shall as far as possible be away from the sections of maximum stress and be staggered. It is recommended that splices in flexural members not be at sections where the bending moment is more than 50 percent of the moment of resistance; and not more than half the bars shall be spliced at a section. Where more than one-half of the bars are spliced at a section or where splices are made at points of maximum stress, special precautions shall be taken, such as increasing the length of lap and/or using closely spaced stirrups around the length of the splice.

10.3.6.2 Lap length including anchorage value of hooks for bars in flexural tension shall be L_{dtm} (*see* **10.3.5.1**) or $30d_{\mathrm{b}}$ whichever is greater and for direct tension shall be $2L_{\mathrm{dtm}}$ or $30d_{\mathrm{b}}$ whichever is greater. The straight length of the lap shall not be less than $15d_{\mathrm{b}}$ or 200 mm.

10.3.6.3 The following provisions shall also apply:

a) Where lap occurs for a tension bar located at:

   1) top of a section as cast and the minimum cover is less than twice the diameter of the lapped bar, the lap length shall be increased by a factor of 1.4; and

   2) corner of a section and the minimum cover to either face is less than twice the diameter of the lapped bar or where the clear distance between adjacent laps is less than 75 mm or 6 times the diameter of lapped bar, whichever is greater, the lap length should be increased by a factor of 1.4.

b) Where both conditions **10.3.6.3**(a)(1) and **10.3.6.3**(a)(2) apply, the lap length should be increased by a factor of 2.0; and

c) Splices in tension members (which are not part of the lateral force resisting system) shall be enclosed in closed loop hoops made of bars not less than 8 mm diameter with spacing not more than 100 mm.

10.3.7 *Curtailment of Tension Reinforcement*

10.3.7.1 In any member subjected to bending, every reinforcing bar should extend, except at end supports, beyond the point at which it is no longer needed, for a distance equal to the effective depth of the member or 12 times the diameter of the bar, whichever is the greater. The point at which reinforcement is theoretically no longer needed is where the design resistance moment of the section, considering only the continuing bars, is equal to the applied design moment. But, reinforcement should not be curtailed in a tension zone unless at least one of the following conditions is satisfied for all arrangements of design load considered:

a) reinforcing bars extend at least the anchorage length appropriate to their design strength from the point at which they are no longer required to resist bending;

b) design shear capacity at the section where the reinforcement stops are greater than twice the shear force due to design loads, at that section; and

c) continuing reinforcing bars at the section where the reinforcement stops provides double the area required to resist the bending moment at that section.

10.3.7.2 Where there is little or no end fixity for a member in bending, at least 25 percent of the area of the tension reinforcement required at mid-span should be carried through to the support. This reinforcement may be anchored in accordance with **10.3.5.3** or by providing:

a) an effective anchorage length equivalent to 12 times the bar diameter beyond the centre line of the support, where no bend or hook begins before the centre of the support; or

b) an effective anchorage length equivalent to 12 times the bar diameter plus $d/2$ from the face of the support, where d is the effective depth of the member, and no bend begins before $d/2$ inside the face of the support.

Where the distance from the face of a support to the nearer edges of a principal load is less than twice the effective depth, all the main reinforcement in a member subjected to bending should continue to the support and be provided with an anchorage equivalent to 20 times the bar diameter.

10.3.8 *Members Subjected to Flexure and Axial Forces*

10.3.8.1 A member which is subjected to axial stress less than $0.1f_m$, may be designed for bending only.

10.3.8.2 *Beams*

Reinforcement in masonry designed as beams shall provided over a support where the masonry is continuous, whether the beam has been designed as continuous or not. Where this occurs, an area of steel not less than 50 percent of the area of the tension reinforcement required at mid-span shall be provided in the top of the masonry over the support and anchored in accordance with **10.3.5.3**. In all cases, at least one quarter of the reinforcement required at mid-span shall be carried through to the support and similarly anchored.

10.3.8.3 *Columns*

The design of reinforced column shall meet the requirements given hereunder.

10.3.8.3.1 Vertical reinforcement shall not be less than 0.25 percent nor exceed 4 percent of the net area of column cross-section. The minimum number of bars shall be four.

10.3.8.3.2 *Lateral ties*

Lateral ties shall be provided in the column as per the following:

a) Longitudinal reinforcement shall be enclosed by lateral ties of at least 8 mm diameter. Vertical spacing of ties along the length of column shall be minimum of:

   1) 16 times diameter of longitudinal bar;

   2) 48 times diameter of lateral tie; and

   3) Least dimension of the column.

b) Arrangement of lateral ties is such that every corner and alternate longitudinal bar shall have lateral support provided by the corner of a lateral tie with an included angle of not more than 135°.

10.3.9 *Members Subjected to Shear*

10.3.9.1 Reinforced masonry walls may be designed taking contribution of shear reinforcement.

10.3.9.2 Where contribution of shear reinforcement is considered in resisting shear force the minimum area of shear reinforcement in the direction of force shall be determined by the following:

$$A_{v,\min} = \frac{V_s}{F_s d},$$

where

V_s = total applied shear force;

F_s = permissible stress in steel reinforcement as per **10.4.1.4**; and

d = distance from extreme compression fiber to centroid of tension reinforcement.

10.3.9.3 The maximum spacing of shear reinforcement shall not be greater than $0.5d$ or 120 mm, whichever is smaller.

10.3.9.4 In cantilever beams, maximum shear shall be used whereas for members subjected to uniformly distributed load it may be assumed that maximum shear load occurs at a distance of $0.5d$ from the face of support when the following conditions are met:

a) support reaction causes compression in the end region of the member; and

b) no concentrated load between face of support and a distance of $0.5d$ from it.

10.3.10 *Reinforcement Detailing*

10.3.10.1 *General*

Reinforcement shall be located such that it acts compositely with the masonry and various ways in which it can be used in reinforced masonry are shown in Fig. 70.

10.3.10.2 *Protection of reinforcement*

Where steel reinforcing bars are embedded in filled cavity (or pockets) or special bond construction, the bars shall have the minimum clear cover of 10 mm in mortar or a minimum clear cover of 15 mm or bar diameter, whichever is more in cement concrete (grout) so as to achieve good bond and corrosion resistance.

For the reinforcement steel placed in mortar bed joint, the minimum depth of mortar cover from the reinforcing steel to the face of masonry shall be 15 mm. Also mortar cover above and below reinforcement placed in bed joints shall not be less than 2 mm.

Reinforcing steel shall be corrosion resistant or protected adequately against corrosion. Reinforcement shall be galvanized reinforcing steel for protection against corrosion.

10.4 Structural Design

10.4.1 *Permissible Compressive Force*

Compressive force in reinforced masonry due to axial load shall not exceed that given by following equation:

$$P_0 = k_s\left(0.25 f_m A_n + 0.65 f_s A_s\right)$$

Where

k_s = stress reduction factor as per Table 10.

f_m = compressive strength of masonry;

A_n = net area of masonry;

f_s = permissible steel tensile stress; and

A_s = area of steel.

10.4.1.1 *Effective compressive width for locally concentrated reinforcement*

When the reinforcement in masonry is concentrated locally such that it cannot be treated as a flanged member (Fig. 71), the reinforced section shall be considered as having a width of not more than:

a) centre-to-centre bar spacing; and

b) 6 times the wall thickness.

10.4.1.2 *Combined permissible axial and flexural compressive stress*

For reinforced members subjected to combined axial load and flexure, the compressive stress in masonry due to combined action of axial load and bending shall not exceed 1.25f_a and compressive stress in masonry due to axial load only shall not exceed f_a. *See* Annex E.

10.4.1.3 *Permissible tensile stress*

Provisions of **5.4.2** shall apply.

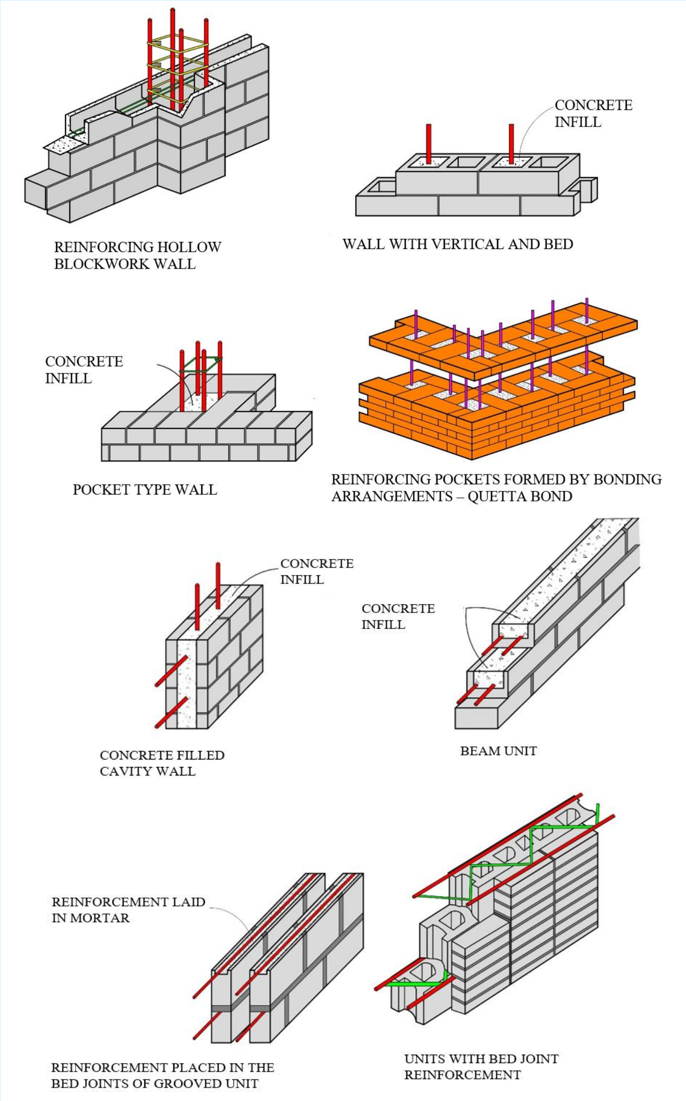

REINFORCING HOLLOW
BLOCKWORK WALL
CONCRETE
INFILL
WALL WITH VERTICAL AND BED
CONCRETE
INFILL
POCKET TYPE WALL
REINFORCING POCKETS FORMED BY BONDING ARRANGEMENTS – QUETTA BOND
CONCRETE
INFILL
CONCRETE FILLED
CAVITY WALL
CONCRETE
INFILL
BEAM UNIT
REINFORCEMENT LAID
IN MORTAR
REINFORCEMENT PLACED IN THE
BED JOINTS OF GROOVED UNIT
UNITS WITH BED JOINT
REINFORCEMENT

FIG. 70 REINFORCEMENT DETAILS

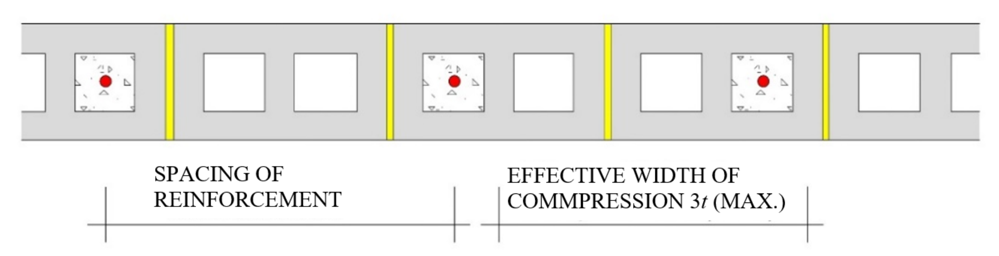

SPACING OF
REINFORCEMENT
EFFECTIVE WIDTH OF
COMMPRESSION 3t (MAX.)

FIG. 71 EFFECTIVE COMPRESSIVE WIDTH

10.4.1.4 *Permissible shear stress*

For members in flexure, the permissible shear stress shall be taken as:

$$f_v = \begin{cases} 0.083\sqrt{f_m} \leq 0.25 \text{ MPa} & \text{Walls without web reinforcement} \\ 0.250\sqrt{f_m} \leq 0.75 \text{ MPa} & \text{Walls with web reinforcement} \end{cases}$$

For walls in compression and bending, the Permissible Shear Stress for reinforced masonry walls shall be according to Table 30.

If there is tension in any part of a section of masonry, the area under tension shall be ignored while estimating the shear stress on the section.

Table 30 Permissible Shear Stress in Reinforced Masonry Walls under Compression and Bending

(*Clause* 10.4.1.4)

Sl No. (1)	Type of Wall (2)	M/Vd (3)	Permissible Shear Stress F_v (Mpa) (4)	Maximum Permissible Shear Stress $F_{v,max}$ (Mpa) (5)
i)	Without web reinforcement	< 1.0	$\frac{1}{36}\left(4 - \frac{M}{Vd}\right)\sqrt{f_m}$	$\left(0.6 - 0.2\frac{M}{Vd}\right)$
		> 1.0	$0.083\sqrt{f_m}$	0.2
ii)	With web reinforcement	< 1.0	$\frac{1}{24}\left(4 - \frac{M}{Vd}\right)\sqrt{f_m}$	$\left(0.6 - 0.2\frac{M}{Vd}\right)$
		> 1.0	$0.125\sqrt{f_m}$	0.4

10.5 Earthquake Design Requirements

10.5.1 The requirements of this section shall apply to the design and construction of reinforced masonry to improve its performance when subjected to earthquake loads. These provisions are in addition to the general requirements of **5** of Part C/Section 1 of this NBCS. *See* Annex F.

10.5.2 *Different Performance Levels of Masonry Shear Walls*

Masonry buildings rely on masonry shear walls for the lateral load resistance and can be detailed for the following three levels of earthquake performance, which can be appropriately chosen for a building considering its importance, location, and acceptable degree of damage. Table 31 summarizes the requirement for these structural walls and *R* values recommended for use in **5** of Part C/Section 1 of this NBCS.

Table 31 Reinforcement and 'R' Values for Reinforced Masonry Buildings with different Wall Types and Earthquake Zones

(*Clause* 10.5.2)

Sl No. (1)	Type of Wall (2)	Description (3)	Reinforcement (4)	Earthquake Zone (5)	R (6)
i)	RMB 1	Reinforced masonry walls with minimum reinforcement	As per **10.5.2.1**	II and III	2.5

Table 31 (*Concluded*)

Sl No. (1)	Type of Wall (2)	Description (3)	Reinforcement (4)	Earthquake Zone (5)	R (6)
ii)	RMB 2	Reinforced masonry walls with design reinforcement	As per **10.5.2.2**	All	3.0
iii)	RMB 3	Reinforced masonry walls with special design reinforcement	As per **10.5.2.2** and **10.5.2.3**	All	3.0

10.5.2.1 *Masonry buildings with walls having prescriptive reinforcement* (*RMB* 1)

The design of masonry walls shall comply with requirements of unreinforced masonry wall **4** and those given in **10.5.2.1**(**b**) and **10.5.2.1**(**c**) (*see* Fig. 72).

The requirements of this section apply to the design and construction of reinforced masonry to improve its performance when subjected to earthquake loads. These provisions are in addition to the general requirements of **4**.

a) Elastic force reduction factor R shall be taken as 3 for *Reinforced Masonry Walls*.

b) *Minimum reinforcement requirements* (Fig. 72) — The vertical reinforcement of at least 100 mm^2 in cross-sectional area shall be provided at a maximum spacing of 3 m on centre at the following critical sections:

   1) wall corners;

   2) within 400 mm of each vertical face on either side of the openings extending from plinth to roof or floor level; and

   3) within 200 mm of the vertical end of the walls.

c) *Minimum horizontal reinforcement requirement* — The horizontal reinforcement of at least 100 mm^2 in cross-sectional area shall be provided along the full height of the wall at a maximum centre-to-centre vertical spacing of 400 mm and continuously along the full perimeter of the building, and at the following critical sections:

   1) in bond beam (below window openings and above plinth level in the first storey or floor slab level in the second and higher storeys) and anchoring into the vertical reinforcement provided around the openings;

   2) within 400 mm of each horizontal face above and below of the openings, extending at least 500 mm or $40d_b$ from the vertical face of the openings, where d_b is diameter of the horizontal bar being used; and

   3) within 400 mm of the top of the walls at structurally connected roof and floor levels.

10.5.2.2 *Masonry buildings with walls having design reinforcement* (*RMB* 2)

The masonry walls with design reinforcement shall be designed with the following requirements:

a) requirements specified in **10.1** to **10.4**;

b) elastic force reduction factor (R) shall be taken as 3; and

c) requirements specified in **10.5.2.1**(**b**) and **10.5.2.1**(**c**).

10.5.2.3 *Masonry buildings with walls having special design reinforcement* (*RMB* 3)

Design of special reinforced masonry wall shall comply with the requirement of reinforced masonry as outlined in **10.5.2.2** and the following:

a) The masonry shall be uniformly reinforced in both horizontal and vertical direction such that the sum of reinforcement area in both directions shall be at least 0.2 percent of the gross cross-sectional area of the wall and minimum reinforcement area in each direction shall be not less than 0.07 percent of the gross cross-sectional area of the wall;

b) Maximum spacing of horizontal and vertical reinforcement shall be smaller of:

   1) one-third length of the wall;
   2) one-third height of the wall; and
   3) 1.2 m.

c) Minimum cross-sectional area of reinforcement in vertical direction shall be one-third of the required shear reinforcement placed in horizontal direction; and

d) Shear reinforcement placed in horizontal direction shall be anchored around vertical reinforcing bars with a 135^0 standard hook.

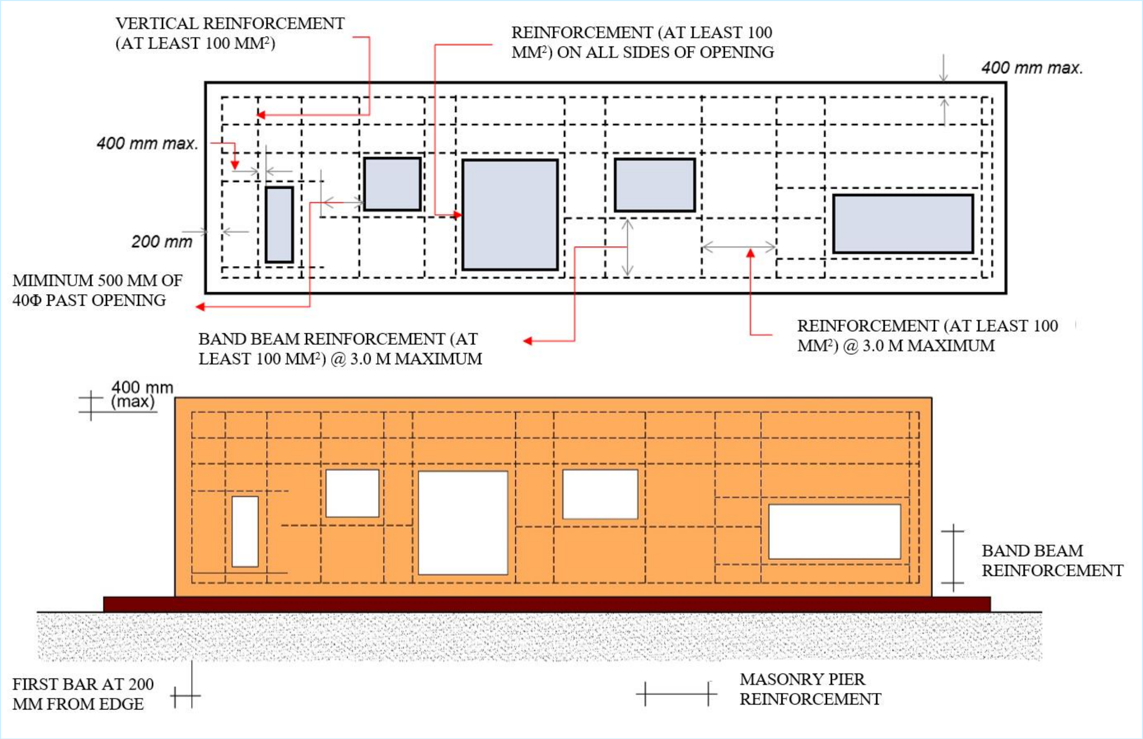

VERTICAL REINFORCEMENT (AT LEAST 100 MM²)
REINFORCEMENT (AT LEAST 100 MM²) ON ALL SIDES OF OPENING
400 mm max.
400 mm max.
200 mm
MIMINUM 500 MM OF 40Φ PAST OPENING
BAND BEAM REINFORCEMENT (AT LEAST 100 MM²) @ 3.0 M MAXIMUM
REINFORCEMENT (AT LEAST 100 MM²) @ 3.0 M MAXIMUM
400 mm (max)
BAND BEAM REINFORCEMENT
FIRST BAR AT 200 MM FROM EDGE
MASONRY PIER REINFORCEMENT

Fig. 72 Requirements of Minimum Reinforcement in Masonry Walls (RMB 1)

11 GUIDELINES FOR IMPROVING EARTHQUAKE RESISTANCE OF LOW STRENGTH MASONRY BUILDINGS

The term 'low strength masonry' includes fired brickwork laid in clay mud mortar and random rubble; uncoursed, undressed or semi-dressed stone masonry in weak mortars; such as cement sand, lime sand and clay mud. Special features of design and construction for improving earthquake resistance of buildings of low strength masonry are given in 11.1 to 11.6.5.7.

11.1 For the purpose of this clause, the terminology given in 8.1 shall apply.

11.2 General Principles

The general principles given in 9.2.1 to 9.2.5 shall be observed in construction of earthquake resistant buildings.

11.2.1 *Lightness*

Since the earthquake force is a function of mass, the weight of the building shall be as minimum as possible, consistent with structural safety and functional requirements. Roofs and upper storeys of buildings, in particular, should be designed as light as possible.

11.2.2 *Continuity of Construction*

11.2.2.1 As far as possible, the parts of the building should be tied together in such a manner that the building acts as one unit.

11.2.2.2 For integral action of building, roof and floor slabs should be continuous throughout as far as possible.

11.2.2.3 Additions and alterations to the structures should be accompanied by the provision of positive measures to establish continuity between the existing and the new construction.

11.2.3 *Projecting and Suspended Parts*

11.2.3.1 Projecting parts should be avoided as far as possible. If the projecting parts cannot be avoided, they should be properly reinforced and firmly tied to the main structure, and their design should be in accordance with good practice [C-4(7)].

NOTE — In cases where stability of projecting parts against overturning is achieved by counterweight in the form of wall, slab, etc, the overturning should be checked by increasing the weight of projecting part and decreasing the weight of stabilizing mass simultaneously in accordance with the vertical seismic coefficient specified in **4.4.2** of good practice [C-4(7)].

11.2.3.2 Ceiling plaster shall preferably be avoided. When it is unavoidable, the plaster shall be as thin as possible.

11.2.3.3 Suspended ceiling shall be avoided as far as possible. Where provided they shall be light, adequately framed and secured.

11.2.4 *Building Configuration*

11.2.4.1 In order to minimise torsion, the building should have a simple rectangular plan and be symmetrical both with respect to mass and rigidity so that the centre of mass and rigidity of the building coincide with each other. It will be desirable to use separate blocks of rectangular shape particularly in seismic zones IV and above.

NOTE — For small buildings, minor asymmetry in plan and elevation may be ignored. Designing such buildings against torsion may be difficult and uncertain.

11.2.5 *Fire Safety*

Fire frequently follows an earthquake and therefore, buildings shall be constructed to make them fire resistant in accordance with the provisions of Part F ‘Fire and Life Safety’ of this NBCS, as relevant.

11.3 Special Construction Features

11.3.1 *Foundations*

11.3.1.1 For the design of foundations, the provisions of Part C/Section 1 and Section 2 of this NBCS shall generally be followed.

11.3.1.2 The subgrade below the entire area of the building shall preferably be of the same type of the soil. Wherever this is not possible, the buildings should preferably be separated into units and then the units should be located separately.

11.3.1.3 Loose fine sand, soft silt and expansive clays should be avoided. If unavoidable, the following measures may be taken to improve the soil on which the foundation of the building may rest:

a) Sand piling/under-reamed piling/stone columns, etc; and

b) Soil stabilization.

11.3.2 *Roofs and Floors*

11.3.2.1 Flat roof or floor should not preferably be made of tiles or ordinary bricks supported on steel, timber or reinforced concrete joists, nor they shall be of a type which in the event of an earthquake is likely to be loosened and parts or all of which may fall. If this type of construction cannot be avoided, the joists should be blocked at ends and bridged at intervals such that their spacing is not altered during an earthquake.

11.3.2.1.1 For pitched roofs, corrugated iron or asbestos sheets should be used in preference to country, Allahabad or Mangalore tiles or other loose roofing units. All roofing materials shall be properly tied to the supporting members. Heavy roofing materials shall generally be avoided.

11.3.2.2 *Pent roofs*

11.3.2.2.1 All roof trusses should be supported on and fixed to timber band, reinforced concrete, or reinforced brick band. The holding down bolts should have adequate size and length as required for earthquake and wind forces.

Where a trussed roof adjoins a masonry gable, the ends of the purlins should be carried on and secured to a plate or bearer which shall be adequately bolted to reinforced concrete or reinforced brick band at the top of gable end masonry.

11.3.2.2.2 At tie level all the trusses and the gable end should be provided with diagonal braces in plan so as to transmit the lateral shear due to earthquake force to the gable walls acting as shear walls.

11.3.2.3 *Jack arches*

Jack arched roofs or floors, where used should be provided with mild steel ties in all spans along with diagonal braces in plan to ensure diaphragm actions.

11.3.3 *Staircases*

11.3.3.1 The inter-connection of the stairs with the adjacent floors should be appropriately treated by providing sliding joints at the stairs to eliminate their bracing effect on the floors. Ladders may be made fixed at one end and freely resting at the other.

11.3.3.2 *Built-in staircase*

When stairs are built monolithically with floors, they can be protected against damage by providing rigid walls at the stair opening. The walls enclosing the staircase, should extend through the entire height of the stairs and to the building foundations.

11.4 Box Type Construction

This type of construction consists of prefabricated or *in-situ* masonry walls along both the axes of the building. The walls support vertical loads and also act as shear walls for horizontal loads acting in any direction. All traditional masonry construction falls under this category. In prefabricated construction attention shall be paid to the connection between wall panels so that transfer of shear between them is ensured.

11.5 Categories of Buildings

For the purpose of specifying the earthquake resisting features in masonry and wooden buildings, the buildings have been categorized in four categories B to E based on the seismic zone and the importance of building I, where I is importance factor applicable to the building, the classification as given in **8.5** shall be applicable. The building categories are given in Table 14.

11.6 Low Strength Masonry Construction

11.6.1 Two types of construction are included herein, namely:

a) Brick construction using weak mortar; and

b) Random rubble and half-dressed stone masonry construction using different mortars such as clay mud, lime-sand and cement sand.

11.6.1.1 These constructions should not be permitted for important buildings and should preferably be avoided for building category D and shall not be used for category E (*see* Table 14).

11.6.1.2 It will be useful to provide damp-proof course at plinth level to stop the rise of pore water into the superstructure.

11.6.1.3 Precautions should be taken to keep the rain water away from soaking into the wall so that the mortar is not softened due to wetness. An effective way is to take out roof projections beyond the walls by about 500 mm.

11.6.1.4 Use of a water-proof plaster on outside face of walls will enhance the life of the building and maintain its strength at the time of earthquake as well.

11.6.1.5 Ignoring tensile strength, free standing walls should be checked against overturning under the action of design seismic coefficient, α_h, allowing for a factor of safety of 1.5.

11.6.2 *Brickwork in Weak Mortars*

11.6.2.1 The fired bricks should have a compressive strength not less than 3.5 MPa. Strength of bricks and wall thickness should be selected for the total building height.

11.6.2.2 The mortar should be lime-sand (1 : 3) or clay mud of good quality. Where horizontal steel is used between courses, cement-sand mortar (1 : 3) should be used with thickness so as to cover the steel with 6 mm mortar above and below it. Where vertical steel is used, the surrounding brickwork of 1 × 1 or 1 ½ × 1 ½ brick size depending on wall thickness should preferably be built using 1 : 6 cement-sand mortar.

11.6.2.3 The minimum wall thickness shall be one brick in one storey construction, and one brick in top storey and 1 ½ brick in bottom storeys of up to three storey construction. It should also not be less than 1/16 of the length of wall between two consecutive perpendicular walls.

11.6.2.4 The height of the building shall be restricted to the following, where each storey height shall not exceed 3.0 m:

a) For Categories B and C: three storeys with flat roof; and two storeys plus attic for pitched roof.

b) For Categories D: two storeys with flat roof; and one storey plus attic for pitched roof.

11.6.2.5 *Special bond in brick walls*

For achieving full strength of masonry, the usual bonds specified for masonry should be followed so that the vertical joints are broken properly from course to course. To obtain full bond between perpendicular walls, it is necessary to make a sloping (stepped) joint by making the corners first to a height of 600 mm and then building the wall in between them. Otherwise the toothed joint should be made in both the walls, alternatively in lifts of about 450 mm (*see* Fig. 20).

11.6.3 *Stone Masonry* (*Random Rubble or Half-Dressed*)

11.6.3.1 The construction of stone masonry of random rubble or dressed stone type should generally follow good practice [C-4(11)].

11.6.3.2 The mortar should be cement-sand (1 : 6), lime sand (1 : 3) or clay mud of good quality.

11.6.3.3 The wall thickness '*t*' should not be larger than 450 mm. Preferably it should be about 350 mm, and the stones on the inner and outer wythes should be interlocked with each other.

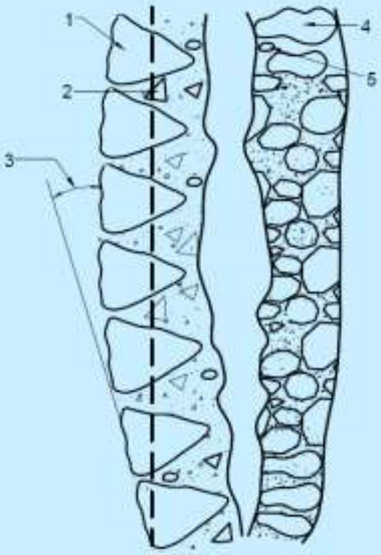
NOTE — If the two wythes are not interlocked, they tend to delaminate during ground shaking, bulge apart (*see* Fig. 73) and buckle separately under vertical load leading to complete collapse of the wall and the building.

11.6.3.4 The masonry should preferably be brought to courses at not more than 600 mm lift.

11.6.3.5 'Through' stones of full length equal to wall thickness should be used in every 600 mm lift at not more than 1.2 m apart horizontally. If full length stones are not available, stones in pairs each of about ¾ of the wall thickness may be used in place of one full length stone so as to provide an overlap between them (*see* Fig. 74).

11.6.3.6 In place of 'through' stones, 'bonding elements' of steel bars 8 mm to 10 mm diameter bent to S-shape or as hooked links may be used with a cover of 25 mm from each face of the wall (*see* Fig. 74). Alternatively, wood bars of 38 mm × 38 mm cross section or concrete bars of 50 mm × 50 mm section with an 8 mm diameter rod placed centrally may be used in place of 'through' stones. The wood should be well treated with preservative so that it is durable against weathering and insect action.

11.6.3.7 Use of 'bonding' elements of adequate length should also be made at corners and junctions of walls to break the vertical joints and provide bonding between perpendicular walls.



1. HALF-DRESSED CONICAL STONE, 2. SMALL ALIGNMENT, 3. ROTATION OF WYTHE, 4. RANDOM RUBBLE, 5. MUD OR WEAK LIME MORTAR.

FIG. 73 WALL DELAMINATED WITH BUCKLED WYTHES

11.6.3.7 Use of 'bonding' elements of adequate length should also be made at corners and junctions of walls to break the vertical joints and provide bonding between perpendicular walls.

11.6.3.8 Height of the stone masonry walls (random rubble or half-dressed) should be restricted as follows, with storey height to be kept 3.0 m maximum, and span of walls between cross walls to be limited to 5.0 m:

a) *For category B* — Two storeys with flat roof or one storey plus attic, if walls are built in lime-sand or mud mortar; and one storey higher if walls are built in cement-sand 1 : 6 mortar; and

b) *For categories C and D* — Two storeys with flat roof or two storeys plus attic for pitched roof, if walls are built in 1 : 6 cement mortar; and one storey with flat roof or one storey plus attic, if walls are built in lime-sand or mud mortar, respectively.

11.6.3.9 If walls longer than 5 m are needed, buttresses may be used at intermediate points not farther apart than 4.0 m. The size of the buttress be kept of uniform thickness. Top width should be equal to the thickness of main wall, *t*, and the base width equal to one sixth of wall height.

11.6.4 *Opening in Bearing Walls*

11.6.4.1 Door and window openings in walls reduce their lateral load resistance and hence should preferably, be small and more centrally located. The size and position of openings shall be as given in Table 32 and Fig. 21.

11.6.4.2 Openings in any storey shall preferably have their top at the same level so that a continuous band could be provided over them including the lintels throughout the building.

11.6.4.3 Where openings do not comply with the guidelines of Table 32, they should be strengthened by providing reinforced concrete lining as shown in Fig. 22 with 2 high strength deformed steel bars of 8 mm diameter.

11.6.4.4 The use of arches to span over the openings is a source of weakness and shall be avoided, otherwise, steel ties should be provided.

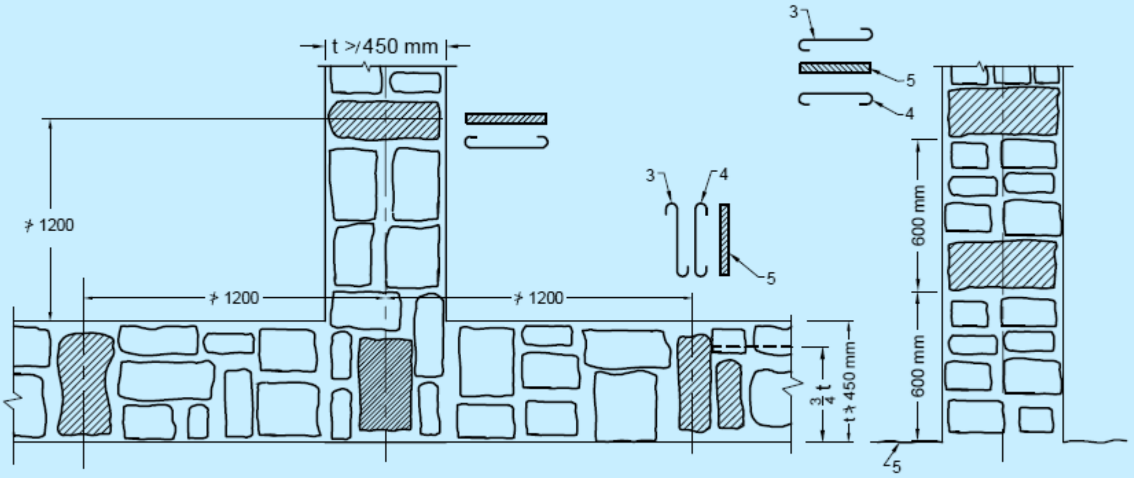


FIG.74(A) SECTIONAL PLAN OF WALL

FIG. 74(B) CROSS-SECTION OF WALL

Keys:

1. Through Stone
2 Pair of Overlapping Stone
3. S-Shape Tie
4. Hooked Tie
5. Wood Plank
6. Floor Level.

All dimensions in millimetres.

FIG. 74 THROUGH STONE AND BAND ELEMENTS

11.6.5 *Seismic Strengthening Arrangements*

11.6.5.1 All buildings to be constructed of masonry shall be strengthened by the methods as specified for various categories of buildings, listed in Table 33 and detailed in subsequent clauses. Fig. 23 and Fig. 24 show, schematically, the overall strengthening arrangements to be adopted for category D buildings, which consist of horizontal bands of reinforcement at critical levels and vertical reinforcing bars at corners and junctions of walls.

11.6.5.2 Lintel band is a band provided at lintel level on all internal and external longitudinal as well as cross walls except partition walls. The details of the band are given in **11.6.5.5**.

11.6.5.3 Roof band is a band provided immediately below the roof or floors. The details of the band are given in **11.6.5.5**. Such a band need not be provided underneath reinforced concrete or reinforced brick slabs resting on bearing walls, provided that the slabs cover the width of end walls fully.

11.6.5.4 Gable band is a band provided at the top of gable masonry below the purlins. The details of the band are given in **11.6.5.5**. This band shall be made continuous with the roof band at the eaves level.

11.6.5.5 *Details of band*

11.6.5.5.1 *Reinforced band*

The band should be made of reinforced concrete of grade not leaner than M15 or reinforced brickwork in cement mortar not leaner than 1 : 3. The bands should be of full width of the wall, not less than 75 mm in depth and should be reinforced with 2 high strength deformed steel bars of 8 mm diameter and held in position by 6 mm diameter bar links, installed at 150 mm apart as shown in Fig. 25.

NOTES

1 In coastal areas, the concrete grade shall be of grade in accordance with Part C/Section 5 of this NBCS and the filling mortar of 1 : 3 ratio (cement- sand) with water proofing admixture.

2 In case of reinforced brickwork, the thickness of joints containing steel bars should be increased to 20 mm so as to have a minimum mortar cover of 6 mm around the bar. In bands of reinforced brickwork, the area of steel provided should be equal to that specified above for reinforced concrete bands.

3 For full integrity of walls at corners and junctions of walls and effective horizontal bending resistance of bands, continuity of reinforcement is essential. The details as shown in Fig. 25 are recommended.

11.6.5.5.2 *Wooden band*

As an alternative to reinforced band, the lintel band could be provided using wood beams in one or two parallel pieces with cross elements as shown in Fig. 75.

11.6.5.6 Plinth band is a band provided at plinth level of walls on top of the foundation wall. This is to be provided where strip footings of masonry (other than reinforced concrete or reinforced masonry) are used and the soil is either soft or uneven in its properties as frequently happens in hill tracts. Where used, its section may be kept same as in **11.6.5.5.1**. This band serves as damp proof course as well.

11.6.5.7 *Vertical reinforcement*

Vertical steel at corners and junctions of walls which are up to 350 mm thick should be provided as specified in Table 34. For walls thicker than 350 mm, the area of the bars should be proportionately increased.

The vertical reinforcement should be properly embedded in the plinth masonry of foundations and roof slab or roof band so as to develop its tensile strength in bond. It should pass through the lintel bands and floor slabs or floor level bands in all storeys. Bars in different storeys may be welded or suitably lapped.

NOTES

1 Typical details of providing vertical steel in brickwork at corners and T-junctions are shown in Fig. 26.

2 For providing vertical bar in stone masonry, use of a casing pipe is recommended around which masonry be built to height of 600 mm (*see* Fig. 53). The pipe is kept loose by rotating it during masonry construction. It is then raised and the cavity below is filled with M15 (or 1 : 2 : 4) grade of concrete mix and rodded to compact it.

Table 32 Size and Position of Openings in Bearing Walls (*see* Fig. 21)

(*Clauses* 11.6.4.1, 11.6.4.3 *and Table* 34)

Sl No.	Description	Building Category	
		B and *C*	*D*
(1)	(2)	(3)	(4)
i)	Distance b_5 from the inside corner of outside wall, *Min,* mm	230	600

Table 32 (*Concluded*)

Sl No.	Description	Building Category	
		B and *C*	*D*
(1)	(2)	(3)	(4)
ii)	Total length of openings, ratio; *Max* $(b_1 + b_2 + b_3)/l_1$ or $(b_6 + b_7)/l_2$ shall not exceed:		
	a) one storeyed building; and	0.46	0.42
	d) b) 2 and 3 storeyed building	0.37	0.33
iii)	Pier width between consecutive openings, b_4, mm	450	560
iv)	Vertical distance between two openings one above the other, h_3, *Min*, mm	600	600
v)	Width of opening of ventilator, b_8, *Max*, mm	750	750

Table 33 Strengthening Arrangements Recommended for Low Strength Masonry Buildings

(*Clause* 11.6.5.1)

Sl No.	Building Category	Number of Storeys	Strengthening to be Provided
(1)	(2)	(3)	(4)
i)	*B*	1 and 2 3	*b,c,f,g* *b,c,d,f,g*
ii)	*C*	1 2 and 3	*b,c,f,g* *b,c,d,f,g*
iii)	*D*	1 and 2	*b,c,d,f,g*

where

b = lintel band (*see* **11.6.5.2**);

c = roof band and gable band where necessary (*see* **11.6.5.3** and **11.6.5.4**);

d = vertical steel at corners and junctions of walls (*see* **11.6.5.7**);

f = bracing in plan at tie level of pitched roofs (*see* **11.3.2.2.2**); and

g = plinth band, where necessary (*see* **11.6.5.6**).

NOTE — For building of category *B* in two storeys constructed with stone masonry in weak mortar, it will be desirable to provide vertical steel of 10 mm dia in both storeys.

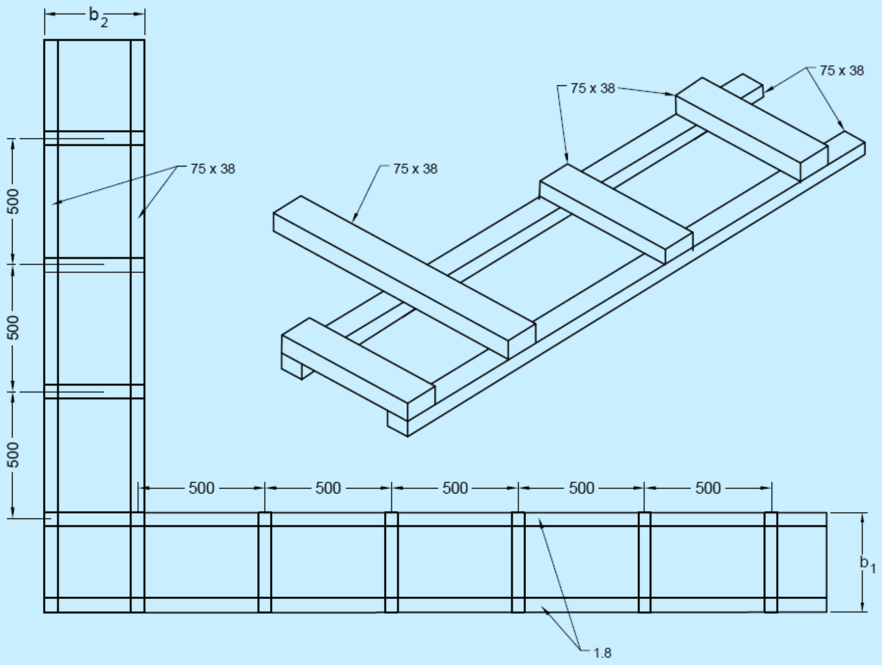


FIG. 75(A) PERSPECTIVE VIEW FIG. 75(B) PLAN OF BAND

All dimensions in millimetres.

FIG. 75 WOODEN BAND FOR LOW-STRENGTH MASONRY BUILDINGS

Table 34 Vertical Steel Reinforcement in Low Strength Masonry Walls

(*Clauses* 11.6.5.7)

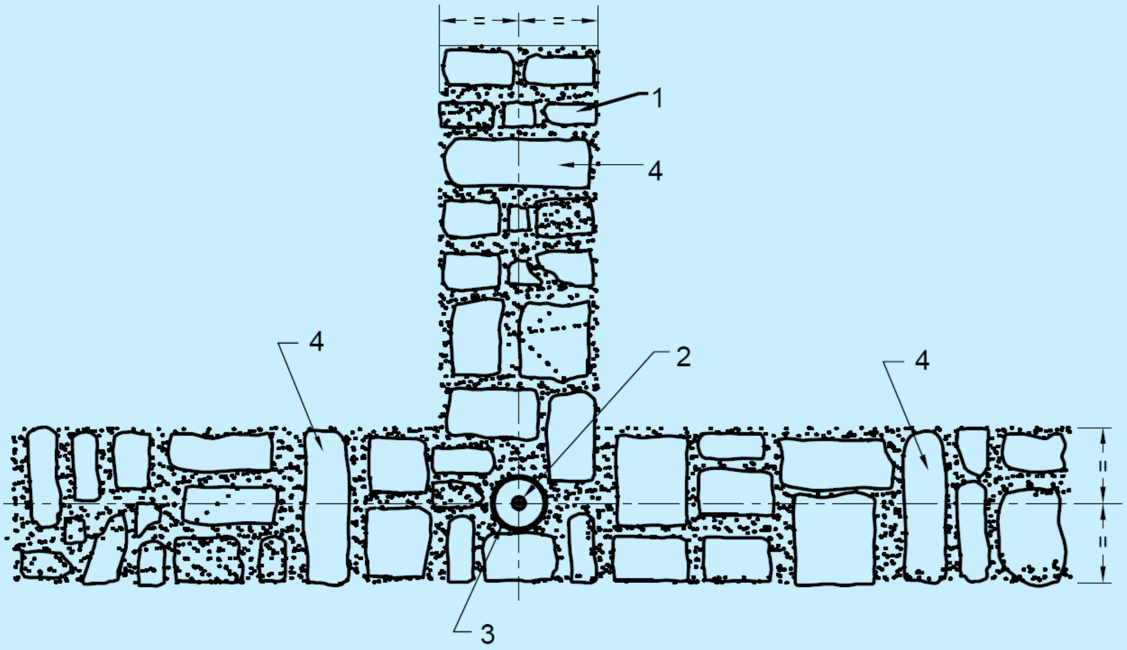
Sl No.	No. of Storeys	Storey	Diameter of HSD Single Bar; in mm, at Each Critical Section for		
			Category *B*	Category *C*	Category *D*
(1)	(2)	(3)	(4)	(5)	(6)
i)	One	—	Nil	Nil	10
ii)	Two	a) Top	Nil	10	10
		b) Bottom	Nil	10	12
iii)	Three	a) Top	10	10	10
		b) Middle	10	10	12
		c) Bottom	12	12	12

NOTES

1 The diameters given above are for high strength deformed bars with yield strength 415 MPa. For mild-steel plain bars, use equivalent diameters.

2 The vertical bars should be covered with concrete of M15 grade or with mortar 1 : 3 (cement-sand) in suitably created pockets around the bars (*see* Fig. 26 and Fig. 76). This will ensure their safety from corrosion and good bond with masonry.

3 For category *B* two storey stone masonry buildings, *see* Note under Table 32.



1. STONE WALL,
2. VERTICAL STEEL BAR,
3. CASING PIPE,
4. THROUGH STONE OR BONDING ELEMENT.

FIG. 76 TYPICAL CONSTRUCTION DETAIL FOR INSTALLING VERTICAL STEEL BAR IN RANDOM RUBBLE STONE MASONRY

12 MASONRY WALLS USING RAT-TRAP BOND TECHNOLOGY

This type of masonry shall be applicable for masonry structures of not more than 2 storeys constructed in seismic zones II and III. For buildings in other seismic zones, this type of masonry wall shall be used only in non-load bearing applications such as partition walls. The provisions for this type of masonry shall be as given in Annex G.

13 SUSTAINABILITY IN MASONRY CONSTRUCTION

The sustainability of masonry structures is addressed by quantifying embodied carbon in the structural system and the sources/types of materials used. For guidelines for selection of materials for masonry and assessing the embodied carbon in the masonry systems, the relevant provisions of the relevant guidelines on sustainability may be followed (Handbook on Approach to Sustainability).

14 NOTATIONS AND SYMBOLS

The various notations and letter symbols used in the text of the Section shall have the meaning as given in Annex H.

ANNEX A

(*Clause* 4.7)

SOME GUIDELINES FOR ASSESSMENT OF ECCENTRICITY OF LOADING ON WALLS

A-1 Where a reinforced concrete roof and floor slab of normal span (not exceeding 30 times the thickness of wall) bear on external masonry walls, the point of application of the vertical loading shall be taken to be at the centre of the bearing on the wall. When the span is more than 30 times the thickness of wall, the point of application of the load shall be considered to be displaced from the centre of bearing towards the span of the floor to an extent of one-sixth the bearing width.

A-2 In case of a reinforced concrete slab of normal span (that is, less than 30 times the thickness of the wall), which does not bear on the full width of the wall and 'cover tiles or bricks' are provided on the external face, there is some eccentricity of load. The eccentricity may be assumed to be one-twelfth of the thickness of the wall.

A-3 Eccentricity of load from the roof/floor increases with the increase in flexibility and thus deflection of the slabs. Also, eccentricity of loading increases with the increase in fixity of slabs/beams at supports. Precast RCC slabs are better than *in-situ* slabs in this regard because of very little fixity. If supports are released before further construction on top, fixity is reduced.

A-4 Interior walls carrying continuous floors are assumed to be axially loaded except when carrying very flexible floor or roof systems. The assumption is valid also for interior walls carrying independent slabs spanning from both sides, provided the span of the floor on one side does not exceed that on the other by more than 15 percent. Where the difference is greater, the displacement of the point of application of each floor load shall be taken as one-sixth of its bearing width on the wall and the resultant eccentricity calculated therefrom.

A-5 For timber and other lightweight floors, even for full width bearing on wall, an eccentricity of about one-sixth may be assumed due to deflection. For timber floors with larger spans, that is, more than 30 times the thickness of the wall, eccentricity of one-third the thickness of the wall may be assumed.

A-6 In multi-storeyed buildings, fixity and eccentricity have normally purely local effect and are not cumulative. They just form a constant ripple on the downward increasing axial stress. If the ripple is large, it is likely to be more serious at upper levels where it can cause cracking of walls than lower down where it may or may not cause local over-stressing.

NOTE — The resultant eccentricity of the total loads on a wall at any level may be calculated on the assumption that immediately above a horizontal lateral support, the resultant eccentricity of all the vertical loads above that level is zero.

A-7 For a wall corbel to support some load, the point of application of the load shall be assumed to be at the centre of the bearing on the corbel.

ANNEX B

(*Clauses* 5.4.1 *and* 5.4.5)

CALCULATION OF BASIC COMPRESSIVE STRESS OF MASONRY BY PRISM TEST

B-1 DETERMINATION OF COMPRESSIVE STRENGTH OF MASONRY BY PRISM TEST

When compressive strength of masonry (f_m) is to be established by tests, it shall be done in advance of the construction, using prisms built of similar materials under the same conditions with the same bonding arrangement as for the structure. In building the prisms, moisture content of the units at the time of laying, the consistency of the mortar, the thickness of mortar joints and workmanship shall be the same as will be used in the structure. Assembled specimen shall be at least 400 mm high and shall have a height to thickness ratio (h/t) of at least 2 but not more than 5. If the h/t ratio of the prisms tested is less than 5 in case of brickwork and more than 2 in case of blockwork, compressive strength values indicated by the tests shall be corrected by multiplying with the factor indicated in Table 35.

Table 35 Correction Factors for Different *h*/*t* Ratios

(*Clause* B-1)

Sl No.	Ratio of height to thickness (h/t)	Correction factors for brickwork[1]	Correction factors for blockwork[1]
(1)	(2)	(3)	(4)
i)	2.0	0.73	1.00
ii)	2.5	0.80	—
iii)	3.0	0.86	1.20
iv)	3.5	0.91	—
v)	4.0	0.95	1.30
vi)	5.0	1.00	1.37

[1] Interpolation is valid for intermediate values.

Prisms shall be tested after 28 days between sheets of nominal 4 mm plywood, slightly longer than the bed area of the prism, in a testing machine, the upper platform of which is spherically seated. The load shall be evenly distributed over the whole top and bottom surfaces of the specimen and shall be applied at the rate of 350 kN/m to 700 kN/m. The load at failure should be recorded.

B-2 CALCULATION OF BASIC COMPRESSIVE STRESS

Basic compressive stress of masonry shall be taken to be equal to 0.25 f_m where f_m is the value of compressive strength of masonry as obtained from prism test.

ANNEX C

(*Clauses* 5.3.3 *and* 5.4.1.5)

GUIDELINES FOR DESIGN OF MASONRY SUBJECTED TO CONCENTRATED LOADS

C-1 EXTENT OF DISPERSAL OF CONCENTRATED LOAD

For concentric loading, maximum spread of a concentrated load on a wall may be taken to be equal to b+4t (b is width of bearing and t is thickness of wall), or stretch of wall supporting the load, or centre-to-centre distance between loads, whichever is less.

C-2 INCREASE IN PERMISSIBLE STRESS

C-2.1 When a concentrated load bears on a central strip of wall, not wider than half the thickness of the wall and is concentric, bearing stress in masonry may exceed the permissible compressive stress by 50 percent, provided the area of supporting wall is not less than three times the bearing area.

C-2.2 If the load bears on full thickness of wall and is concentric, 25 percent increase in stress may be allowed.

C-2.3 For loading on central strip wider than half the thickness of the wall but less than full thickness, increase in stress may be worked out by interpolation between values of increase in stresses as given in **C-2.1** and **C-2.2**.

C-2.4 In case concentrated load is from a lintel over an opening, an increase of 50 percent in permissible stress may be taken, provided the supporting area is not less than 3 times the bearing area.

C-3 CRITERIA OF PROVIDING BED BLOCK

C-3.1 If a concentrated load bears on one end of a wall, there is a possibility of masonry in the upper region developing tension. In such a situation, the load should be supported on an RCC bed block (of M20 Grade) capable of taking tension.

C-3.2 When any section of masonry wall is subjected to concentrated as well as uniformly distributed load and resultant stress, computed by making due allowance for increase in stress on account of concentrated load, exceeds the permissible stress in masonry, a concrete bed block (of M20 Grade) should be provided under the load in order to relieve stress in masonry. In concrete, angle of dispersion of concentrated load is taken to be 45° to the vertical.

C-3.3 In case of cantilevers and long span beams supported on masonry walls, indeterminate but very high edge stresses occur at the supports and in such cases it is necessary to relieve stress on masonry by providing concrete bed block of M20 Grade concrete. Similarly when a wall is subjected to a concentrated load from a beam which is not sensibly rigid (for example, a timber beam or an RS joist), a concrete bed block should be provided below the beam in order to avoid high edge stress in the wall because of excessive deflection of the beam.

ANNEX D

(*Clause* 5.5.5)

GUIDELINES FOR APPROXIMATE DESIGN OF NON-LOAD BEARING WALL

D-1 PANEL WALLS

A panel wall may be designed approximately as under, depending upon its support conditions and certain assumptions:

a) when there are narrow tall windows on either side of panel, the panel spans in the vertical direction. Such a panel may be designed for a bending moment of $PH/8$, where P is the total horizontal load on the panel and H is the height between the centres of supports. Panel wall is assumed to be simply supported in the vertical direction;

b) when there are long horizontal windows between top support and the panel, the top edge of the panel is free. In this case, the panel should be considered to be supported on sides and at the bottom, and the bending moment should depend upon height to length ratio of panel and flexural strength of masonry. Approximate values of bending moments in the horizontal direction for this support condition, when ratio (μ) of flexural strength of wall in the vertical direction to that in horizontal direction is assumed to be 0.5, are given in Table 36; and

c) When either there are no window openings or windows are of 'hole-in-wall' type, the panel is considered to be simply supported on all four edges. In this case also, amount of maximum bending moment depends on height to length ratio of panel and ratio (μ) of flexural strength of masonry in vertical direction to that in the horizontal direction. Approximate values for maximum bending moment in the horizontal direction for masonry with $\mu = 0.50$, are given in Table 37.

Table 36 Bending Moments in Laterally Loaded Panel Walls, Free at Top Edge and Supported on Other Three Edges

[*Clause* D-1 (b)]

Sl No.	$\dfrac{\textbf{Height of Panel, } H}{\textbf{Length of Panel, } L}$	**Bending Moment**
(1)	(2)	(3)
i)	0.30	$P.L/25$
ii)	0.50	$P.L/18$
iii)	0.75	$P.L/14$
iv)	1.00	$P.L/12$
v)	1.25	$P.L/11$
vi)	1.50	$P.L/10.5$
vii)	1.75	$P.L/10$

NOTE — For H/L ratio less than 0.30, the panel should be designed as a free-standing wall and for H/L ratio exceeding 1.75, it should be designed as a horizontally spanning member for a bending moment value of $PL/8$.

Table 37 Bending Moments in Laterally Loaded Panel Walls Supported on All Four Edges

[*Clause* D-1 (c)]

Sl No. (1)	$\frac{\text{Height of Panel}, H}{\text{Length of Panel}, L}$ (2)	Bending Moment (3)
viii)	0.30	$P.L/72$
ix)	0.50	$P.L/36$
x)	0.75	$P.L/24$
xi)	1.00	$P.L/18$
xii)	1.25	$P.L/15$
xiii)	1.50	$P.L/13$
xiv)	1.75	$P.L/12$

NOTE — When H/L is less than 0.30, value of bending moment in the horizontal direction may be taken as nil and panel wall may be designed for a bending moment value of $PH/8$ in the vertical direction; when H/L exceeds 1.75, panel may be assumed to be spanning in the horizontal direction and designed for bending moment of $PL/8$.

D-2 CURTAIN WALLS

Curtain walls may be designed as panel walls taking into consideration the actual supporting conditions.

D-3 PARTITION WALLS

D-3.1 These are internal walls usually subjected to much smaller lateral forces. Behaviour of such wall is similar to that of panel wall and these could, therefore, be designed on similar lines. However, in view of smaller lateral loads, ordinarily these could be apportioned empirically as follows:

a) Walls with adequate lateral restraint at both ends but not at the top :
   1) the panel may be of any height, provided the length does not exceed 40 times the thickness;
   2) the panel may be of any length, provided the height does not exceed 15 times the thickness (that is, it may be considered as a free-standing wall); or
   3) where the length of the panel is over 40 times and less than 60 times the thickness, the height plus twice the length may not exceed 135 times the thickness;

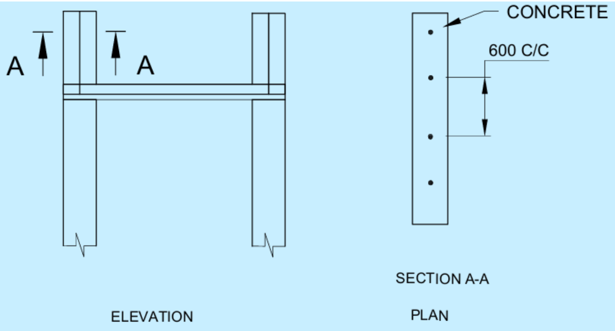
b) Walls with adequate lateral restraint at both ends at the top:
   1) the panel may be of any height, provided the length does not exceed 40 times the thickness;
   2) the panel may be of any length, provided the height does not exceed 30 times the thickness; or
   3) where the length of the panel is over 40 times and less than 110 times the thickness, the length plus three times the height should not exceed 200 times the thickness; and

c) When walls have adequate lateral resistant at the top but not at the ends, the panel may be of any length, provided the height does not exceed 30 times the thickness.

D-3.2 Strength of bricks used in partition walls should not be less than 3.5 N/mm^2 or the strength of masonry units used in adjoining masonry, whichever is less. Grade of mortar should not be leaner than M2.

D-4 CANTILEVER PROJECTIONS

D-4.1 The provisions given under **5** of Part C/Section 1 of this NBCS shall be applicable. As a general guide, the details of connection between parapets and slabs for existing structures shall be as given in Fig. 77.



NOTES

1. HOLE SHALL BE MADE IN BRICKS IN ADVANCE TO ACCOMMODATE THE REINFORCEMENT BARS OF SLAB.
2. BOTTOM BAR OF SLAB CONTINUED IN THE PARAPET AT SPACING OF 600 mm c/c.

FIG. 77 PARAPET WALLS

ANNEX E

(*Clause* 10.4.1.2)

TYPICAL ITERATIVE METHOD FOR WALLS SUBJECTED TO FLEXURE AND AXIAL LOAD

E-1 There is no closed form solution available for the computation of stress in walls due to combined action of bending and axial compression. Engineers normally prefer to use Design charts for computation of stresses in such conditions, but design charts for most masonry systems are not readily available. Therefore, iterative methods are used as most common tools for masonry structures. Two types of iterative procedures are given below, which can be used to analyse the adequacy of the section under specified load and determine the amount of reinforcement required, wherever necessary.

E-2 ITERATIVE PROCEDURE 1

Fig. 78 shows a diagram of a wall subjected to an axial load and bending moment. The same diagram is applicable to both in-plane and out-of-plane bending of walls. There are three possible conditions for the wall:

a) wall is uncracked;

b) wall is cracked with the steel in compression (the extent of the crack has not reached the steel); or

c) wall is cracked with the steel in tension.

Fig. 78 shows the interaction between bending moment and axial load. Loading conditions beyond the limits of the diagram are beyond the allowable stresses. The condition of the wall can be quickly diagnosed by using the non-dimensional parameter M/Pd. This parameter represents a straight line radiating from the diagram's origin as shown in Fig. 79. By summing moments, it can be shown that certain values of M/Pd divide the diagram into three regions. These values are given in Table 38. The allowable moments for regions 1 and 2 can be obtained in closed form with simple equations. But in region 3, it is complicated a bit. The process consists of initial assumption of thickness, length and other necessary parameters and determination of the amount of steel required.

For region 3, the process starts with another assumption that the tension in steel controls. By making an initial guess about the location of the neutral axis, the expressions for M_p and a_2 provide an iterative process that quickly converges. The equations are derived from the summation of forces and moments and by using linear stress-strain relationships. The equations should always converge for all values of P, l_w, M, and n. If convergence is not obtained, it is likely that the assumed initial value of a has exceeded d. The initial value of a is to be reduced and same procedure is to be repeated. The iteration will often result in a negative steel area. This signifies that the element does not need reinforcement to resist the loads within the allowable stresses, even though the section is cracked (region 3).

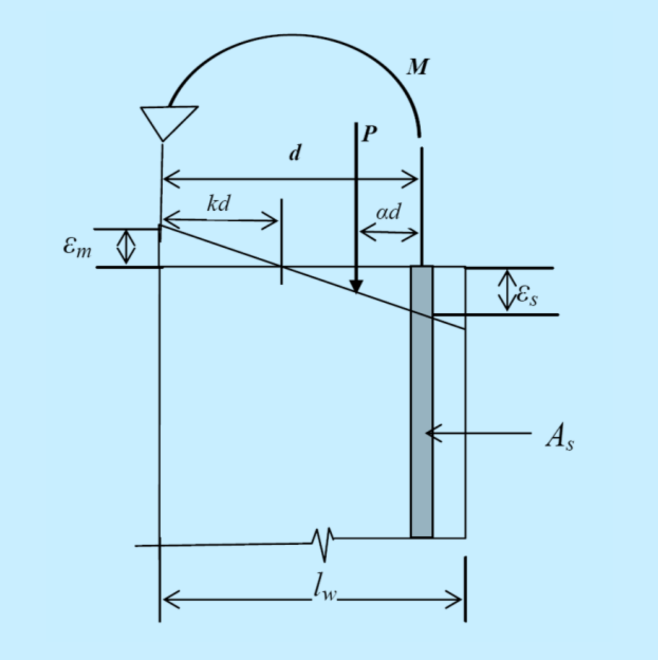

M
P
d
kd
αd
ε_m
ε_s
A_s
l_w

FIG. 78 FLEXURE AND AXIAL WALL LOADING

Following convergence, a check is made of the initial assumption that tension in steel controls. If not valid, then the compression controls and a new set of equations that do not require iteration are used.

E-3 The following is a detailed step-by-step procedure of the analysis methodology described above:

a) Step 1 — Determine the wall condition:

1) calculate α as the distance from the axial load to the centroid of the tension steel divided by *d*;
2) calculate the quantity M/*Pd*; and
3) use Table 38 to determine the region for analysis. (*see* Fig. 78).

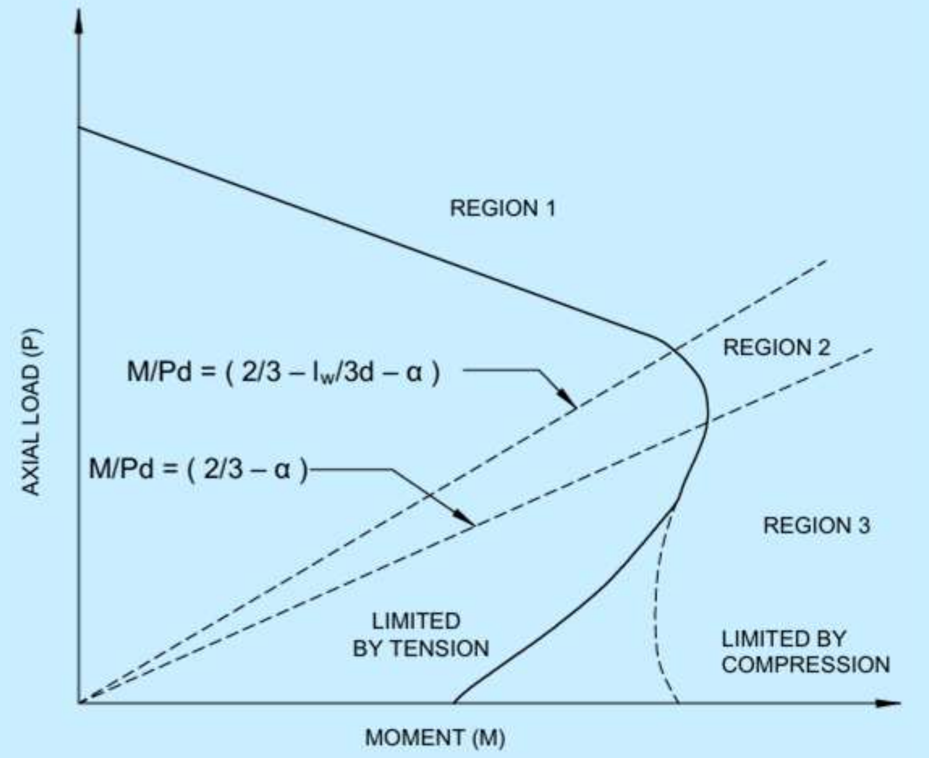

AXIAL LOAD (P)
REGION 1
REGION 2
REGION 3
M/Pd = (2/3 – l_w/3d – α)
M/Pd = (2/3 – α)
LIMITED BY TENSION
LIMITED BY COMPRESSION
MOMENT (M)

FIG. 79 INTERACTION DIAGRAM

Table 38 Flexure and Axial Loading — Wall Analysis

(*Clauses* E-2 *and* E-3)

Sl No. (1)	Region (2)	Condition of Wall (3)	Test (4)
i)	1	Wall is in compression and not cracked	$\frac{M}{Pd} \leq \left[1 - \frac{l_w}{3d} - \alpha\right]$
ii)	2	Wall is cracked but steel is in compression	$\frac{M}{Pd} \leq \left[\frac{2}{3} - \alpha\right]$
iii)	3	Wall is cracked and steel is in tension	$\frac{M}{Pd} > \left[\frac{2}{3} - \alpha\right]$

b) Step 2 — Calculate the allowable moment:

1) Region 1 — The moment is limited by flexural compression in the masonry;

$$M_m = \frac{b l_w^2}{6} F_b - P \frac{l_w}{6}$$

If M_m is greater than M applied, the section is satisfactory.

2) Region 2 — The moment is also limited by flexural compression in the masonry; and

$$M_m = P(1 - \alpha)d - \frac{2}{3}\left[\frac{P^2}{F_b b}\right]$$

If M_m is greater than M applied, the section is satisfactory.

3) Region 3 — The moment may be limited by either the compression in the masonry or tension in the steel. An iterative approach as below shall be adopted.

   i) Assume a compression centroid location, a; and

   ii) Perform the following iteration that assumes the tension in the steel controls (remember that A_s may be negative).

$$M_p = P\left(\frac{l_w}{2} - \alpha\right)$$

$$A_s = \frac{M - M_p}{F_s(d - a)}$$

$$\zeta = \frac{(P + A_s F_s)n}{F_b b}$$

$$a_2 = \frac{\sqrt{\zeta^2 + 2\zeta d} - \zeta}{3}$$

where

a = estimate of internal compression load centroid distance from the extreme compression fibre;

A_s = area of trim or edge steel;

b = width of the wall for out-of-plane bending (thickness of wall for in-plane bending);

d = distance from the extreme compression fibre to the steel centroid;

F_s = allowable steel tension stress;

I_w = width of the wall for in-plane bending (thickness of wall for out of plane bending);

M = applied moment;

M_p = moment of applied axial load with respect to the centroid of internal compression force; and

P = applied axial load at the centre of the wall.

Use a_2 for a, and repeat until the value of a converges.

c) Step 3 — If the iteration converges and the resulting a is less than the following value, the wall is limited by the tension reinforcement and the analysis is complete. Otherwise continue to step 4:

$$\mathrm{a} = \frac{d}{3\left(1 + \dfrac{F_s/F_b}{n}\right)}$$

d) Step 4 — If the value of a is larger than the above value, determine the required steel area using the following:

$$a = \frac{d}{2} - \sqrt{\left(\frac{d^2}{4} - \frac{2(P\alpha d + M)}{3F_b b}\right)}$$

If $\sqrt{\left(\frac{d^2}{4} - \frac{2(P\alpha d + M)}{3F_b b}\right)}$ is negative, there is inadequate compression capacity.

Increase b or F_b or both. The steel area is:

$$A_s = \frac{\left(\dfrac{3F_b ab}{2} - P\right)}{\left[nF_b\left(\dfrac{d}{3a} - 1\right)\right]}$$

In all cases the wall trim steel should not be less than minimum values.

E-4 ITERATIVE PROCEDURE

The following is another procedure to determine the state of stress in wall elements subjected to combined action of bending and axial compression. Free body diagram of a wall with axial load, bending moment, and tensile and compressive forces is given in Fig. 80. The location of C is based on the neutral axis location kd. The location of T is at the centroid of the reinforcement.

The problem can be solved by taking moments about the centerline of the wall, the tensile reinforcement (assuming that masonry compressive stresses control), or the compressive force (assuming that the stresses in the reinforcement control). By inserting the allowable value of stresses, which is assumed to control, a quadratic equation in terms of kd may be developed and solved.

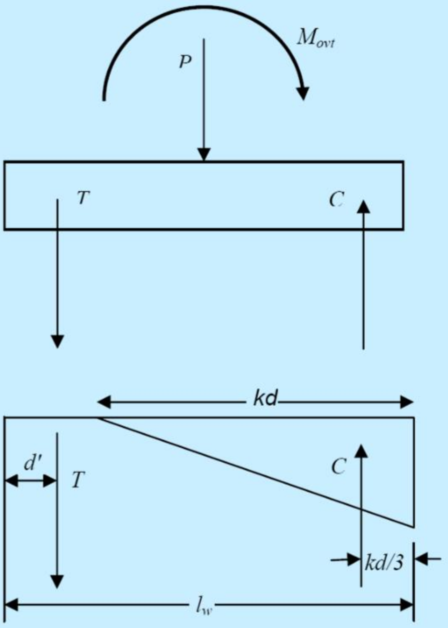


FIG. 80 FLEXURE BODY DIAGRAM OF A WALL

For example if P is at the centerline of the wall, taking moments about the centroid of the tensile reinforcement results in the equation:

$$C\left[\left(l_w - d'\right) - \left(\frac{kd}{3}\right)\right] = P\left(\frac{l_w}{2} - d'\right) + M$$

but $C = \frac{1}{2} F_m bkd$ and $l_w - d' = d$. Then:

$$\frac{1}{2} F_m bkd\left(d - \frac{kd}{3}\right) = P\left(\frac{l_w}{2} - d'\right) + M$$

Dividing both side by $\frac{1}{2} F_m b$ results in

$$kd^2 - \frac{(kd)^2}{3} = \frac{P\left(\frac{l_w}{2} - d'\right) + M}{\frac{1}{2} F_m b}$$

Multiplying by -3 and rearranging terms:

$$(kd)^2 - 3d(kd) + \frac{3\left[P\left(\frac{l_w}{2} - d'\right) + M\right]}{\frac{1}{2} F_m b} = 0$$

$$kd = \frac{3d - \sqrt{(-3d)^2 - 4\left(\frac{3\left[P\left(\frac{l_w}{2} - d'\right) + M\right]}{\frac{1}{2} F_m b}\right)}}{2}$$

Inserting the values for P, M, l_w, b, d and F_m yields kd. Note that this method is iterative since a location of d' shall be assumed.

Having solved for kd one can calculate C.

By $\Sigma F_v = 0$, $T = C - P$

From strain compatibility:

$$f_s = \left(\frac{1-k}{k}\right) nF_m \text{, Thus } f_s \text{ can be calculated.}$$

If $f_s < F_s$, the masonry compressive stress controls and the solution is finished by calculating $A_s = T/f_s$. If however, $f_s > F_s$ the assumption that masonry stresses control is incorrect, and the neutral axis location is wrong.

A good starting assumption to calculate f_m is to take T assuming that masonry compressive stresses control, and to divide by F_s to get a trial A_s. This allows the designer to choose a bar layout and verify the initial assumption of d', the distance to the centroid of reinforcement.

$$A_s = T/F_s$$

Since $C = T + P$ the effects of the axial load can be included by using an effective amount of reinforcement.

$$(A_s)_{\text{eff}} = A_s + \frac{P}{F_s} \; (or \frac{T+P}{F_s})$$

$$\rho_{\text{eff}} = \frac{(A_s)_{\text{eff}}}{bd}$$

$$k = \left[(n\rho)^2 + 2n\rho\right]^{\frac{1}{2}} - n\rho$$

$$j = 1 - \frac{k}{3}$$

The steel stress may be checked using

$$f_s = \frac{M'}{(A_s)_{\text{eff}} \, jd}$$

where

$$M' = P\left(\frac{l_w}{2} - d'\right) + M$$

$$T_{\text{eff}} = (A_s)_{\text{eff}} \times f_s$$

$$T = T_{eff} - P$$

The masonry stress may be checked by using:

$$f_m = \frac{2M'}{bjkd^2}$$

If $f_s > F_s$, a second iteration may be required may be required with a larger bar size or an extra bar. In a shear wall if an extra bar is added, the value of d', and the moments calculated using:

$$P\left(\frac{l_w}{2} - d'\right) + M$$

will need to be re-evaluated. Then one can reiterate from:

$$(A_s)_{\text{eff}} = A_s + \frac{P}{F_s}$$

to reduce f_s so that it is less than F_s.

ANNEX F

(*Clause* 10.5.1)

DISTRIBUTION OF LATERAL FORCES IN THE PIERS OF A MASONRY WALL

F-1 Masonry walls are often seen to be perforated to make arrangement for windows and doors. The distribution of lateral force in a masonry wall is dependent on the position of the openings and the relative rigidity of the masonry piers created due to the presence of the openings in the masonry wall. The relative rigidity is dependent on the height by length ratio (h/L ratio) of the piers and the end conditions of those masonry piers as the deflection of the masonry piers due to horizontal loading changes due to the end condition of the piers (*see* Fig. 81). Here is a simple process is described which can be used to distribute the lateral force in a wall which can be considered to be consist of some piers with some specific arrangements.

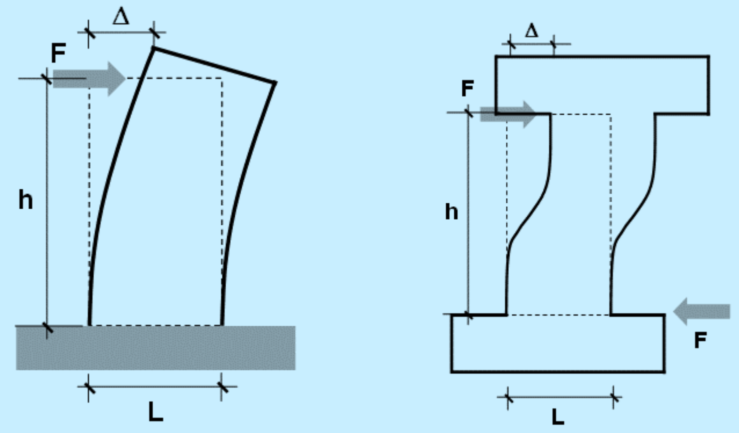


FIG. 81(A) CANTILEVERED WALL OR PIER (TOP FREE TO ROTATE)

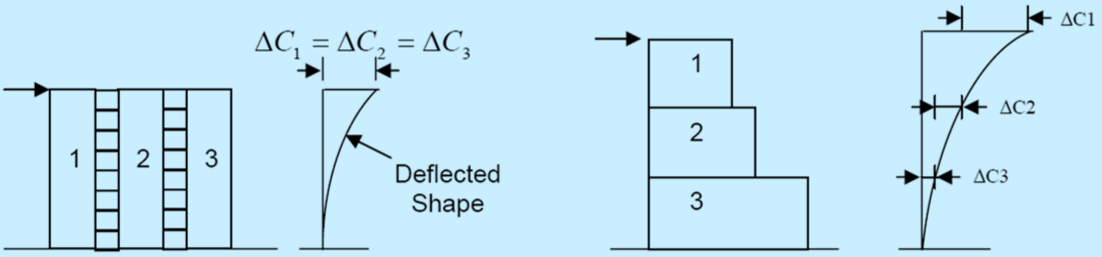
FIG. 81(B) PIER BETWEEN OPENINGS (TOP RESTRAINED FROM ROTATION)

FIG. 81 DEFLECTION DUE TO END CONDITIONS OF PIERS

F-2 In any kind of placing of opening, the wall can be represented as a horizontal and vertical combination of piers with their respective end condition which will be used to find out their rigidities. Where large openings occur, it is difficult to obtain effective coupling of the wall segments or piers. If the wall is analysed as a horizontal combination of piers as shown in the Fig. 82 (a) and the combined rigidity

$$R = R_{c1} + R_{c2} + R_{c3}$$

where R_{c1} , R_{c2} , R_{c3} are the rigidities of the piers 1, 2, 3, respectively.



(a) HORIZONTAL COMBINATION OF WALL SEGMENTS

(b) VERTICAL COMBINATION OF WALL SEGMENTS

FIG. 82 WALL COMBINATIONS FOR CALCULATING RIGIDITIES OF WALLS WITH OPENINGS

If the segments are combined vertically, as shown in Fig. 82 (b), the combined rigidity can be calculated as:

$$R = \frac{1}{\Delta C_1 + \Delta C_2 + \Delta C_3} = \frac{1}{\dfrac{1}{R_{c1}} + \dfrac{1}{R_{c2}} + \dfrac{1}{R_{c3}}}$$

Where R_{c1}, R_{c2} , R_{c3} are the rigidities of the piers 1, 2, 3 respectively. Combination of these two types can be used to find the effective relative stiffness of a masonry wall.

The expression ignores the rotations that occur at the tops of segment 2 and 3 and therefore overestimates the rigidity of the wall. Along with this, it is valid only for the application of loads at the top level of the building.

As already said the rigidity R of the pier is dependent on its dimensions, modulus of elasticity E, modulus of rigidity G, and the support conditions. For a cantilever pier the displacement due to combined action of bending and shear is

$$\Delta_c = \frac{Fh^3}{3EI} + \frac{1.2Fh}{GA}$$

where

A = area of the pier = Lt;

F = horizontal force applied to the pier;

G = modulus of Rigidity = $0.4E_m$;

h = height of the pier;

I = moment of inertia of pier = $tL^3/12$;

L = length of the pier; and

t = thickness of pier.

So, displacement of the cantilever pier is:

$$\Delta C = \frac{1}{Et}\left[4\left(\frac{h}{L}\right)^3 + 3\left(\frac{h}{L}\right)\right]$$

The rigidity of a wall is proportional to the inverse of the deflection. For cantilever walls the rigidity will be:

$$R_c = \frac{1}{\Delta C} = \frac{Et}{\left[4\left(\frac{h}{L}\right)^3 + 3\left(\frac{h}{L}\right)\right]}$$

$$\Rightarrow \frac{R_c}{Et} = \frac{1}{\left[4\left(\frac{h}{L}\right)^3 + 3\left(\frac{h}{L}\right)\right]}$$

For a pier with both ends fixed against rotation the deflection due to combined action of bending and shear will be:

$$\Delta f = \frac{Fh^3}{12EI} + \frac{1.2Fh}{GA} = \frac{F}{Et}\left[\left(\frac{h}{L}\right)^3 + 3\left(\frac{h}{L}\right)\right]$$

$$\Rightarrow \frac{R_f}{E_t} = \frac{1}{\left[\left(\frac{h}{L}\right)^3 + 3\left(\frac{h}{L}\right)\right]}$$

Values of R/E_t for different h/L ratio can be taken from the chart in the Fig. 83.

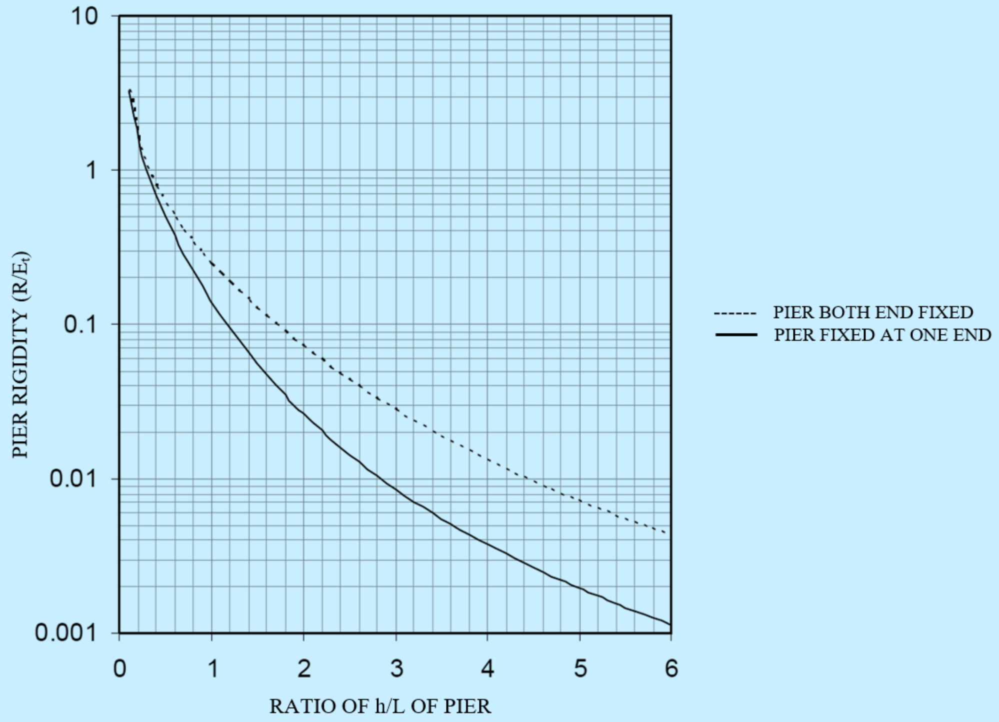


FIG. 83 CHARTS FOR CALCULATING WALL RIGIDITIES

From the relations given in equations above it is found that the relative contributions of the bending and shear deformation depend on the wall aspect ratio (*h/L*) and therefore, the rigidity varies over the height of the building. For high *h/L* ratios, the effect of shear deformation is very small and calculation of pier rigidities based on flexural stiffness is relatively accurate. For very squat walls (with *h/L< 0.25*), rigidities based on shear deformation are reasonably accurate, but for intermediate walls with *h*/*L* from 0.25 to 4, both components of relative rigidity should be considered.

F-3 The method is explained further explained by one illustration. For the wall as shown in Fig. 84.

$$R_{\text{wall}} = \frac{1}{\Delta_{1c} + \Delta_{2,3,4,5,6(\text{f})}} = \frac{1}{\dfrac{1}{R_{1c}} + \dfrac{1}{R_{2,3,4,5,6(\text{f})}}} \quad \text{(Vertical combination)}$$

where

$$R_{2,3,4,5,6(f)} = R_{2(f)} + R_{3,4,5,6(f)} \quad \text{(Horizonta l combination)}$$

$$\text{and } R_{3,4,5,6(f)} = \frac{1}{\Delta_{3,4,5(\text{f})} + \Delta_{6(\text{f})}} = \frac{1}{\dfrac{1}{R_{3,4,5(\text{f})}} + \dfrac{1}{R_{6(\text{f})}}} \quad \text{(Vertical combination)}$$

$$R_{3,4,5(\text{f})} = R_{3(\text{f})} + R_{3(\text{f})} + R_{3(\text{f})} \text{ (Horizontal combination)}$$

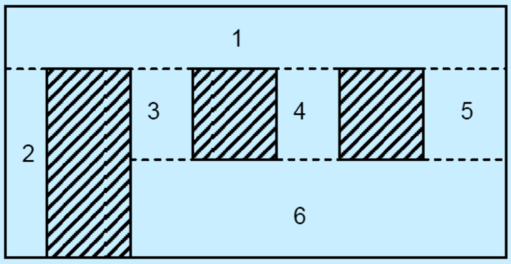


FIG. 84 WALL WITH OPENINGS (CALCULATION OF RIGIDITY AND LOAD DISTRIBUTION)

ANNEX G

(*Clause* 12)

MASONRY WALLS USING RAT-TRAP BOND

G-1 GENERAL

The following covers the construction of masonry walls using rat-trap bond. Only masonry with bricks (burnt clay bricks, fly ash-clay bricks, fly ash-lime bricks and stabilized soil blocks) is dealt herein. Use of other types of bricks/blocks and mud mortar are not specifically covered hereunder.

G-2 NECESSARY INFORMATION

G-2.1 For efficient planning, design and execution of the work, detailed information with regard to the following shall be furnished to those responsible for the work:

a) layout plans showing the orientation of the structure;

b) dimensioned details of the structure with details of sections (to a suitably large scale that is 1 : 20), levels of foundation, finished ground level, clear floor to floor heights of rooms, sizes of openings, etc;

c) type and class of brickwork, types of bond and final finish for the brickwork; the mixes of mortar to be used, etc, full size details of architectural features, mouldings and other special work. Also course plans at different levels of sill and lintel to be made available for proper understanding and execution, if required; and

d) location and other details of openings, chases, embedment of service lines, such as for water supply, drainage, electrical installations, etc, and location and details of hearths, flues and chimneys in the brickwork.

G-2.2 All information as in **G-2.1** shall be made available to those who are responsible for the masonry work. Necessary drawings and instructions for planning the work shall be furnished. Arrangements shall also be made for the proper exchange of information between those engaged in masonry work and all those whose work will affect or will be affected.

NOTE — If necessary a brief training of the masons may be carried out orienting them with the technology know-how.

G-3 MATERIALS

G-3.1 Bricks

Burnt-clay bricks, heavy duty bricks and bricks made out of other suitable materials like fly ash, stabilized soil block, etc, conforming to accepted standards [C-4(12)] with compressive strength greater than 6.0 MPa shall be used.

G-3.2 Mortars

Shall conform to grade H2 mortar for good practice [C-4(3)].

G-3.3 Storage of Materials

Storage of materials shall be in accordance with good practice [C-4(2)].

G-3.4 Materials for Damp-Proof Courses

Materials for damp proof courses shall be as specified in [C-4(5)].

G-3.5 Materials for Flashing and Weathering

Lead flashing with sheet thickness between 1.6 mm and 2 mm or bitumen felts shall be in accordance with the accepted standards [C-4(13)].

G-3.6 Metal Reinforcement

Metal reinforcement for use in brick masonry shall be as per accepted standards [C-4(14)].

G-4 DESIGN CONSIDERATIONS

G-4.1 Selection of Bricks

The brick shall be selected in accordance with Table 1 of good practice [C-4(4)].

When the requirements for strength of masonry predominate in the particular situation of use, the bricks shall be of such class to give the required strength for masonry and shall be selected in accordance with **4**.

G-4.2 Rat-Trap Bond Details

G-4.2.1 The rat-trap bond is laid by placing the bricks on edge forming a cavity of 80 mm (for a traditional brick size) with alternate course of stretchers and headers (Fig. 85). The headers and stretchers are staggered in subsequent layers to impart strength and stability to the walls.

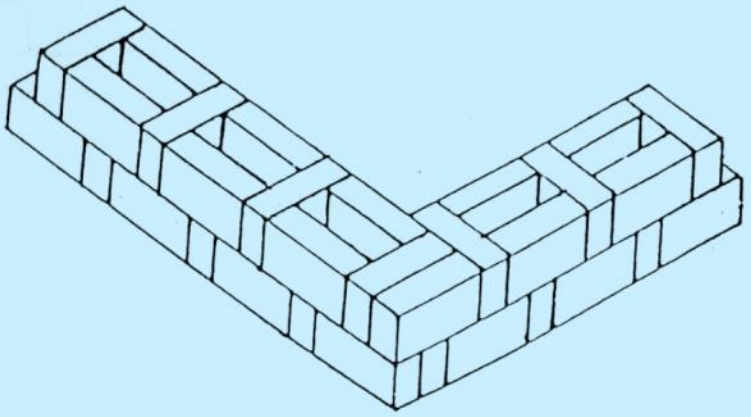


FIG. 85 ARRANGEMENT IN RAT-TRAP BOND

The primary object of bond is to give strength to masonry, but when exposed, it also creates aesthetically pleasing view. This masonry technology is modular in nature, so the dimensions of the wall to be based on the module dimensions in multiples.

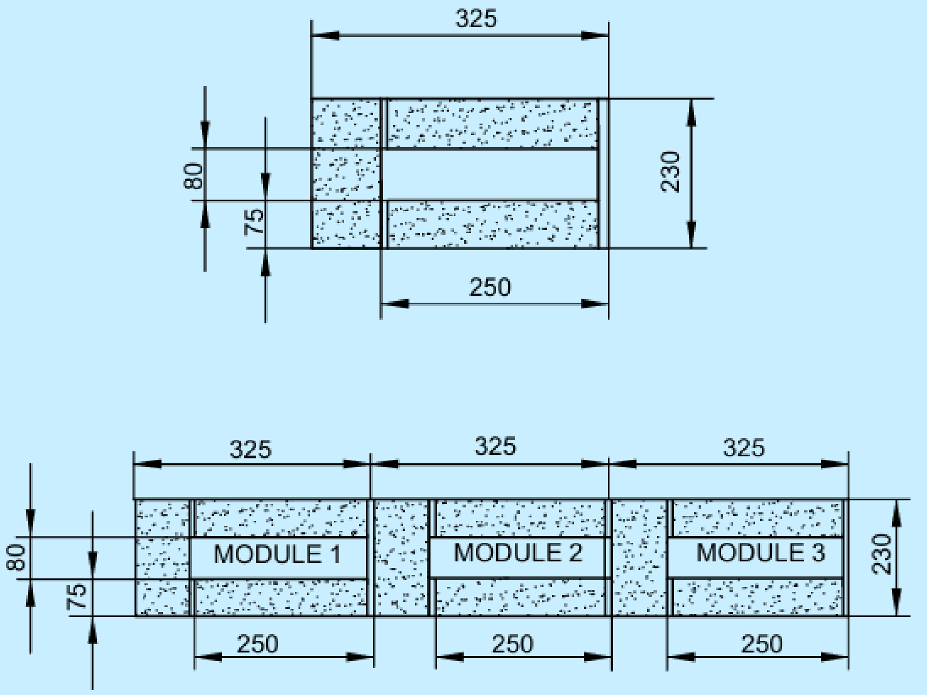
G-4.2.2 A typical module detail is shown in Fig. 86 with conventional bricks of size 230 mm × 110 mm × 75 mm. The brick adjacent to the openings has to be solid as per Fig. 87. So, the opening dimensions also to be in multiple of the rat-trap bond module. This will be important as opening dimensions are predefined depending on the module dimension. In brickwork the cross joints in any course shall not be nearer than a quarter of brick length from those in the course below or above it.

G-4.3 Precautions

This type of masonry construction shall have to be carried out by trained masons to avoid wastage of mortar falling into the gap. Rat-trap bond shall never be carried out with brick which are below their minimum strength requirements.

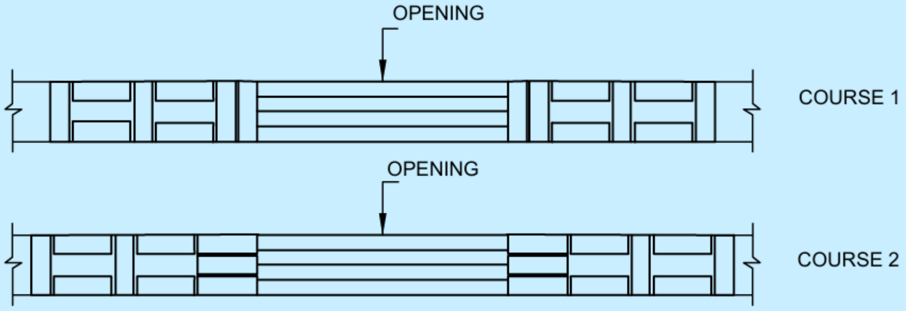
G-4.4 Strength of Rat-Trap Bond

The compressive strength of rat-trap bond will be different from that of solid wall of similar thickness. Rat-trap bond wall provides continuous cavity over the entire wall height and hence it is convenient to reinforce if necessary to resist lateral loads. The compressive strength of the unreinforced rat-trap bond wall can be determined either based on the cavity wall design guidelines following **5.5.1.2** or the basic compressive stress can be assessed following the tests on prism specimen given at **G-7**.



PLAN

FIG. 86 TYPICAL MODULE DETAILS OF RAT-TRAP BOND



PLAN

FIG. 87 OPENING IN RAT-TRAP BOND MASONRY

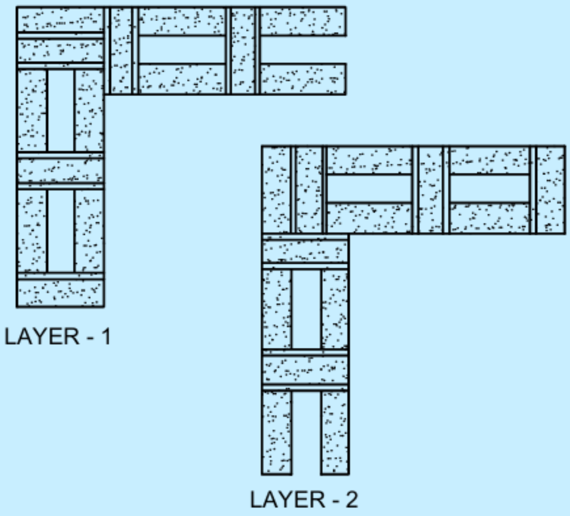
G-4.5 Thickness of Joint

No bed joint shall be thicker than 12 mm. Further the thickness of the bed joints shall be such that four courses and three joints taken consecutively shall measure as follows:

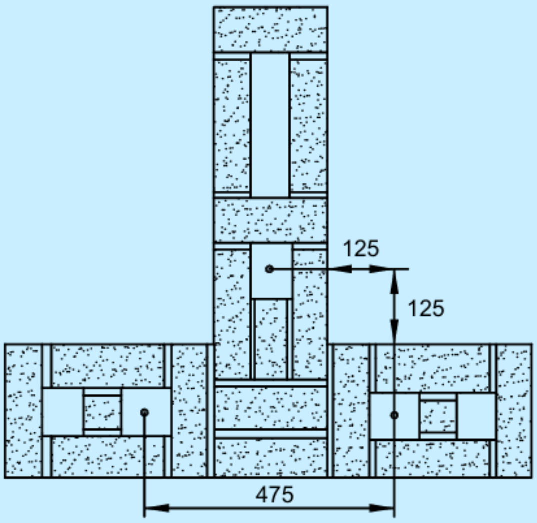
a) *In the case of traditional bricks* — Four times the actual thickness of the brick plus 30 mm.;

b) *In the case of modular bricks* — 390 mm conforming to the relevant accepted standards. The vertical mortar joints to be of the thickness of 10 mm and be applied directly to the brick before placing it. This requires some special skill, but defines the strength as well as the stability of the Rat-trap bond wall. Besides, applying the mortar joint directly to the brick is a basic skill requirement of a mason and determines the speed of work and finally the cost of the Rat-trap bond wall; and

c) The *face* jolts of brickwork may be finished by 'jointing' or by 'pointing'. In case where brick size is less, the elevation of the header bricks to be made even in line with the stretcher brick by cement mortar same grade as bedding mortar. The main reasons for pointing the surface of block or brickwork joints are to increase its weather resistance and to give a neat finish to the work. Pointing can be carried out as construction of the brickwork proceeds, using ordinary mortar in which the bricks are bedded.



L - JUNCTION DETAIL FOR ALTERNATE LAYERS



All dimensions in millimetres.

FIG. 88 TYPICAL LAYING OF RAT-TRAP BOND

G-4.6 Structural and Functional Characteristics of Brickwork

G-4.6.1 *Structural Stability and Strength*

Reference may be made to Part C/Section 2 of this NBCS, and 4 of this Section.

G-4.6.2 *Resistance to Moisture Penetration*

The suitability of various walls under different conditions of exposure is indicated in Table 3 of good practice [C-4(4)].

G-4.6.3 *Thermal Stresses*

The coefficient linear expansions of brick vary from $5 \times 10^{-6}/°C$ to $11 \times 10^{-6}/°C$. Variations of temperature tend to produce linear changes in walls which, when restrained, may lead to internal stress resulting in cracks especially when the walls exceed 30 m. The effects of these stresses shall be taken into consideration for a proper design.

G-4.7 Control of Shrinkage Cracking

G-4.7.1 To confine cracks to the joints and to dissipate these into a large number of fine joints, it is desirable that the mortar used shall be weaker than the bricks.

G-4.7.2 Cracking due to shrinkage normally will occur at openings or other points where the vertical or horizontal section of a wall changes. A long wall with a few openings will tend to show wider cracks above and below the openings than a similar wall with many openings. Metal reinforcement may be embedded in brickwork at points where cracking is likely to occur.

G-4.8 Thermal Insulation

For requirements of thermal insulation in walls, the provisions of good practice [C-4(15)] shall apply.

G-4.9 Fire Resistance

For requirements regarding resistance to fire, the provisions of good practice [C-4(16)] shall apply.

G-4.10 Sound Insulation

Requirements for insulation against airborne sound are laid down in good practice [C-4(17)] shall apply.

G-5 LAYING OF BRICKWORK

G-5.1 Brick shall be laid on a full bed of mortar. When laying the bricks, it shall be slightly pressed so that the mortar gets into all the pores of the brick surface to ensure proper adhesion. Cross joints and wall joints shall be properly flushed and packed with mortar so that no hollow spaces are left. Properly filled joints ensure maximum strength and resistance to penetration of moisture which takes place mainly through joints.

G-5.2 The following specific guidelines shall be followed:

a) In areas with a very high ground water table, it is advisable to build the first 4 to 5 courses of the wall, with either English or a Flemish bond. This is to avoid ground and spill water related dampness problems;

b) Always clean the surface where the first layer of bricks is to be laid, which is usually above the plinth level;

c) Arrange the joints between the bricks in such a way that only full bricks (shiners) fit. Ensure that the bonding is correct;

d) To properly maintain the brick cross, lay the first two masonry courses by marking mark each of the shiner and the header bricks at the centre;

e) Place the shiner/stretcher and header brick now in such a way that the marks are exactly matching. The remaining courses may then be laid to match with the first two courses;

f) Spread a full bed of mortar, and furrow it with a trowel. This will ensure that plenty of mortar is on the bottom of the bricks for the first course;

g) Lay the corner bricks first. Carefully position the corner bricks first. Be sure to lay all bricks with the frog inside the cavity of the wall in order to create an aesthetically pleasing outer wall surface;

h) The vertical mortar joints shall be applied directly to the brick before placing it. This requires some special skill, but defines the strength as well as the stability of the rat-trap bond wall;

j) The maximum rat-trap bond brick wall height per day should not exceed more than 9 layers; and

k) Cavities of rat-trap bond shall be closed for the first course after damp proof course, below sill level, below and above lintel and at the top most course; this can be made by a layer of headers or headers.

G-5.3 Protection Against Damage

Care shall be taken during construction that edges of jambs, sills, heads, etc are not damaged. In inclement weather, newly built work shall be covered with gunny bags or tarpaulin so as to prevent the mortar from being washed away.

G-6 INSPECTION

G-6.1 General

The object of inspection of brick masonry work is to ensure its satisfactory performance and also to ascertain whether all the recommended practice of workmanship is adopted at every stage. As the correct strength of masonry cannot be ascertained without destruction, a close supervision during the course of construction is necessary to ensure satisfactory performance. The strength of brickwork depends on the strength of individual brick, strength of mortar, bond and workmanship.

G-6.2 Inspection of Materials

In case of large works, samples of bricks, sands, *Surkhi*, lime, cement, etc, which goes to form the brickwork, shall be periodically tested in a laboratory to make sure that they conform to the requirements stated in **G-3**. Simple field tests may suffice in the case of small works.

G-6.3 Inspection of Workmanship

A close supervision while the work is in progress will ensure a better quality work with the materials available for use. The following shall be observed at the time of inspection:

a) all loose materials, dirt and set lumps of mortar which may be lying over the surface over which brickwork is to be freshly started, shall be removed with a wire brush;

b) all the bricks shall be thoroughly soaked in potable water before use;

c) the surface over which the brickwork is to be started shall be made moist;

d) plastic mortar results in thorough bedding of the brick and more complete filling of the joints which ensure greater strength. Care shall be taken to see that the required quantity of water is added to the mortar at the mixing platform itself and not over the courses;

e) all the joints shall, as far as possible, be thin and the specifications mentioned in **G-4.5** in this regard shall be strictly adhered to;

f) care shall be taken to see that there is no through joints and the lap is not less than half the width of the brick, and that all the vertical joints are properly filled with mortar;

g) the verticality of the walls and horizontality of the courses shall be checked very often with plumb bob and spirit level respectively;

h) no portion of the work shall be left more than 1 m lower than the other. Where the masonry of one part has to be delayed the work shall be ‘raked back’ suitably at an angle not exceeding 45° according to bond and not toothed;

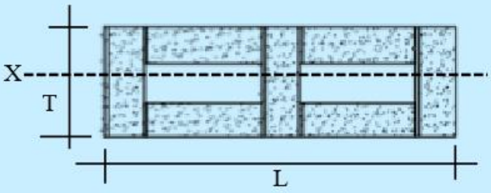
j) where plastering is required to be done all the vertical as well as horizontal joints shall be raked to a depth of about 10 mm while the mortar is wet, and this will ensure satisfactory adhesion between the plaster and brickwork; and

k) care shall be taken to ensure that the brick work is kept wet for first seven days using appropriate curing methods.

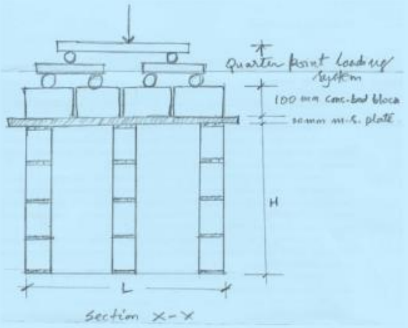
G-7 TESTING METHOD FOR RAT-TRAP BOND WALL SAMPLES

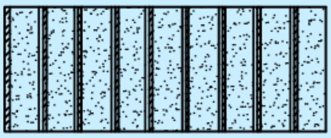
G-7.1 A Prism specimen as shown in Fig. 89 shall be used. The prism specimen should have similar mortar and bricks/blocks as that to be used in the rat-trap bond wall of the structure. The prism height (H) to width (T) ratio should be between 2 and 5 and based on H/T ratio the prism strength should be corrected following the correction factors given in **B-1** for blockwork.

The number of prism specimens to be tested and the necessary correction factors to be applied to derive modified compressive strength of the prism shall be ascertained following the procedure given in **5.4**. The modified mean prism compressive strength shall be divided by 4 (as per **B-2**) to assess the basic compressive stress for the rat-trap bond wall, which can be used in calculating the compressive strength of rat-rap bond masonry wall. A similar test as above should be done in an English bond per coupon (*see* Fig. 90).

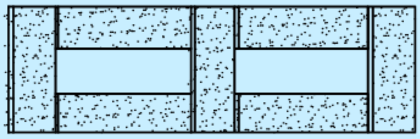


Plan of the Prism

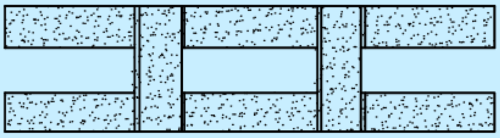




LAYER 0 AND 5



LAYER 1 AND 3



LAYER 2 AND 4

FIG. 89 PRISM SIZE AND LOADING ARRANGEMENT FOR THE RAT-TRAP BOND PRISM SPECIMEN

G-7.2 The load on rat-trap bond specimen should be not less than 85 percent of the load capacity of English bond wall compressive strength.

G-7.3 While designing the compressive stress on rat-trap bond wall, it should be ensured that the stress is not more than 0.85 of that of solid wall as per **4** of this Section.

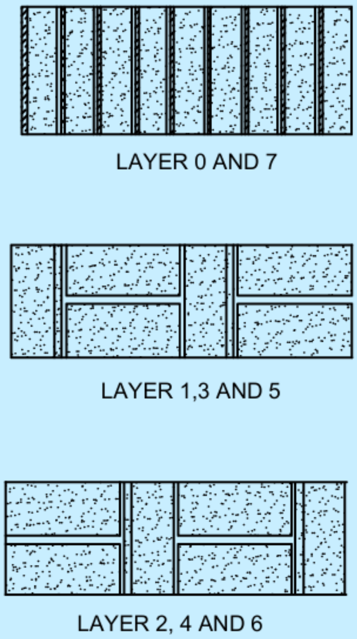


FIG. 90 ENGLISH BOND TEST SPECIMEN

ANNEX H

(*Clause* 14)

NOTATIONS, SYMBOLS AND ABBREVIATIONS

H-1 The following notations, letter symbols and abbreviations shall have the meaning indicated against each, unless otherwise specified in the text of this Section of this NBCS:

A = Area of a section

b = Width of bearing

DPC = Damp proof course

e = Resultant eccentricity

f_b = Basic compressive stress

f_c = Permissible compressive stress

f_d = Compressive stress due to dead loads

f_s = Permissible shear stress

f_m = Compressive strength of masonry (in prism test)

GL = Ground level
H = Actual height between lateral supports
H' = Height of opening
$H1$, $H2$ = High strength mortars
h = Effective height between lateral supports
k_a = Area factor
k_p = Shape modification factor
k_s = Stress reduction factor
L = Actual length of wall
$L1$, $L2$ = Lower strength mortars
$M1$, $M2$ = Medium strength mortars
P = Total horizontal load
PL = Plinth level
RCC = Reinforced cement concrete
RS = Rolled steel
S_p = Spacing of piers/buttresses/cross walls
SR = Slenderness ratio
t = Actual thickness
t_p = Thickness of pier
t_w = Thickness of wall
W = Resultant load
W_1 = Axial load
W_2 = Eccentric load
w_p = Width of piers/buttresses/cross walls
μ = Ratio of flexural strength of wall in the vertical direction to that in the horizontal direction

LIST OF STANDARDS

The following list records those standards which are acceptable as ‘good practice’ and ‘accepted standards’ in the fulfilment of the requirements of this NBCS. The latest version of a standard shall be adopted at the time of enforcement of this NBCS. The standards listed may be used by as a guide in conformance with the requirements of the referred clauses in this NBCS.

In the following list, the number appearing in the first column within parentheses indicates the number of the reference in this Section.

	IS No.	*Title*
(1)	IS 1077 : 2025	Common burnt clay building bricks — Specification (*sixth revision*)
	IS 1725 : 2023	Specification for stabilized soil blocks used in general building construction (*third revision*)
	IS 2180 : 1988	Specification for heavy duty burnt clay building bricks (*third revision*)
	IS 2185	Concrete masonry units — Specification:
	(Part 1) : 2005	Hollow and solid concrete blocks (*third revision*)
	(Part 2) : 1983	Hollow and solid light weight concrete blocks (*first revision*)
	(Part 3) : 1984	Autoclaved cellular (aerated) concrete blocks (*first revision*)
	(Part 4) : 2008	Cellular preformed foam cellular concrete blocks
	IS 2222 : 1991	Specification for burnt clay perforated building bricks (*third revision*)
	IS 2849 : 1983	Specification for non-load bearing gypsum partition blocks (solid and hollow types) (*first revision*)
	IS 3115 : 1992	Specification for lime based blocks (*second revision*)
	IS 3316 : 1974	Specification for structural granite (*first revision*)
	IS 3620 : 1979	Specification for laterite stone block for masonry (*first revision*)
	IS 3952 : 2013	Burnt clay hollow bricks and blocks for walls and partitions — Specification (*third revision*)
	IS 4139 : 1989	Specification for calcium silicate bricks (*second revision*)
	IS 12440 : 1988	Specification for precast concrete stone masonry blocks
	IS 12894 : 2002	Specification for pulverized fuel ash lime bricks (*first revision*)
	IS 13757 : 1993	Specification for burnt clay fly ash building bricks
	IS 16720 : 2018	Pulverized fuel ash-cement bricks — Specification
(2)	IS 4082 : 1996	Recommendations on stacking and storage of construction materials and components at site (*second revision*)
(3)	IS 2250 : 1981	Code of practice for preparation and use of masonry mortars (*first revision*)
(4)	IS 2212 : 1991	Code of practice for brickwork (*first revision*)
	IS 1597	Code of practice for construction of stone masonry:
	(Part 1) : 1992	Rubble stone masonry (*first revision*)
	(Part 2) : 1992	Ashlar masonry (*first revision*)
	IS 2572 : 2005	Code of practice for construction of hollow and solid concrete block masonry (*first revision*)
	IS 2110 : 1980	Code of practice for in-situ construction of walls in building with soil-cement (*first revision*)

	IS 2849 : 1983	Specification for non-load bearing gypsum partition blocks (solid and hollow types) (*first revision*)
	IS 3630 : 1992	Construction of non-load bearing gypsum block partitions — Code of practice (*first revision*)
	IS 6041 : 1985	Code of practice for construction of autoclaved cellular concrete block masonry (*first revision*)
	IS 6042 : 1969	Code of practice for construction of lightweight concrete block masonry
(5)	IS 2212 : 1991	Code of practice for brickwork (*first revision*)
(6)	IS 3414 : 1968	Code of practice for design and installation of joints in buildings
(7)	IS 10440 : 1983	Code of practice for construction of RB and RBC floors and roofs
(8)	IS 1904 : 2021	General requirements for design and construction of foundations in soils — Code of practice (*third revision*)
(9)	IS 883 : 2016	Code of practice for design of structural timber in building (*fifth revision*)
(10)	4326 : 2013	Earthquake resistant design and construction of buildings — Code of practice
(11)	IS 1597 (Part 2) : 1992	Code of practice for construction of stone masonry: Part 2 Ashlar masonry (*first revision*)
(12)	IS 1077 : 1992	Common burnt clay building bricks — Specification (*fifth revision*)
	IS 2180 : 1988	Specification for heavy duty burnt clay building bricks (*third revision*)
	IS 1725 : 2023	Stabilized soil blocks used in general building construction — Specification (*third revision*)
(13)	IS 405 (Part 2) : 1992	Lead sheets and strips — Specification: Part 2 for other than chemical purposes (*third revision*)
	IS 1322 : 1993	Bitumen felts for water proofing and damp-proofing (*fourth revision*)
(14)	IS 432	Specification for mild steel and medium tensile steel bars and hard-drawn steel wire for concrete reinforcement:
	(Part 1) : 1982	Mild steel and medium tensile steel bars (*third revision*)
	(Part 2) : 1982	Part 2 Hard- drawn steel wire (*third revision*)
	IS 1566 : 1982	Specification for hard-drawn steel wire fabric for concrete reinforcement (*second revision*)
	IS 412 : 1975	Specification for expanded metal steel sheets for general purposes (*second revision*)
	IS 2062 : 2011	Hot rolled medium and high tensile structural steel — Specification (*seventh revision*)
(15)	IS 3792 :1978	Guide for heat insulation of non-industrial buildings (*first revision*)
(16)	IS 1642 : 2013	Code of practice for fire safety of buildings (general): Details of construction (*second revision*)
(17)	IS 1950 : 1962	Code of practice for sound insulation of non-industrial buildings

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NATIONAL BUILDING CONSTRUCTION STANDARDS

PART C STRUCTURAL DESIGN

SECTION 5 STRUCTURAL CONCRETE

BUREAU OF INDIAN STANDARDS

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National Building Code Sectional Committee, CED 46

FOREWORD

This NBCS (Part C/Section 5) covers the structural design aspects of plain and reinforced concrete and also the prestressed concrete.

This Section 5 was first published in 1970 having Subsections 5A 'Plain and reinforced concrete' and 5B 'Prestressed concrete' of SP 7 (Part 6) and were subsequently revised in 1983, 2005 and 2016 as a chapter of National Building Code of India.

This Section is largely based on IS 456 : 2000 'Code of practice for plain and reinforced concrete (*fourth revision*)' and IS 1343 : 2012 'Prestressed concrete — Code of practice (*second revision*)' both of which are currently under revision and are being merged in the fifth revision of IS 456, likely to be titled as 'Structural concrete — Code of practice' at the time of the publication of this NBCS.

Major changes have been envisaged in the revision of IS 456 (amalgamating IS 1343). In the absence of availability of finalized version of revised IS 456, at the time of the revision of this publication, the provision of design as per existing IS 456 : 2000 and IS 1343 : 2012 have been continued through appropriate reference to the same.

In the 2016 version of the Code, in addition to the provisions of IS 456, provisions relating to special concrete namely self-compacting concrete, high performance concrete and steel fibre reinforced concrete were introduced.

In this revision, the publication has been renamed as National Building Construction Standards (NBCS).

In this fourth revision of this Section, Subsections 5A and 5B have been merged into a single Section 5, 'Structural concrete', and the following additional changes are made:

a) Special concretes, namely self-compacting concrete**,** high-performance concrete, and steel fibre reinforced concrete, which were earlier covered in **16A**, **16B** and Annex A of the erstwhile NBC, are now included in Annex B, Annex C, and Annex D respectively;

b) Informative Annex (Annex A) on updated provisions regarding materials for making concrete is introduced;

c) Criteria for structural safety of tall concrete buildings is introduced in Annex E. This provides prescriptive requirements for design of reinforced concrete tall buildings. The following salient aspects, which are based on the prescriptive approach, are addressed in the Annex E:

    1) Structural systems admissible for tall building in different seismic zones;

    2) General requirements including: (i) height limitations of different structural systems, (ii) elevation and plan aspect ratios, (iii) lateral drift, (iv) storey stiffness and strength, (v) modes of vibration, (vi) floor systems, (vii) materials, and (viii) progressive collapse mechanism;

    3) Wind and seismic effects: (i) load combinations, and (ii) acceptable serviceability criteria for lateral accelerations;

    4) Methods of structural analysis to be adopted, and section properties (in cracked and uncracked states) of reinforced concrete member to be considered in analysis;

    5) Structural design aspects for various applicable structural systems;

    6) Issues to be considered in design of foundations; and

    7) Systems needed for structural health monitoring.

The upcoming fifth revision of IS 456 introduces a holistic design philosophy that emphasizes that concrete structures shall not only be strong but also safe, durable, serviceable under expected loads, and resilient in the face of extreme and accidental events. To this end, the standard stipulates that structural design shall meet six design criteria that are strength, serviceability, durability, robustness, integrity, and restorability. Each of these criteria is associated with performance objectives and corresponding design requirements, ensuring that structural behaviour is assessed comprehensively across its entire lifecycle, including performance during and after any adverse events.

The design philosophy outlined in the above revised standard includes the classification of the design process into the prescriptive process and the closed-loop process. The prescriptive process follows conventional rule-based checks and is applicable to structures where only the basic three criteria (strength, serviceability, and durability) are of concern. In contrast, the closed-loop process is intended for important or critical structures and involves a more rigorous approach, requiring not only quantitative compliance for the first three criteria but also qualitative and performance-based verification for robustness, integrity, and restorability. This two-tier approach introduces flexibility in application while ensuring that safety and resilience are not compromised, especially in vital infrastructure. By integrating modern concerns like post-disaster repairability (restorability), progressive collapse prevention (integrity), and resistance to accidental actions (robustness), the design philosophy ensures that structures are not just built to withstand known demands but also prepared for uncertainties. It promotes reliability, sustainability, and long-term performance.

The revision of IS 456 highlights that structural analysis should correctly capture how structures behave under all types of loads, including static, dynamic, and accidental forces. For regular structures, linear static analysis is generally sufficient. However, for structures affected by dynamic forces like earthquakes, wind, or machine vibrations, dynamic analysis is necessary. In critical cases, the standard also recommends using non-linear dynamic analysis to better reflect the actual behaviour of materials and structures. This approach moves towards more detailed and performance-based analysis to improve safety, serviceability, durability, and resilience in concrete structures.

Apart from drawing from IS 456 : 2000 and IS 1343 : 2012, this revision incorporates provision relating to tall concrete buildings, drawn from IS 16700 : 2023 ‘Criteria for structural safety of tall concrete buildings (*first revision*)’.

All standards, whether given herein above or cross-referred to in the main text of this Section, are subject to the revision. The parties to agreement based on this Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

As the regulation of land development and buildings is a State subject and is dealt by the States and local bodies such as urban local bodies within their jurisdiction through building regulatory documents like building regulations, building byelaws, and fire regulations, this document is voluntary in nature and is non-binding. The implementation depends on adoption by concerned parties or stipulations in a contract or by appropriate adoption by the concerned authorities.

For the purpose of deciding whether a particular requirement of this Subsection is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 ‘Rules for rounding off numerical values (*second revision*)’. The number of significant places retained in the rounded off value should be the same as that of the specified value in this section.

Important Explanatory Note for Users of the NBCS

In any Part/Section of this NBCS, where reference is made to **'good practice'** in relation to design, constructional procedures or other related information, and where reference is made to **'accepted standard'** in relation to material specification, testing, or other related information, the Indian Standards listed at the end of the Part/Section shall be used as a guide to the interpretation.

At the time of publication, the editions indicated in the standards were valid. All standards are subject to revision and parties to agreements based on any Part/ Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

In the list of standards given at the end of a Part/Section, the number appearing within parentheses in the first column indicates the number of the reference of the standard in the Part/Section. For example:

a) Good practice [C-5(2)] refers to the Indian Standard(s) give at serial number (2) of the list of standards given at the end of this Part C/Section 5, that is, IS 456 : 2000 'Plain and reinforced concrete — Code of practice (*fourth revision*)'.

b) Accepted standard [C-5(4)] refers to the Indian Standard(s) give at serial number (4) of the list of standards given at the end of this Part C/Section 5, that is, IS 269 : 2015 'Ordinary Portland cement — Specification (*sixth revision*)'.

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART C STRUCTURAL DESIGN

SECTION 5 STRUCTURAL CONCRETE

1 SCOPE

This NBCS (Part C/Section 5) deals with the structural use of plain, reinforced, and prestressed concrete.

2 TERMINOLOGY

For the purpose of this Section, the definitions given in accepted standards [C-5(1)] shall apply.

3 MATERIALS

All materials used in plain, reinforced and prestressed concrete construction shall conform to Part B 'Building Materials' of this NBCS as available.

4 STRUCTRAL DESIGN USING PLAIN, REINFORCED AND PRESTRESSED CONCRETE

The provision relating to design and general structural use of plain, reinforced and prestressed concrete, including on:

a) materials, including special concrete, workmanship, inspection and testing;

b) general design consideration;

c) special design requirements for structural members and systems; and

d) structural design: limit state method.

shall be in accordance with good practices contained in section 2, section 3, section 4 and section 5 of the good practice [C-5(2)] and section 2, section 3 and section 4 of the good practice [C-5(3)].

> NOTE — At the time of publication of this section, IS 456 and IS 1343 were under revision, with IS 1343 being amalgamated into IS 456. Once the revised IS 456 is published, it shall replace the provisions given in **4**.

The informative Annex A to this Section suggests the updated list of materials and few tests. Users are encouraged to investigate the possibility of applying the provisions given in Annex A which are listed in consonance with the provisions regarding materials in the good practice [C-5(2)].

5 STRUCTURAL SAFETY OF TALL REINFORCED CONCRETE (RC) BUILDINGS

For criteria for structural safety of tall reinforced concrete (RC) buildings of heights greater than 50 m and less than 250 m, normally intended for use as residential, office and other commercial buildings, reference may be made to Annex E and accepted standard [C-5(4)].

6 EARTHQUAKE RESISTANT DESIGN AND DETAILING OF STRUCTURES

The provisions on earthquake-resistant design and detailing of concrete buildings are covered in [C-5(5)].

ANNEX A

(*Foreword and Clause 4*)

MATERIALS FOR MAKING CONCRETE

A-1 AGGREGATES

A-1.1 Normal Weight Aggregates

Aggregates derived from natural sources and other than natural sources (manufactured aggregates such as iron slag, copper slag, bottom ash from thermal power plants, recycled concrete aggregates and recycled aggregates), shall comply with the requirements of the accepted standard [C-5(6)]. These are natural or synthetic aggregates with in-place density (unit weight) between 22.40 kN/m^3 to 27.00 kN/m^3.

A-1.2 Heavyweight Aggregates

Natural or synthetic aggregates with in-place density (unit weight) more than 27.00 kN/m^3 and can range up to 45.00 kN/m^3 for aggregates other than steel. Steel aggregates (if used) will have further higher density. Heavy weight aggregate is most commonly used for radiation shielding, counterweights and other applications where a high mass-to-volume ratio is desired. Goethite, limonite, barite, illmenite, magnetite, hematite, ferrophosphorus and steel are some examples of heavy weight aggregate.

A-1.3 Lightweight Aggregates

Natural or synthetic with in-place density (unit weight) between 14.40 kN/m^3 to 18.40 kN/m^3. The lightweight is due to the cellular or high internal porous structure, which gives this type of aggregate a low specific gravity. The most important aspect of lightweight aggregate is the porosity. They have high absorption values, which requires a modified approach to concrete proportioning. Light weight aggregates namely sintered fly ash aggregates may be used for making light weight structural concrete (a type of special concrete). Sintered flyash coarse aggregates when used shall conform to the accepted standard [C-5(7)].

A-2 CEMENT

A-2.1 For general use in plain, reinforced and prestressed concrete construction, cement used shall be any of the following and the type selected should be appropriate for the intended use:

a) Ordinary Portland cement conforming to the accepted standard [C-5(8)];

b) Portland slag cement conforming to the accepted standard [C-5(9)];

c) Portland pozzolana cement (fly ash based) and Portland pozzolana cement (calcined clay based), conforming to the accepted standard [C-5(10)];

d) Composite cement conforming to the accepted standard [C-5(11)] and containing a declared clinker content not less than 45 percent, fly ash content not more than 25 percent and a minimum 28-day compressive strength of 43 MPa can be used for reinforced concrete construction; and

e) Portland calcined clay limestone cement conforming to the accepted standard [C-5(12)]. At locations where temperatures are predominantly below 15 °C for 6 months, the use of Portland calcined clay limestone cement shall not be permitted in underground structures and structural elements in contact with ground water.

A-2.2 Other cements as given below can be used for specific applications:

a) Sulphate resisting portland cement conforming to the accepted standard [C-5(13)];

b) Microfine ordinary portland cement conforming to the accepted standard [C-5(14)];

c) Hydrophobic cement conforming to the accepted standard [C-5(15)];

d) Low heat Portland cement conforming to the accepted standard [C-5(16)];

e) Rapid-hardening portland cement conforming to the accepted standard [C-5(17)];

f) High alumina cement conforming to the accepted standard [C-5(18)];

g) Supersulphated cement conforming to the accepted standard [C-5(19)]; and

h) White cement conforming to the accepted standard [C-5(20)].

A-3 WATER

A-3.1 Water used for mixing and curing shall be clean and free from excessive amounts of total dissolved solids (TDS), oils, acids, alkalis, salts, sugar, organic materials or other substances that may be deleterious to steel and setting and strength development of concrete.

A-3.2 Types of Water

In general, the suitability of water for the production of concrete depends upon its origin. Water to be used for mixing and curing of concrete shall be any of the types described below. Any type of water to be used for mixing and curing shall be tested as per stated procedures and shall meet all the requirements given in **A-3.3**.

A-3.2.1 *Potable Water*

This water is considered as suitable for use in concrete if meeting the requirements of the accepted standard [C-5(21)] wherein the chloride content shall be limited to 500 PPM and alkalinity is less than or equal to 25 ml (**A-3.3**). Such water needs no further testing. In case of any doubt it shall be tested for conformity according to **A-3.3**.

A-3.2.2 *Natural Surface Water*

This water, if found suitable, can be used in concrete but shall satisfy the requirements of **A-3.3**.

A-3.2.3 *Treated Water*

Appropriately treated water, conforming to **A-3.3**, from industrial, municipal and other sources can be used in concrete.

A-3.2.4 *Water Recovered from Processes in the Concrete Industry*

This includes:

a) water that was part of surplus concrete;

b) water used to clean the inside of the stationery mixers, mixing drums of truck mixer or agitators and concrete pumps; and

c) process water from sawing, grinding and water blasting of hardened concrete.

This water may be taken from:

1) Basins provided with suitable equipment that distributes the solid matter evenly throughout the water; and

2) Sedimentation basins or similar installations, provided the water is left in the basin for a sufficient amount of time to allow the solids to settle properly.

Water recovered from process in the concrete industry contains varying concentrations of very fine particles, the size of which is generally less than 0.25 mm. Water recovered from processes in the concrete industry or combined water can be used provided the following requirements are met:

i) The additional mass of solid material in the concrete resulting from the use of water recovered from processes in the concrete industry shall be less than 1 percent mass fraction of the total mass of aggregates present in the concrete; and

ii) The amount of recovered water shall be spread as evenly as possible over a day's production.

A-3.2.5 *Water from Other Sources*

A-3.2.5.1 *Recycled water*

This includes water recovered from concrete production operation or water generated from sewage, greywater or storm water systems and treated to a standard that is appropriate for its intended use.

A-3.2.5.2 *Desalinated water*

Desalinated water conforming to **A-3.3** can be used. However normal sea water or brackish water shall not be used for mixing of concrete because of presence of harmful salts.

A-3.3 Requirements for Preliminary Inspection of Mixing and Curing Water

A-3.3.1 *Preliminary Inspection*

The water shall be examined for oil and fats, detergents, colour, suspended matter, odour and humic matter shall meet the requirements given in Table 1 in accordance with test procedures stated below.

A small subsample shall be assessed as soon as possible after sampling. Bring any material that has settled back into suspension by shaking the sample. Pour 80 ml of the sample into a 100 ml measuring cylinder. Seal with a suitable stopper and shake the cylinder vigorously for 30 s. Smell the sample for any odours other than those of clean water. If in doubt about the odour, test the water for its odour level in accordance with national regulations for potable water. The odour level of the water shall be lower than the maximum level accepted for potable water. Observe the surface for foam. Set the cylinder in a place free from vibration and allow to stand for 30 min. After 2 min, check the sample for the continuing presence of foam and signs of any oils or fats. After 30 min have elapsed, observe the apparent volume of the settled solids and the colour of the water. Measure the pH using indicator paper or a *p*H metre. Then, add 0.5 ml hydrochloric acid, mix and then smell or test for the presence of hydrogen sulphide.

Put 5 ml of the sample into a test tube. Bring it to a temperature between 15 °C and 25 °C by allowing it to stand indoors. Add 5 ml of 3 percent sodium hydroxide solution, shake and leave for 1 h. Observe the colour.

Table 1 Requirements for Preliminary Inspection of Mixing Water

(*Clause* A-3.3.1)

Sl No. (1)	Parameter (2)	Requirements (3)
i)	Oils and fats	Not more than visible traces
ii)	Detergents	Any foam should disappear within 2 min
iii)	Colour	Water not from sources classified as potable: the colour shall be assessed qualitatively as pale yellow or pale
iv)	Odour	Water from sources classified as potable: no smell, except the odour allowed for potable water and a slight smell of cement; where blast-furnace slag is present in the water, a slight smell of hydrogen sulphide Water from other sources: no smell, except the odour allowed for potable water; no smell of hydrogen sulphide after addition of hydrochloric acid
v)	*p*H value	6.0 to 8.5
vi)	Humic matter	The colour shall be assessed qualitatively as yellowish/brown or paler after addition of NaOH

A-3.3.2 Permissible limits for solids shall be as given in Table 2.

Table 2 Maximum Permissible Limit for Solids for Mixing and Curing Water

(*Clauses* A-3.3.2 *and* A-3.4)

Sl No.	**Parameter**	**Tested as per Accepted Standard**	**Maximum Permissible Limit**	
			For Mixing Water	For Curing Water
(1)	(2)	(3)	(4)	(5)
i)	Organic	[C-5(22)]	200 mg/l	200 mg/l
ii)	Inorganic	[C-5(22)]	3 000 mg/l	3 000 mg/l
iii)	Sulphate (as SO_3^-)	[C-5(23)]	400 mg/l	800 mg/l
iv)	Chloride (as Cl^-)	[C-5(24)]	2 000 mg/l for concrete not containing embedded steel and 500 mg/l for reinforced concrete work[1]	500[1] mg/l for reinforced concrete or prestressed concrete work and 2 000 mg/l for concrete not containing embedded steel
v)	Suspended matter	[C-5(25)]	2 000 mg/l	2 000 mg/l

[1] 1 000 mg/l chloride in water for reinforced concrete work (but not for prestressed concrete) can be permitted provided the chloride content of hardened concrete is checked at the time of concrete mix design and conform to requirement of total chloride content in the concrete.

A-3.4 Testing and Requirements of Curing Water

Permissible limits for solids shall be as given in Table 2. Water used for curing should not produce any objectionable stain or unsightly deposition on the concrete surface. The presence of tannic acid or iron compounds is objectionable.

A-3.5 Sampling of Water Concrete Making and Curing

A sample of water not less than 5 litre shall be taken. The sample of water taken for testing shall represent the water proposed to be used for concreting with due account being paid to seasonal variation. The sample shall be stored in a clean container previously rinsed out with similar water.

A-4 ADMIXTURES

A-4.1 Admixtures can be used to:

a) Alter the composition of concrete by replacing some of the cement in the concrete by pozzolanic and hydraulic reaction (and are called mineral admixtures or supplementary cementitious materials);

b) Enhance a certain function of concrete (and are called chemical admixtures); and

c) The following types of admixtures shall be used in production of concrete.

A-4.2 Mineral Admixtures/Supplementary Cementitious Materials (SCMs)

SCMs as given below may be used as part replacement of cement. They can be pozzolanic material or reactive mineral admixture or combination of both.

A-4.2.1 *Fly Ash* (*Pulverized Fuel Ash*)

Fly ash conforming to the accepted standard [C-5(26)] may be used as part replacement of ordinary Portland cement. For concrete having steel, the replacement level of fly ash shall be restricted to 35 percent by weight of cementitious material wherein fly ash shall have a minimum fineness of 280 m^2/kg and lime reactivity of 4.5 N/mm^2 or more.

A-4.2.2 *Silica Fume*

Silica fume conforming to the accepted standard [C-5(27)] may be used as part replacement of cement. Silica fume is usually used in proportion of 3 percent to 10 percent of the cementitious content of a mix. The total replacement by fly ash and silica fume shall not be more than 35 percent for reinforced cement concrete. The total replacement by GGBF slag and silica fume/Ultrafine ground granulated blast furnace slag (UFGBS) shall not be more than 60 percent for reinforced cement concrete.

The above limits shall also apply where PPC or PSC is used. The fly ash or slag content mentioned on the bag shall be considered.

Only for mass concrete, structures below ground (not exposed to atmosphere) and for plain concrete, the use of more than one type of mineral admixture with ordinary Portland cement or a mineral admixture with blended cements such as PPC and PSC can be permitted after necessary trials (to control heat of hydration). However, silica fume may be used as an additional mineral admixture in reinforced concrete subjected to limits specified above. Uniform blending of the mineral admixtures with the cement should be ensured. In such cases, fly ash and GGBS together may be used within following limits:

Total replacement (*Max*) = 45 percent of total cementitious content
Fly ash (*Max*) = 20 percent
GGBS (*Max*) = 25 percent

A-4.2.3 *Metakaolin*

Metakaolin conforming to the accepted standard [C-5(28)] may be used as pozzolanic material in concrete as part replacement of ordinary Portland cement only. The replacement level shall be maximum up to 15 percent.

A-4.2.4 *Ground Granulated Blast Furnace Slag* (*GGBS*)

GGBS conforming to the accepted standard [C-5(29)] may be used as part replacement of ordinary Portland cement. For concrete having embedded steel, the replacement level of GGBS shall be restricted to 50 percent by weight of cementitious materials. For resistance to sulphate and alkali aggregate reaction, GGBS up to 60 percent can be used.

A-4.2.5 *Ultrafine Ground Granulated Blast Furnace Slag* (*UFGBS*)

UFGBS conforming to the accepted standard [C-5(30)] may be used as part replacement of cement. The replacement level shall be up to 20 percent.

A-4.2.6 *Ultrafine Fly Ash*

Ultrafine fly ash produced through classification route and conforming to the accepted standard [C-5(31)] may be used as part replacement of ordinary Portland cement. The replacement level shall be up to 20 percent.

A-4.3 Chemical Admixtures

A-4.3.1 Chemical admixtures, as mentioned in Table 3 if used, shall comply with the accepted standard [C-5(32)]. Previous experience with and data on such materials should be considered in relation to the likely standards of supervision and workmanship to the work being specified.

Table 3 Types of Chemical Admixtures and their Constituents

(*Clause* A-4.3.1)

Sl No.	Type of Admixture		Typical Active Constituents
(1)	(2)		(3)
i)	Air-entraining	a)	Salts of wood resins
		b)	Some synthetic detergents
		c)	Salts of sulphonated lignin
		d)	Salts of petroleum acids
		e)	Salts of proteinaceous material
		f)	Fatty and resinous acids and their salts
		g)	Tall oils and gum rosin salts
		h)	Alkylbenzene sulfonates
		j)	Salts of sulphonated hydrocarbons
ii)	Retarding	a)	Unrefined lignosulphonate containing sugars
		b)	Modified derivatives of unrefined lignosulphonate
		c)	containing sugars
		d)	Hydroxycarboxylic acids and their salts
		e)	Carbohydrates including sugars
		f)	Heptonates related to sugars and starches
iii)	Accelerating	a)	Calcium chloride
		b)	Triethanolamine
		c)	Sodium thiocyanate
		d)	Sodium formate or calcium formate
		e)	Sodium nitrite or calcium nitrite
		f)	Calcium nitrate
		g)	Aluminates
		h)	Silicates
iv)	Water-reducing	a)	Lignosulfonic acids and their salts
		b)	Hydroxylated carboxylic acids and their salts
		c)	Polysaccharides
		d)	Melamine polycondensation products
		e)	Naphthalene polycondensation products
		f)	Polycarboxylates
v)	High range water-reducing : Normal and retarding	a)	Melamine sulfonate polycondensation products
		b)	Naphthalene sulfonate polycondensation products
		c)	Polycarboxylates
vi)	Shrinkage reducing	a)	Polyoxyalkylene alkyl ether
		b)	Propylene glycol

Table 3 (*Concluded*)

(*Clause* A-4.3.1)

Sl No. (1)	Type of Admixture (2)	Typical Active Constituents (3)
vii)	Corrosion inhibiting	a) Amine carboxylates aminoester organic emulsion
		b) Calcium nitrite
		c) Organic alkyidicarboxylic
		d) Chromates
		e) Phosphates
		f) Hypophosphites
		g) Alkalis
		h) Fluorides
viii)	Permeability-reducing admixture	
	1) *Non-hydrostatic conditions* (*PRAN*)	a) Long-chain fatty acid derivatives (stearic, oleic, caprylic capric)
		b) Soaps and oils (tallows, soya-based)
		c) Petroleum derivatives (mineral oil, paraffin)
		d) Fine particle fillers (silicates, talc)
	2) *Hydrostatic conditions* (*PRAH*)	Crystalline hydrophilic polymers (latex, water-soluble, or liquid polymer)

A-4.3.2 Chemical admixtures can be achieved by a spectrum of materials and manufacturing processes, but shall comply with accepted standard [C-5(28)]. Further, **c**hemical admixtures can be achieved by a spectrum of materials and manufacturing processes, but shall comply with the accepted standard [C-5(32)]. Further,

a) The workability, compressive strength and the slump loss of concrete with and without the use of admixtures shall be established during the trial mixes before use of admixtures;

b) The relative density of liquid admixtures shall be checked for each drum containing admixtures and compared with the specified value before acceptance;

c) If two or more admixtures are used simultaneously in the same concrete mix, data shall be obtained to assess their interaction and to ensure their compatibility;

d) Admixtures shall neither impair durability of concrete nor combine with the constituent to form harmful compounds nor increase the risk of corrosion of reinforcement; and

e) The chloride content of admixtures shall be independently tested for each batch before acceptance.

A-4.3.3 The amount of admixture added to a mix shall be recorded in the production record. Additional dose of admixture may be added at project site and mixed adequately in mixer itself to regain the workability of concrete (if necessary) with mutual agreement between the producer/supplier and the purchaser/user of concrete. But, the producer/supplier shall assure the ultimate quality of concrete supplied by him and maintain record of quantity and time of addition.

A-4.3.4 Shrinkage compensating admixtures shall not be used in structural concrete.

A-5 FIBRES

Fibres may be added to concrete for special applications to enhance select properties. But, such fibres shall be approved by the competent authority on the recommendation of a duly constituted competent peer review committee. In any case, the presence of fibres shall not be taken advantage of in the estimation of strength.

A-6 REINFORCEMENT

A-6.1 Reinforcing bars and prestressing strands shall be specified in accordance with the provisions of good practices [C-5(2) and (3)], respectively.

A-6.2 Reinforcement couplers shall comply with the relevant clauses of accepted standard [C-5(33)].

A-6.3 If glass fibre reinforced polymer bars are used, the material shall conform to the requirement of the accepted standard [C-5(34)].

A-6.4 Welded wire reinforcement shall conform to the requirements of the accepted standard [C-5(35)].

A-6.5 Prestressing accessories shall comply with the requirements of good practice [C-5(3)].

ANNEX B

(*Foreword*)

SELF COMPACTING CONCRETE

B-1 GENERAL

The self compacting concrete (SCC) is highly flowable, non-segregating concrete that fills uniformly and completely every corner of formwork by its own weight without the need for any compaction and encapsulates reinforcement or any other embedment. The provisions relating to its application areas, features, mix proportioning principles, and production and engineering properties are given hereunder. The provisions for concrete making materials and concrete as given in 'materials, workmanship, inspection and testing' section of the good practice [C-5(2)] shall apply to SCC except where different provisions or departures have been indicated hereunder.

B-2 APPLICATION AREAS

SCC may be used in in-situ concrete or for precast concrete applications. It is particularly appropriate for sections with highly congested reinforcement such as, nuclear power plant structures, machine foundations, piers and abutments; and areas having restricted access to concrete placement and compaction like shafts in hydropower structures. SCC is also suitable for the construction of tunnel lining sections and casting of concrete-filled steel tubular columns. SCC may also be used for columns and beams in normal construction with appropriate formwork design.

SCC may be produced in a batching plant on site or in ready-mixed concrete plant and transported to site by transit mixers. It may be placed either by pumping or other placement methods into horizontal or vertical forms.

B-3 FEATURES OF FRESH SELF COMPACTING CONCRETE

The features of fresh SCC are:

a) Filling ability (flowability);
b) Passing ability;
c) Segregation resistance; and
d) Viscosity.

B-3.1 Filling Ability (Flowability)

Filling ability of SCC determines its ability to flow into and fill all spaces within the formwork, under its own weight. The filling ability is tested using slump-flow test.

B-3.1.1 *Procedure*

Slump flow test shall be carried out in accordance with the accepted standard [C-5(36)].

B-3.1.2 *Classes of Slump-Flow and their Application*

There are three classes of slump-flow, as follows:

a) *SF*1 (slump flow 550 mm to 650 mm) – This class of SCC is appropriate for:

   1) unreinforced or slightly reinforced concrete structures that are cast from the top with free displacement from the delivery point (such as slabs); and

   2) casting by a pump injection system (such as tunnel linings), and 3) sections those are small enough to prevent long horizontal flow (example, piles and some deep foundations).

b) *SF*2 (slump flow 650 mm to 750 mm) is suitable for many normal applications (example, walls, columns); and

c) *SF*3 (slump flow 750 mm to 850 mm) is typically produced with a small maximum size of aggregates (less than 20 mm) and is used for vertical applications in structures having congested reinforcement, structures with complex shapes, etc. *SF*3 will often give better surface finish than *SF*2 for normal vertical applications but segregation resistance is more difficult to control.

B-3.2 Passing Ability (Free from Blocking at Reinforcement)

Passing ability describes the capacity of the fresh mix to flow through confined spaces and narrow openings such as areas of congested reinforcement without segregation. If there is little or no reinforcement, there may be no need to specify passing ability as a requirement. L-box test is generally carried out to check the passing ability and the procedure shall be in accordance with the accepted standard [C-5 (36)]. In this test, the height of the concrete left in the vertical section (h_1) and at the end of the horizontal section (h_2) is measured. The ratio of h_2/h_1 is calculated as the blocking ratio; which shall be between 0.8 and 1.0.

B-3.3 Segregation Resistance (Stability)

Segregation Resistance is the ability of fresh concrete to remain homogeneous in composition while in its fresh state. Segregation resistance is generally carried out using sieve test to check this property of fresh concrete.

B-3.3.1 *Procedure*

Segregation resistance (sieve) test shall be carried out in accordance with accepted standard [C-5(36)].

B-3.3.2 *Test Results*

There are two classes of segregation resistance, namely *SR*1 and *SR*2. For *SR*1 class, segregation resistance should be above 15 percent and $\leq$ 20 percent, and for *SR*2 it should be $\leq$ 15 percent.

*SR*1 is generally applicable for thin slabs and for vertical applications with a flow distance of less than 5 m and a confinement gap greater than 80 mm. *SR*2 is preferred in vertical applications if the flow distance is more than 5 m with a confinement gap greater than 80 mm in order to take care of segregation during flow. Segregation resistance becomes an important parameter with higher slump-flow classes and/or the lower viscosity class, or if placing conditions promote segregation. If none of these apply, it is usually not necessary to specify a segregation resistance class.

B-3.4 Viscosity

Viscosity can be assessed by the V-funnel flow time. Concrete with a low viscosity will have a very quick initial flow and then stop. Concrete with a high viscosity may continue to creep forward over an extended time.

B-3.4.1 *Procedure*

Viscosity by V-funnel test is carried out in accordance with accepted standard [C-5 (36)]. A V-shaped funnel is filled with fresh concrete and the time taken for the concrete to flow out of the funnel is measured and recorded as the V-funnel flow time.

B-3.4.2 *Test Results*

The viscosity is divided into two classes, namely V_1 and V_2. For V_1 class, the time taken to pass the concrete from V-funnel shall be $\leq$ 8 s and for V_2 class, it shall be above 8 s and $\leq$ 25 s.

V_1 has good filling ability even with congested reinforcement. It is capable of self levelling and generally has excellent surface finish. V_2 class viscosity is more likely to exhibit thixotropic effects, which may be helpful in limiting the formwork pressure or improving segregation resistance. But it may cause negative effects on surface finish and sensitivity to stoppages or delays between successive lifts.

B-4 MIX PROPORTIONING

B-4.1 Mix Proportion Principles

The principles listed below shall be followed:

a) Lower coarse aggregate content;

b) Increased paste content;

c) Low water/powder ratio (*see* Note);

d) High range superplasticizer; and

e) Viscosity modifying admixture, if required.

NOTE — Powder is the material of particle size smaller than 0.125 mm. It includes this size fraction in the cement, mineral admixtures and aggregate.

B-4.2 Mix Design Procedure

For mix design procedure, reference may be made to good practice [C-5(37)].

B-5 PRODUCTION OF SELF COMPACTING CONCRETE

B-5.1 General

SCC is less tolerant to changes in constituent characteristics and batching variances as compared to conventional concrete. Accordingly, it is important that all aspects of the production and placing processes are carefully supervised.

The production of SCC should be carried out in plants where the equipment, operation and materials are suitably controlled under a Quality Assurance Scheme. It is important that all personnel who will be involved in the production and delivery of SCC are adequately trained including practical demonstrations.

B-5.2 Constituents

SCC is more sensitive than conventional concrete to variation in the physical properties of its constituents and especially to changes in aggregate moisture content, grading and shape. So, more frequent production checks are necessary. The moisture content of aggregates should be continuously monitored and the mix adjusted to account for any variation.

Storage of constituent materials for SCC shall be same as that for materials for conventional concrete. However, as the SCC mix is more sensitive to variations, special precautions shall be taken for storage of aggregates, which should be properly stored to avoid cross-contamination between different types and sizes and protected from weather to minimize the fluctuation of surface moisture content and movement of fines. Ground stock should be stored in purpose-built partitioned bays, which should allow free drainage of excess moisture in the aggregates and rainwater.

B-5.3 Mixing Equipment and Trial Mixes

SCC shall be produced with efficient forced action concrete mixers. The time necessary to achieve complete mixing of SCC may be longer than for conventional concrete due to reduced frictional forces and to fully activate the superplasticizer.

B-5.4 Formwork

Formwork should be watertight and grout tight when placing SCC. The need to design the formwork for water tightness is greater than conventional formwork so as to avoid honeycombs and surface defects. The high fluid nature of SCC may lead to higher formwork pressure than conventional concrete, especially when the casting rate is high. As a result of the highly fluid nature of SCC, a high placement rate is likely and should be anticipated. Formwork designs, that accommodate the expected liquid head formwork pressure, can allow unrestricted placement rates and permit fast casting rate of the SCC. It is recommended to design the formwork for full liquid head.

B-5.5 Curing

Curing is essential for all concrete, and early protection of exposed surfaces is essential to preventing rapid moisture loss that could lead to plastic shrinkage cracking. The top-surface of elements made with SCC can dry quickly because of the increased quantity of paste, the low water/fines ratio and the lack of bleed water at the surface. Initial curing should therefore commence as soon as practicable after placing and finishing in order to minimize the risk of surface crusting and shrinkage cracks caused by early age moisture evaporation.

B-6 ENGINEERING PROPERTIES

B-6.1 General

SCC and conventional concrete of similar compressive strength have comparable properties.

B-6.2 Compressive Strength

SCC with a similar water-cement ratio usually have a slightly higher strength compared to conventional concrete due to the lack of vibration giving an improved interface between the aggregate and hardened paste.

B-6.3 Tensile Strength

SCC may be supplied with any specified concrete grade. For a given concrete grade, the tensile strength may be safely assumed to be the same as the one for a conventional concrete as the volume of paste (cement + fines + water) has no significant effect on tensile strength.

B-6.4 Static Modulus of Elasticity

Increasing the paste volume may decrease the modulus of elasticity, E_c. As SCC has higher paste content than conventional concrete, some difference can be expected and the E_c may be somewhat lower and should be adequately covered by the safe assumptions in design.

If SCC does have a slightly lower E_c than conventional concrete, in prestressing work, this will affect the relationship between the compressive strength and the camber due to pre-tensioning or post-tensioning. For this reason, careful control should be exercised over the strength at the time when the pre-tensioning and post-tensioning strands or wires are released.

B-6.5 Creep

Due to the higher volume of cement paste, the creep coefficient for SCC may be expected to be higher than for conventional concrete of equal strength, but such differences are small and shall be covered by the safe assumptions in design.

B-6.6 Shrinkage

As concrete compressive strength is related to the water-cement ratio, in SCC with a low water-cement ratio drying shrinkage reduces, but with increased cementitious content and increased water content the drying shrinkage and autogenous shrinkage can increase.

B-6.7 Durability

SCC is free from shortcomings due to improper compaction and result in consistently low and uniform permeability, offering less weak points for deleterious actions of the environment.

ANNEX C

(*Foreword*)

HIGH PERFORMANCE CONCRETE

C-1 GENERAL

High performance concrete is a concrete whose ingredients, proportions and production methods are specifically chosen to meet special performance and uniformity requirements. The higher performance requirements may be:

Sl No. (1)	*Higher Performance Requirements* (2)	*Remarks/Applications* (3)
i)	High resistance to deterioration of reinforced concrete due to carbonation	This is to help achieve longer service life. This is particularly applicable in semi-arid regions
ii)	High resistance to chloride attack/ingress	This is for longer service life of reinforced concrete exposed to severe chloride environment/coastal environment
iii)	High resistance to abrasion	This may be required in concrete structures, like parts of hydraulic structures exposed to continuous abrasive action due to silt, such as spillways/glacis; and concrete pavements exposed to heavy traffic
iv)	High resistance to impact	This may be required in structures like blast resistant structures and spillways
v)	Improvement in flexure and shear performance	This is required in bridge girders, joints of RCC framed structure, shear walls, etc
vi)	High resistance to cracking due to shrinkage (plastic and drying shrinkage)	This may be required in concrete/mortar used for repair of distressed concrete structures, etc

High strength concrete generally improves performance of all above parameters. The concrete mix proportioning for high strength concrete may be carried out in accordance with the good practice [C-5(37)]. However, special measures are needed to further improve the specific performance requirements. As a guide, the measures given in **C-2** may be adopted. For further details, expert literature may be referred.

C-2 MEASURES FOR IMPROVING SPECIFIC PERFORMANCE REQUIREMENTS

C-2.1 Resistance to Carbonation

Resistance to carbonation of concrete is dependent mainly upon:

a) Type of binder, content of binder and *p*H value of concrete; and

b) Permeability of concrete.

Addition of silica fume, GGBS and fly ash improve denseness and reduce permeability, thus increasing resistance to ingress of carbon dioxide and moisture (needed for carbonation). The addition of fly ash above 35 percent tends to lower the alkalinity, and thus the resistance to carbonation. Lower water-cement ratios and higher grades of concrete can be adopted to improve performance in this case. Minimum OPC content is essential for adequate carbonation resistance for different exposure conditions.

Carbonation resistance can be checked by using accelerated carbonation tests (using 3 percent to 4 percent CO_2 concentrations for minimum 70 days exposure) at mix proportioning stage. For quality assurance purpose, rapid tests like rapid chloride ion penetration test (RCPT), air permeability test or electrical resistivity test may be used. Their values may be established by correlation with accelerated carbonation test values at mix proportioning stage.

C-2.2 Resistance to Chloride Ingress

To improve performance of concrete exposed to chloride environment, two aspects need to be considered:

a) Total initial chloride content in concrete should be minimized; and

b) Permeability of concrete should be low.

Whereas chloride content of concrete can be controlled by checking chloride content of mix ingredients, the permeability of concrete can be reduced by careful selection of mix proportions and by use of supplementary cementing materials, either through use of blended cements like PPC and PSC or by direct addition of mineral admixtures, like fly ash, GGBS and silica fume. To control permeability, durability test of resistance to chloride ions shall be carried out by using chloride diffusion test by immersion or ponding method (using 3 percent NaCl exposure for 90 days) at mix proportioning stage. For quality assurance purpose rapid tests corresponding values like rapid chloride ion penetration test (RCPT) or electrical resistivity test shall be carried out. Corresponding values for these tests shall be established by developing a correlation with chloride diffusion test (by immersion/ponding) at mix proportioning stage.

C-2.3 Resistance to Abrasion

To ensure good performance against abrasion, following points should be considered:

a) Use of higher grades of concrete;

b) Use of good quality strong aggregate;

c) Use of silica fume; and

d) Use of steel fibres (suited for increasing abrasion resistance in spillways/glacis, etc).

Test methods for measuring abrasion resistance are:

a) Revolving disc type test; and

b) Under water abrasion resistance test using steel balls.

For further details regarding test methods and criteria, specialist literature may be referred.

C-2.4 Improving Performance in Flexure, Shear, Impact, Ductility and Energy Absorption

Resistance to impact is generally increased when the strength of concrete is high and energy absorption is high. Energy absorption and toughness can be increased by use of steel fibres in concrete. Whereas addition of steel fibres, glass or carbon fibres improves flexural and shear strength also, the use of synthetic fibres like polypropylene fibres do not significantly improve the above properties. Polypropylene fibres do however reduce shrinkage cracking and are suitable for concrete/mortar used for concrete repairs.

For checking impact resistance, falling weight impact test can be used, wherein number of blows for crack initiation in small concrete slab panel are counted.

For further details regarding test methods and criteria, specialist literature may be referred. The use of steel fibre reinforced concrete shall be further governed by **C-2.4.1**.

C-2.4.1 *Use of Steel Fibre Reinforced Concrete* (*SFRC*)

Following properties of concrete can be improved by using SFRC:

a) Ductility;

b) Toughness and energy absorption;

c) Abrasion; and

d) Flexural strength and shear strength.

Compressive and direct tensile strength gain in flexural and direct tensile strength is very significant when higher percentage of steel fibres are used which give the concrete a strain hardening effect (increase in ultimate load after initial crack). However significant improvements are achieved in strain softening zone also.

Steel fibres having aspect ratio 60 to 80 may be incorporated in concrete of different grades to improve the ductility of concrete. Fibre content varying from 0.5 percent to 2.5 percent volume may be incorporated in to the concrete to improve different mechanical and durability characteristics. However higher addition can cause problems in uniform mixing and placing of concrete which need to be checked at mix proportioning stage before using the mix. Corrosion of steel fibres can also occur particularly in lower grades, so use of coated fibres and higher grades of concrete are recommended. Alternatively, a plain concrete cover of few millimetre can also be provided.

Design of steel fibre reinforced concrete (SFRC) for structural performance shall be in accordance with Annex D.

ANNEX D

(*Foreword and Clause* C-2.4.1)

DESIGN OF STEEL FIBRE REINFORCED CONCRETE

D-1 GENERAL

This Annex shall apply where steel fibres are used to improve the performance and capacity of reinforced and prestressed concrete structures.

The design of steel fibre reinforced concrete (SFRC) at both the ultimate and serviceability limit states shall be based on the stress (σ) ≠ strain (ϵ) relationships for SFRC as specified in **D-3.3** (*see* Note 1).

Steel fibres shall not be relied upon in plastic hinge regions for strength requirements (*see* Note 2).

Steel fibres shall not be relied upon at constructions joints for either serviceability or strength requirements. Design procedure in this clause is for steel-fibre-reinforced concrete with a softening classification only (*see* Fig. 1). Hardening SFRC and the use of synthetic fibres is beyond the scope of this annex.

NOTES

1 When using brittle fibres that rely on a fibre pull-out failure mechanism to obtain member ductility, care is required for cases where a significant number of fibres fracture or where fibres result in local crushing of the concrete due to the local forces imposed on the matrix by the fibres. Fibre fracture may occur where the bond between the fibre and the matric is high, and this is more likely in a high strength concrete combined with fibres of high bond capacity and of lower strength steels.

2 The anchorage capacity of steel fibres may be lost in areas where crack widths exceed about 3.5 mm. Cracking of this magnitude can be expected in regions where plastic rotations are expected.

D-2 DEFINITIONS

For the purposes of this Annex the following definitions shall apply:

D-2.1 Crack Mouth Opening Displacement (CMOD) — The width of a crack shall be measured at its mouth in a flexural tensile test. To measure the CMOD, a displacement transducers/clip gauge shall be mounted along the longitudinal axis at the mid width of the test specimen (beam with nominal size of 150 mm × 150 mm and length L so that 550 mm < L < 700 mm).

D-2.2 Crack Opening Displacement (COD) — The width of a single localized crack, taken as an average on four sides, for a direct tensile test on a strain softening SFRC dog-bone shaped specimen in accordance with D-3.3.7.

D-2.3 Steel Fibre Reinforced Concrete (SFRC) — A mixture of concrete and steel fibres.

D-2.4 Hardening Behaviour — A material that displays an enhanced strength with increasing crack widths beyond that measured at the point of initial cracking of the cementitious matrix.

D-2.5 Softening Behaviour — A material that exhibits a loss of strength upon cracking.

D-2.6 Target Dosage — The specified quantity of fibres in kilograms per cubic metre of concrete (kg/m^3).

D-3 PROPERTIES OF SFRC

D-3.1 General

SFRC shall be classified in terms of both its characteristic compressive (cylinder) strength (f'_c) (*see* D-3.2) and its characteristic residual tensile strength ($f'_{1.5}$) (*see* D-3.3.3).

D-3.2 Compressive Strength

The characteristic compressive strength of SFRC at 28 days (f'_c) shall be determined in accordance with the accepted standard [C-5(38)].

In the absence of more accurate data, the mean value of the in situ compressive strength (f_{cmi}) shall be taken as 90 percent of the mean value of the cylinder strength ($f$cm).

NOTE — The compressive strength of steel fibre reinforced concrete (SFRC) should be determined by means of standard tests on concrete cylinders. The addition of steel fibres to concrete in conventional dosages (less than 100 kg/m^3) does not change the compressive properties of the concrete.

D-3.3 Tensile Properties

D-3.3.1 *Classification*

SFRC shall be classified as either softening or hardening as shown in Fig. 1. Hardening SFRC is outside the scope of this Annex.

NOTES

1 A hardening material is defined as one with a tensile strength equal to or greater than 1.1 times the strength of the matrix without fibres and taken at a crack opening displacement (COD) of equal to or greater than 0.3 mm.

2 A hardening material is one where multiple cracks can occur prior to crack localization. For material hardening to occur, the fibre dosage is typically such that the strength of the SFRC is at least 10 percent greater than the strength of the same concrete mix without fibres. The value of COD of 0.3 is sufficiently high such that matrix contribution to the strength of the composite is minimal and the tension at this point is substantially taken by the fibres alone.

D-3.3.2 *Matrix Tensile Strength*

The matrix tensile strength of the softening SFRC (f_{ct}) shall be obtained using flexural tensile testing, in accordance with good practice [C-5(2)].

When only the characteristic compressive (cylinder) strength (f'_c) has been determined, the mean and characteristic flexural tensile strength of SFRC shall be calculated in accordance with the good practice [C-5(2)].

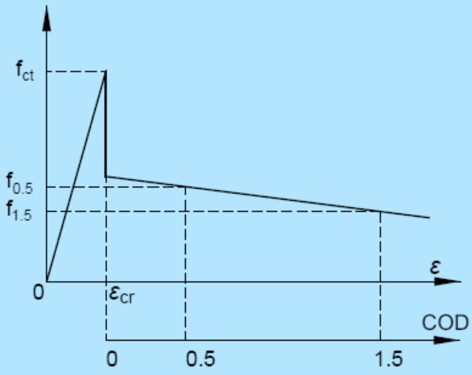
NOTE — For strain softening SFRC, the peak strength of the composite may be approximated as the strength of the concrete mix without fibres.

D-3.3.3 *Residual Tensile Strength*

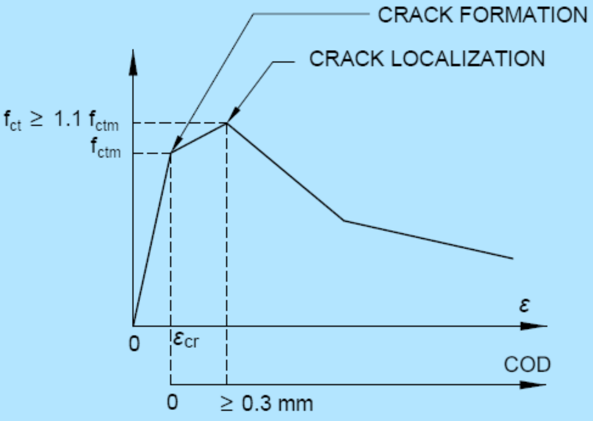
The standard characteristic residual tensile strength grades ($f'_{1.5}$) are 0.4 MPa, 0.6 MPa, 0.8 MPa, 1.2 MPa, 1.6 MPa and 2.0 MPa.

The characteristic residual tensile strengths of concrete at 28 days ($f'_{1.5}$) shall be determined statistically from tests carried out in accordance **D-3.3.4** or **D-3.3.5**.

NOTE — The characteristic residual tensile strength depends on the fibre-matrix bond strength, which is usually a function of the compressive strength of the parent concrete, as well as the fibre content. It may be unrealistic to specify a high value of $f'1.5$ when using a relatively low value of $f'c$.



1A STRAIN SOFTENING SFRC



1B STRAIN HARDENING SFRC

FIG. 1 CLASSIFICATION OF SFRC

D-3.3.4 *Determination of Strength by Direct Testing*

The characteristic residual tensile strength ($f'_{1.5}$) shall be obtained using direct tensile tests as specified in **D-3.3.7**.

Alternatively, where matched direct and indirect testing has been undertaken in accordance with **D-3.3.6** for similar SFRC mixtures, the characteristic residual tensile may be determined as:

$$f'_{1.5} = k_{R,4}\, f'_{R,4}$$

Where $f'_{R,4}$ is determined in accordance with **D-3.3.8** and calculated statistically, and the factor $k_{R,4}$ determined from **D-3.3.6**.

For the purposes of this clause, similar SFRC mixtures are defined as having the same:

a) Fibre type and content;

b) Water to cementitious material ratio;

c) Maximum aggregate particle size; and

d) Compressive strength (f'_c).

NOTES

1 In calculating the characteristic strength, the population may be treated normally distributed and the strength determined in accordance with accepted standard. A confidence level of 75 percent shall be used that 95 percent of the population exceeds the characteristic value.

2 The sample standard deviation shall not exceed 25 percent.

D-3.3.5 *Determination of Strength by Indirect Testing*

The characteristic residual tensile strength ($f'_{1.5}$) may be obtained using indirect tests as specified in **D-3.3.8** and calculated as:

$$f'1.5 = 0.4f'_{R,4} - 0.07f'_{R,2}$$

D-3.3.6 *Residual Tensile Strength-Residual Flexural Strength Relationship*

The relationship between residual tensile strength and the residual flexural strength shall be obtained by matched using the same SFRC mixture. Residual tensile strength specimens shall be prepared and tested in accordance with **D-3.3.7**. Residual flexural tensile tests shall be in accordance with the procedure as mentioned below:

The average width of the specimen and distance between the tip of the notch and the top of the specimen in the mid-span section shall be determined from two measurements to nearest 0.1 mm width and distance in the notch port of the specimen using calipers.

When the CMOD is measured, the displacement transducer shall be mounted along the longitudinal axis at mid width of test specimen such that the distance 'y' between the bottom of specimen and line of measurement is 5 mm or less as mentioned in Fig. 2.

a) The concrete mix shall be batched to ensure a uniform distribution of fibres, the SFRC shall be placed in the moulds in a manner that does not interfere with the distribution of the fibres and, the SFRC shall be compacted using lightly applied external vibration; and

b) A minimum of 12 specimens shall be tested.

The reference factor $k_{R,4}$ shall be determined as:

$$k_{R,4} = f_{1.5m}/f_{R,4m}$$

where

$f_{1.5m}$ = mean residual tensile strengths corresponding to a COD of 1.5 mm, determined in accordance with **D-3.3.7**.

$f_{R,4m}$ = mean residual flexural tensile strengths corresponding to a CMOD of 3.5 mm, determined in accordance with **D-3.3.8**.

NOTE — The residual tensile strength (as obtained from a direct tensile test) is a fundamental material property of SFRC. This clause allows the concrete producer and steel fibre manufacturer to correlate the direct tensile strength of their particular SFRC mix design with the flexural tensile strength.

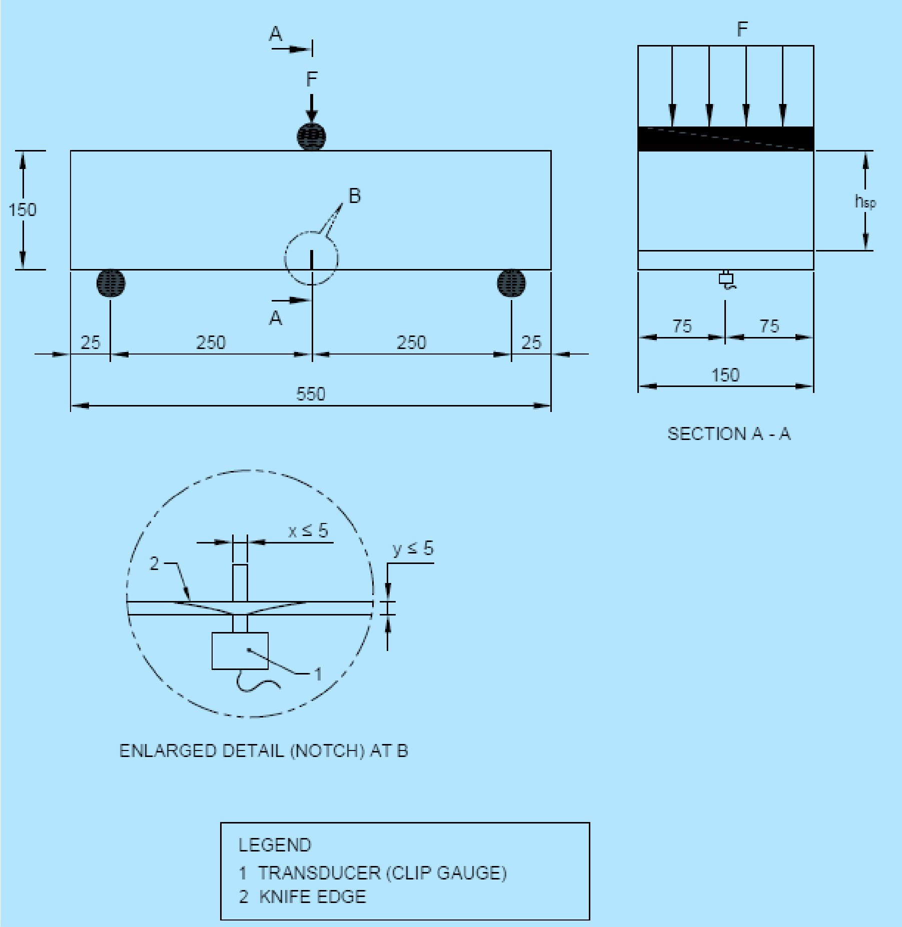


FIG. 2 ARRANGEMENT FOR RESIDUAL FLEXURAL TENSILE TEST

D-3.3.7 *Residual Tensile Strength Test*

The residual tensile strength shall be obtained using the testing arrangement shown in Fig. 3 and with the following criteria:

a) The critical section shall be where the cross sectional area is a minimum;

b) The SFRC mix shall be batched to ensure a uniform distribution of fibres, and shall be placed in the moulds in a manner that does not interfere with the distribution of the fibres. The SFRC shall be compacted using lightly applied external vibration;

c) The specimen shall be connected to the testing machine in such a manner that the machine does not apply a load to the specimen during the process of tightening of the grips and prior to testing;

d) One end of the specimen shall be connected to the testing machine through a universal joint such that no moment is applied to the end of the specimen;

e) Displacement measurements shall be taken on each of the four sides with the COD taken as the average of these measurements;

f) A minimum of twelve specimens shall be tested;

g) Tests where the failure of the specimen is outside of the testing region, or where the results are influenced by the test specimen boundaries, shall be retested;

h) The characteristic values of the tensile strength $f_{0.5}$ and $f_{1.5}$, corresponding to CODs of 0.5 mm and 1.5 mm, respectively, shall be determined statistically as the 95 percentile confidence value assuming the population is normally distributed; and

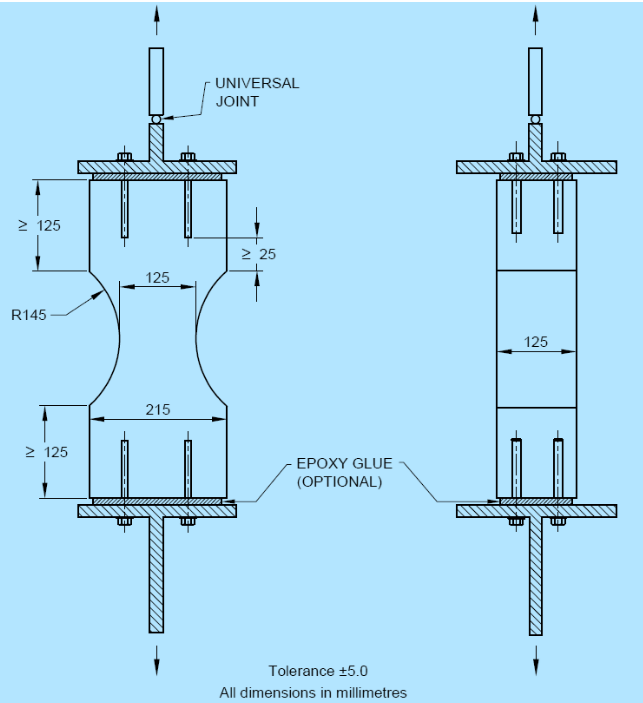
j) The mean values of $f_{0.5m}$ and $f_{1.5m}$, corresponding to CODs of 0.5 mm and 1.5 mm, respectively, shall be determined statistically as the 50th percentile confidence value assuming the population is normally distributed.

The stress results obtained from the test shall be multiplied by the three-dimensional orientation factor k_1, where,

$$k_1 = \frac{1}{0.94 \ + 0.6\ell_f/b} \leq 1$$

And ℓ_f is the length and b is taken as the average of the width and depth of the specimen taken at the critical section.

NOTE — The factor k_1 removes the influence of the boundaries on the fibre distribution and converts the results of the test to a state where the fibres can be considered to be randomly orientated in three-dimensional space.



Tolerance ±5.0
All dimensions in millimetres

FIG. 3 TESTING ARRANGEMENT FOR DIRECT TENSION

NOTE — There is considerable discussion in the literature on whether the ends of the specimens should be fixed at each end, pinned at each end or fixed at one end and pinned at the other. The adoption of one pinned and one fixed end is a pragmatic decision between the ideal condition (fixed at each end) and limitations in manufacturing of specimens that are perfectly square at their ends for alignment within the testing machine. With both ends fixed any misalignment induces a moment in the specimen during gripping. This moment can induce a tensile stress on one side of the specimen, weakening the specimen. In some situations, the moment induced may be sufficient to crack the concrete. The inclusion of the universal joint at one end eliminates residual tensions that may result from the gripping procedure.

D-3.3.8 *Residual Flexural Tensile Strength*

The residual flexural tensile strength (F_R) shall be determined from 3 point notched bending tests on 150 mm square section prisms. The notch depth shall be 25 mm and the test conducted in accordance with **D-3.3.6**. The force F shall be plotted against the crack mouth opening displacement (CMOD), as shown in Fig. 4 and the residual flexural stress calculated as:

$$F_R = \frac{3F_{RJ}L}{2bh_{sp}^2}$$

where

F_{RJ} = load recorded at CMOD$_j$ (*see* Fig. 4).

L = span, in mm;

b = width, in mm of the specimen; and

h_{sp} = distance, in mm between tip of the notch and top of cross section.

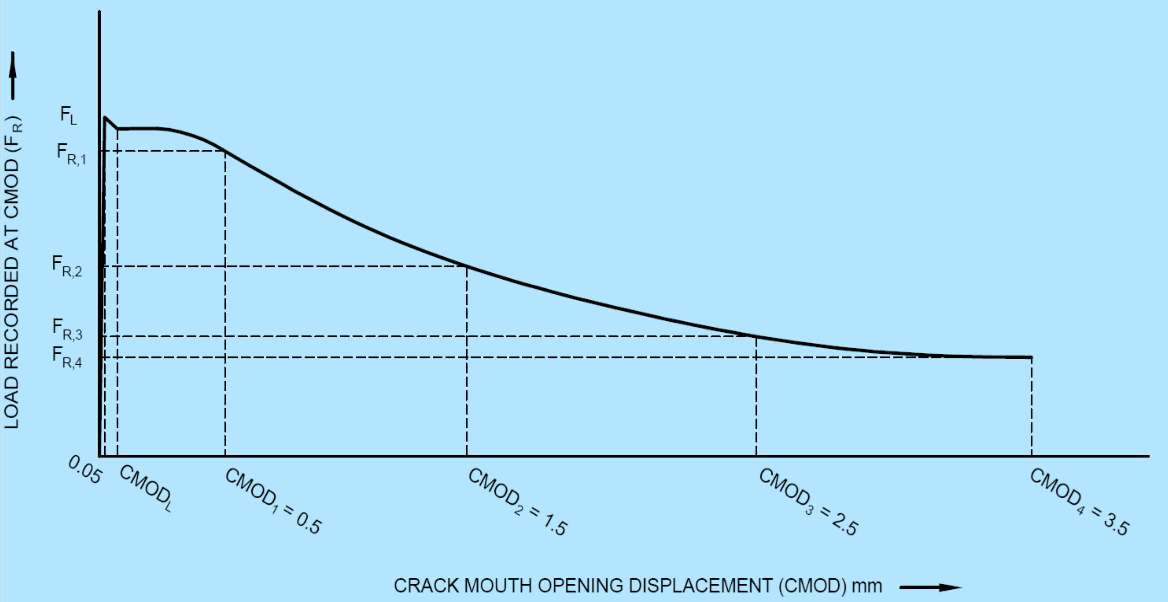


FIG. 4 LOAD *VERSUS* CMOD FOR RESIDUAL FLEXURAL TENSION

D-3.4 Modulus of Elasticity

The mean modulus of elasticity at the appropriate age (E_{cj}) shall be determined in accordance with accepted standard [C-5(38)].

NOTE — The addition of steel fibres to concrete in conventional dosages (100 kg/m^3 and less) does not change the elastic modulus of the concrete.

D-4 DESIGN OF REINFORCED SFRC MEMBERS

D-4.1 General

This clause applied to reinforced and prestressed beams subjected to any combination of shear force, bending moment and axial force. This clause does not apply when torsion acts in conjunction with shear or to non-flexural members.

D-4.2 Strength of Beams in Bending and Combined Bending and Axial Force

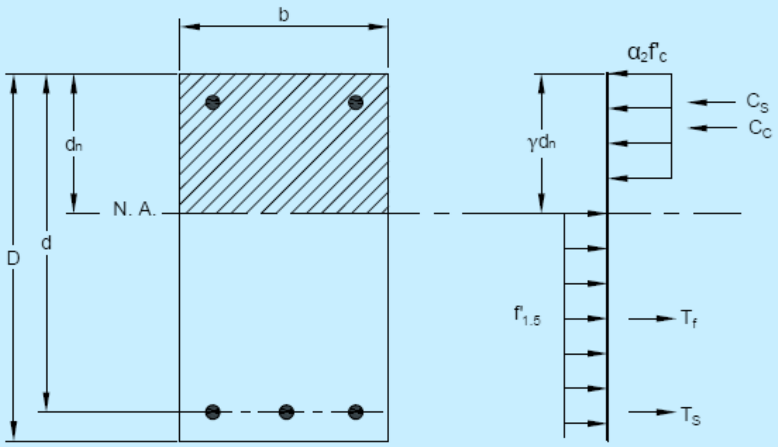
Calculations for strength of cross sections in bending shall incorporate equilibrium and strain-compatibility considerations and be consistent with the following assumptions:

a) Plane sections normal to the axis shall remain plane after bending;

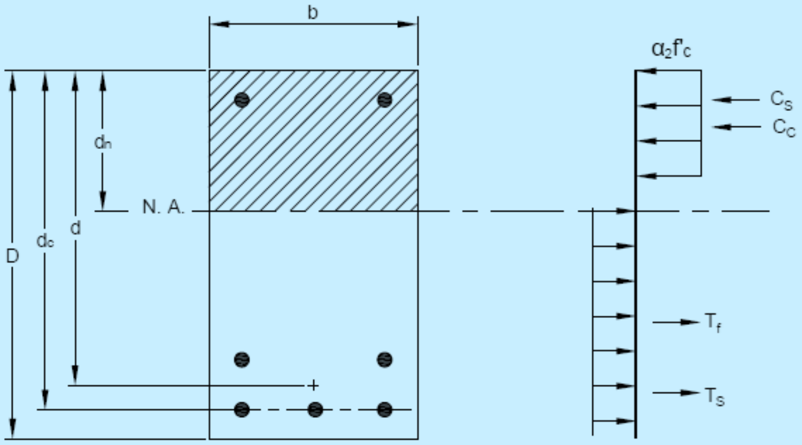
b) Stress in the fibre reinforced concrete in that part of the cross section in tension shall be taken to be $f'_{1.5}$, where $f'_{1.5}$ is the characteristic residual tensile stress determined in accordance with **D-3.3.3**; and

c) Distribution of compressive stress shall be determined from a stress-strain relationship for the concrete.

The strength of a section in bending, or in combined bending and axial force, shall be determined using rectangular stress blocks for the concrete in compression and concrete in tension, as shown in Fig. 5.



5A SINGLE TENSILE REINFORCEMENT LAYER



5B MULTIPLE TENSILE REINFORCEMENT LAYERS

FIG. 5 STRESS BLOCKS AND FORCES ON REINFORCED SFRC SECTION

D-4.3 Minimum Reinforcement Requirements for Bending

The minimum tensile reinforcement shall be not less than that determined using the principles given in this annex, excluding fibres.

D-4.4 Strength of Beams in Shear

D-4.4.1 *Design Shear Strength of a Beam*

The design shear strength of a beam shall be taken as V_u

where

$$V_u = V_{uc} + V_{uf} + V_{us}$$

where V_{uc} and V_{us} are determined from **39** of accepted standard [C-5(38)] and V_{uf} is determined from D-4.4.2.

Notwithstanding the above equations, the fibres component to the shear strength of a beam, V_{uf}, shall not exceed the greater of 0.3 V_u and that determined by D-4.4.3 with V_{us} taken as zero.

D-4.4.2 *Contribution to Shear Strength by Steel Fibres*

The contribution of the fibres to the ultimate shear strength (V_{uf}) of an SFRC beam shall be calculated from the following equation:

$$V_{uf} = 0.7 k_\theta b_v d_0 f'_{1.5}$$

where

k_θ = $\cot \theta_v \leq 1.28$

b_v = The effective width of the web (the vertical part of the beam).

d_0 = The effective depth of the beam.

$f'_{1.5}$ = characteristic residual tensile strength of concrete (at 28 days) at a Crack Opening Displacement (COD) of 0.5 mm.

θ_v = the angle between the axis of the concrete compression strut and the longitudinal axis of the member and shall be taken as not less than 38°.

D-4.4.3 *Minimum Shear Reinforcement*

The minimum contribution from the total of the transverse steel reinforcement and fibres shall satisfy the following:

$$(V_{us} + V_{uf})_{min} \geq 0.1 b_v d_0 \sqrt{f'_c} \quad and \quad \geq 0.6 b_v d_0$$

D-4.5 Design for Serviceability Limit States

D-4.5.1 *General*

When an SRFC cross sectional is uncracked, the full cross section shall be assumed to be active and both concrete and steel are assumed to be elastic in tension as well as in compression.

When an SRFC cross section is cracked, the SFRC shall be assumed to be elastic in compression, and capable of sustaining a tensile stress equal to 1.1 $f'_{1.5}$.

NOTE — Prior to cracking, linear elastic behaviour is assumed for the SFRC, reinforcement and the bonded tendons in both tension and compression. After cracking, the SFRC in tension is assumed to carry a tensile stress of 1.1 $f'_{1.5}$, while the SFRC in compression, the reinforcement and the bonded tendons are assumed to be linear elastic.

D-4.5.2 *Stress Limits*

D-4.5.2.1 *Concrete*

The maximum compressive stress in the concrete at the serviceability limit states shall not exceed $0.6 f_{cm}(t)$. Under permanent effect loading, the maximum compressive stress in the concrete shall not exceed $0.4 f_{cm}(t)$.

NOTES

1 The satisfaction of limits on the concrete tensile stress at the serviceability limit state is not necessary if the member performance is satisfactory at the ultimate limit state.

2 Compressive stresses are limited to avoid large time-dependent deformations and to ensure creep behaviour remains linear with respect to stress. Restrictions on the tensile stress in SFRC are not necessary provided the member satisfies all other requirements at the strength and serviceability limit states.

D-4.5.2.2 *Reinforcing steel*

To avoid any inelastic deformation that could lead to large, permanently open cracks, tensile stresses in the reinforcement at the serviceability limit states shall not exceed $0.8 f_{sy}$.

D-4.5.3 *Minimum Reinforcement for Crack Control*

The minimum amount of longitudinal reinforcement required to obtain controlled crack formation shall be:

$$A_{\mathrm{st,min}} = k_1 k_\mathrm{c} k_\mathrm{p} f_{\mathrm{ct,ef}} - 1.1 f'_{1.5} \frac{A_{\mathrm{ct}}}{f_{\mathrm{s,max}}} \geq 0.0 \text{ (mm}^2\text{)}$$

where

$A_{\mathrm{st,min}}$ = minimum area of reinforcement required within the tensile zone (mm^2). If $A_{st,\mathrm{min}}$ is zero only steel fibres are necessary to control cracking;

k_1 = coefficient which allows for the effect of non-uniform self-equilibrating stresses due to non-linear shrinkage or temperature profiles through the member depth. In the absence of more detailed analysis, k_1 may be taken as 0.8;

k_c = coefficient that takes account of the nature of the stress distribution within the section immediately prior to cracking. The relevant stress distribution is that resulting from the combined effects of loading and restrained imposed deformations:

= 1.0 for pure tension ($e = M/N = 0$)

= 0.6 for pure bending

k_p = a coefficient that takes account of the level of prestress and is given by:

$$k_p = 1 - \frac{\sigma_{\mathrm{cp}}}{k k_c f_{ct,ef}}\left(1 - k_c + 2.4\frac{e}{D} - 6k_c\frac{e}{D}\right)$$

$f_{\mathrm{ct,ef}}$ = tensile strength of the concrete effective at the time when the cracks may first be expected to occur (MPa). Values of $f_{\mathrm{ct,ef}}$ shall be obtained from $0.6\sqrt{f_{\mathrm{cm}}}$ but not less than 3.0 MPa and f_{cm} is the mean concrete compressive strength at the time cracking is expected to occur;

A_{ct} = area of concrete within the tensile zone (mm^2). The tensile zone is that part of the cross section calculated to be in tension just before formation of the first crack;

$f_{\mathrm{s,max}}$ = maximum stress permitted in the reinforcement immediately after formation of the crack;

e/D = ratio of the eccentricity of the prestressing force on the cross section, e, measured from the centroidal axis of the uncracked section to the overall depth of the cross section, D; and

σ_{cp} = average intensity of the effective prestress ($P_\mathrm{e}/A_\mathrm{g}$).

D-4.5.4 *Deflection Control*

D-4.5.4.1 *General*

The deflection of an SFRC member shall be calculated using the procedures outlined in **D-4.5.4.2** and **D-4.5.4.3**. Allowance shall be made for the expected load history, the expected construction procedure and any anticipated deflections resulting from deformation of forms or settlement of props.

D-4.5.4.2 *Short-term deflection*

The short-term deflections due to external loads and prestressing, which occur immediately on their application, shall be calculated using the value of E_{cj} determined in accordance with this Annex and the value of the effective second moment of area of the member (I_{ef}). The value of I_{ef} may be determined from the values of I_{ef} at nominated cross sections as follows:

a) For a simply supported span, the value at mid-span;

b) In a continuous beam:

   1) For an interior span, half the mid-span value plus one quarter of each support value; or

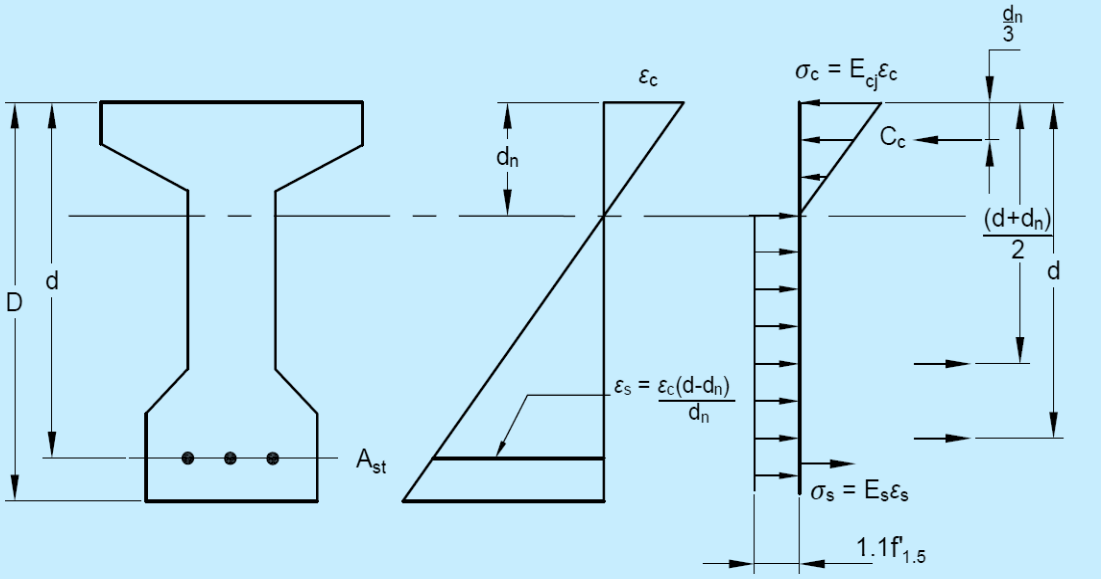
   2) For an end span, half the mid-span value plus half the value at the continuous support.

c) For a cantilever, the value at the support.

For the purpose of the above determinations, the value of I_{ef} at each of the cross sections nominated in items (a) to (c) is obtained from the instantaneous curvature $k_\mathrm{i} = M_s^*/(E_{\mathrm{cj}}\, I_{\mathrm{ef}})$ calculated as the slope of the strain diagram in

Fig. 6B and obtained by satisfying the requirements for rotational and horizontal equilibrium of the stress distribution in Fig. 6C.

NOTE — The procedure for calculating short-term deflection is consistent with the approach in this Annex. Short-term deflection of a cracked section is calculated based on the assumed stress and strain distribution shown in Fig. 6. The assumption of a uniform tensile stress in the cracked region of the SFRC is considered to be reasonable for the determination of the neutral axis location and curvature and, hence, for the determination of the effective second moment of area (I_{ef}).


D
d
A_{st}
ε_c
d_n
$\varepsilon_s = \frac{\varepsilon_c(d-d_n)}{d_n}$
$\sigma_c = E_{cj}\varepsilon_c$
C_c
$\frac{d_n}{3}$
$\frac{(d+d_n)}{2}$
d
$\sigma_s = E_s\varepsilon_s$
$1.1f'_{1.5}$

6A SELECTION 6B STRAIN 6C STRESS 6D FORCES

Fig. 6 Stress and Strain Distribution on a Cracked Section Subjected to Applied In-Service Bending Moment (M_s*)

D-4.5.4.3 *Long-term deflection*

For reinforced and prestressed SFRC flexural members, that part of the deflection that occurs after the short term deflection shall be calculated as the sum of:

a) The shrinkage component of the long-term deflection, determined from the design shrinkage strain of concrete (ε_{cs}) and the principles of mechanics; and

b) The additional long-term creep deflections, determined from the design creep coefficient of concrete (φ_{cc}) and the principles of mechanics.

In the absence of more accurate calculations, the additional long-term deflection of a reinforced SFRC beam due to creep and shrinkage may be calculated by multiplying the short-term deflection caused by the sustained loads by a multiplier, k_{cs}, as follows:

$$k_{cs} = \left[2 - 1.2\left(\frac{A_{sc}}{A_{st}}\right)\right] \geq 0.8$$

NOTES

1 For the calculation of long-term deflection, two alternative approaches are specified. For reinforced and prestressed beams, the shrinkage and creep components of the long-term deflection may be calculated separately using the material data specified in the Annex and the principles of mechanics. The shrinkage component of the long-term deflection may be readily determined from the shrinkage-induced curvatures calculated at the critical sections along the span of the beam using the design shrinkage strain, (εcs). The creep component of long-term deflection may be obtained from the creep-induced curvatures at the critical sections under the sustained service loads using the creep coefficient for concrete, (φcc).

2 Alternatively, for reinforced concrete beams and slabs, the additional long-term deflection caused by creep and shrinkage may be approximated by multiplying the short-term or immediate deflection caused by the sustained load by the deflection multiplier kcs. The deflection multiplier depends on the ratio Asc/Ast, where Asc is the area of the longitudinal reinforcement in the compressive zone of the cracked section (that is, between the neutral axis and the extreme compressive fibre of the cracked cross section) and *A*st is the area of the tensile reinforcement.

D-5 DURABILITY

The minimum concrete grade and cover for SFRC in respective exposure classification shall be as for concrete without fibres and shall apply to the steel reinforcement only. SFRC shall not be used in exposure classification C1 or C2.

NOTES

1 Steel fibres do not require concrete cover as specified for steel reinforcement.

2 SFRC may not be suitable in some exposure classification U environments.

3 Fibres close to the surface are subject to corrosion and may result in surface staining. This will not impact durability.

D-6 FIRE

The structural performance of SFRC for fire shall be determined in accordance with this annex. The material properties for SFRC shall be as specified for concrete in this Annex except that to characteristic residual tensile stress of SFRC at elevated temperatures ($f'_{1.5 2\theta}$) shall be either:

a) Taken as ($f'_{1.5 2\theta}$) = $k_{\theta 1} \times f'_{1.5}$ where $k_{\theta 1}$ is given in Table 4; or

b) Determined statistically from tests.

Table 4 Elevated Temperature Coefficient for Residual Tensile Stress of SFRC

(*Clause* D-6)

Sl No. (1)	Temperature of SFRC °C (2)	$k_{\theta 1}$ (3)
i)	0	1.0
ii)	100	1.0
iii)	500	0.6
iv)	700	0.1
v)	1200	0.0

NOTE — Linear interpolation between the values is permitted.

D-7 PRODUCTION OF SFRC

D-7.1 Fibres

Steel fibres shall comply with accepted standard. The 'Certificate of Conformity' shall be supplied on request to the relevant authority.

NOTE — Till the availability of a separate Indian Standard specification for steel fibres, reference may be made to ASTM A820 : 2022 'Standard Specification for steel fibers for fiber-reinforced concrete'.

D-7.2 Mixing of Fibres

Fibres of the type and quantity specified shall be added in a controlled process ensuring that they are dispersed uniformly through the concrete mix. If added after the main mixing process, the concrete shall be remixed until the fibres have been completely dispersed throughout the batch.

NOTES

1 Balling of fibres should be avoided.

2 A record of fibre content should be recorded for each batch.

D-7.3 Pre-Construction Testing of Materials

Pre-construction testing in the form of initial type tests shall be undertaken in accordance with Table 5. New initial type tests shall be undertaken when any of the following occur:

a) The concrete composition changes;

b) At least one source material of the concrete changes;

c) The results of compressive tests undertaken as per this Annex do not meet the specification; and

d) At least once in a period of 12 months.

The pre-construction tests shall be performed with the same personnel, materials and equipment that will be used during production.

Table 5 Pre-Construction Tests

(*Clause* D-7.3)

Sl No. (1)	**Material** (2)	**Inspection/Test** (3)	**Purpose** (4)
i)	Steel fibres	a) Check delivery note	Verify that the delivery is in accordance with the order, and is shipped from the correct source
		b) Check conformity label	Verify that the fibres have the correct conformity label which matches the corresponding certificate of conformity
ii)	Steel fibre content in the fresh concrete	Testing according to **D-7.5** on the basis of 9 samples	Conformity with the target dosage. Verify homogeneous distribution of the steel fibres in the mix
iii)	Steel fibre concrete performance	Check limit of proportionality, and post-crack flexural strength in accordance with **D-3.3.6** on a minimum of 12 beams	Verify, if the performance is in accordance to the specification. The performance level serves as the reference for continuous production control

NOTE — The strength of the population may be treated as normally distributed and the characteristic strength determined in accordance with this annex. A confidence level of 75 percent shall be used such that 95 percent of the population exceeds the characteristic value. For a sample of 12 specimens, the characteristic strength may be calculated from the mean strength using characteristic strength = mean strength × (1 – 1.84 × COV). The coefficient of variation (COV as a percentage) shall not exceed 25 percent.

D-7.4 Factory Production Control

Factory production control is accordance with Table 6 shall be undertaken to establish a production process for the steel fibre reinforced concrete, and shall include the following:

a) Checking the correct concrete constituents are being used in production;

b) Steel fibres are checked against specified requirements;

c) Compressive tests undertaken in accordance with good practice [C-5 (40)]; and

d) Fibre content and distribution.

Table 6 Routine Production Control

(*Clause* D-7.4)

Sl No.	Subject	Inspection/Test	Purpose	Frequency
(1)	(2)	(3)	(4)	(5)
i)	*Equipment inspection*			
	a) Automatic dosing equipment for steel fibres	1) Visual inspection	Assure correct functioning of dosing device	Once per production day
		2) Control of accuracy	Avoid improper fibre dosage	On installation periodically in case of doubt
ii)	*Materials inspection*			
	a) Steel fibres	1) Check delivery note	Verify that the delivery is in accordance with the order, and is shipped from the correct source	Each delivery
		2) Check conformity requirements	Verify that the fibres matches the corresponding Certificate of Conformity	Each delivery
		3) Visual control, measure fibre dimensions	Compare the fibre geometry with the fibres used for ITT	Each delivery
iii)	*Production process inspection*			
	a) Fibres content-record	1) Record the quantity added	Check the content	Every batch
	b) Fibre content in the fresh concrete	2) Testing according to **D-7.5**	Conformity with the target dosage Verify homogenous distribution of the steel fibres in the mix	Beginning of each day and every/ 50 m^3 (manual dosing) and/150 m^3 (auto dosing)
	c) Concrete mix	3) Visual Check	Correct mixing with correct fibre type and even fibre distribution without balling	Daily
iv)	*Finished product inspection*			
	a) Steel fibre concrete performance	1) Check limit of proportionality, and post-crack flexural strength in accordance with **D-3.3.6**	Check performance level of the specification	2 beams every other day of production

D-7.5 Determining the Steel Fibre Content

Steel fibre content shall be measured from samples taken from the production concrete, by volume of concrete.

In addition:

a) A sample shall be taken from the batch of concrete at unloading from the first third, middle third and final third of the batch;

b) Each sample shall be a minimum of 10 litre;

c) The sample container shall be filled in one continuous pour and where possible directly from the discharge chute; and

d) Wash out or magnetic separation only shall be used.

The conformity of the correct steel fibre dosage is proven if the criteria in Table 7 are met.

Table 7 Criteria of Acceptance for Steel Fibre Dosage

(*Clause* D-7.5)

Sl No. (1)	Test Control (2)	Test Control (3)	Criteria (4)
i)	Each sample	Each partial test	≥ 0.80 of the specified target dosage
ii)	Average of 3 samples from the batch	Each test	≥ 0.85 of the specified target dosage
iii)	Continuous control: average of > 3 tests	Continuous control average of > 3 tests	≥ 0.90 of the specified target dosage

D-7.6 Sampling, Testing and Assessment for Compliance of Hardened SFRC

When concrete is specified by parameters other than strength grade, the method of production control and, if required, project control shall be specified together with the relevant compliance criteria.

Methods of control and assessment shall provide a reliable operating characteristic curve so that:

a) Concrete with a proportion defective of 0.05 has a probability of acceptance of at least 50 percent; and

b) Concrete with a proportion defective of 0.30 has a probability of rejection of at least 98 percent.

ANNEX E

(*Foreword and Clause* 5)

CRITERIA FOR STRUCTURAL SAFETY OF TALL CONCRETE BUILDINGS

E-1 SCOPE

E-1.1 This Annex covers the following design aspects of reinforced concrete (RC) buildings of height greater than 50 m, but less than or equal to 250 m. Generally, these requirements are based on prescriptive approach and covers the following design aspects of tall buildings:

a) Selection of appropriate structural system;

b) Geometric proportioning of the building;

c) Integrity of structural system;

d) Resistance to wind and earthquake effects; and

e) Other special considerations related to tall buildings.

E-1.2 This Annex is not applicable for tall buildings located in the near-field of seismogenic faults. For the purposes of this standard, near-field is taken as 10 km (shortest distance) from a seismogenic fault.

E-1.3 This Annex is applicable only for buildings that house 20 000 or fewer persons.

E-1.4 This Annex may also be used for design of buildings of height equal to or less than 50 m. The provisions of this Annex will add value to the design of such buildings. However, this Annex is not applicable for design of buildings of height more than 250 m.

E-1.5 This Annex addresses the following typical structural systems of tall concrete buildings:

a) Structural wall systems;

b) Moment frame systems;

c) Moment frame — Structural wall systems;

d) Structural wall — Flat slab floor systems with perimeter moment frame;

e) Structural wall — Framed tube systems;

f) Framed-tube system;

g) Tube-in-tube system;

h) Multiple tube system;

j) Hybrid system; and

k) Any of the above with additional framing systems, for example, outrigger trusses, belt trusses and braced frames.

E-1.6 This Annex shall be read along with all Indian Standards relevant to design and construction of buildings and structures. In case of conflict, clauses given in this Annex shall be applicable.

E-1.7 For buildings that do not conform to the prescriptive requirements of this Annex, a more rigorous procedure is necessary for design and review.

E-2 -

NOTE — (This clause is intentionally left blank.)

E-3 TERMINOLOGY

For the purpose of this Annex, the following definitions shall apply.

E-3.1 Building Height — The difference in levels between the base level of a building, at which inertia forces generated in the structure are transferred to the foundation, which then transfers these forces to the ground, and the highest level of a building, which is the roof of the topmost level which is structurally integral and continuous with the floor below (*see also* E-4).

E-3.2 Connecting Structure — A structure that links two or more towers, except at the podium levels.

NOTE — There are two distinctive types of connecting structures with each one requiring a different structural treatment, namely, (a) the connecting structure having the role of transferring gravity loads only and with no participation in the role of resisting the lateral loads on either of the towers; and (b) the connecting structure participating in the lateral load resisting structural system, where the two towers act together when one or both towers is subjected to lateral loads due to the interaction provided by the connecting tower.

E-3.3 Core — An assembly of structural walls coupled with link elements and offering lateral stiffness in two orthogonal directions.

E-3.4 Coupled Structural Wall Building — A building comprising of structural walls linked by in-plane beam elements, wherein the vertical and lateral loads are resisted by these structural walls, through axial load, in-plane bending moment and shear force, and the coupling action created by push-pull in the wall elements by framing action provided by link beams.

E-3.5 Frame Building — A building comprising beams and columns, wherein the vertical and lateral loads are resisted by these elements through moment-frame action.

E-3.6 Gravity Columns — Vertical members that are intended to carry primarily the vertical loads arising out of the dead and imposed loads on the building, and do not participate in the lateral load resisting system. Such columns shall be capable primarily of carrying the gravity loads and additional induced loads while complying with the relative lateral deformation effects imposed on them during lateral earthquake shaking.

E-3.7 Key Elements — The element such that its failure would cause the collapse of more than a limited area close to it. The limited area may be taken equal to 70 m^2 or 15 percent of the area of the storey, whichever is lesser. If key elements exist, it is preferable to modify the layout so that the key element is avoided.

E-3.8 Linking Beams (Also called coupling beams) — Horizontal members spanning two (vertical) structural walls.

E-3.9 Mixed Building or Hybrid Building — A building in which select primary elements resisting vertical and/or lateral loads comprise more than one material; composite elements comprising structural steel and reinforced concrete are common examples.

E-3.10 Multi-Tower Structures Linked by Podium — Two or more towers above a common podium structure that are not separated by a movement joint at the podium level.

E-3.11 Natural Period — The time taken (in seconds) by the structure to complete one cycle of oscillation in its natural mode of oscillation.

E-3.12 Structural Systems and Sub-Systems

E-3.12.1 *Structural Wall System* — A structural system comprising of inter-connected structural walls, wherein the vertical and lateral loads are resisted by the walls through axial load, in-plane bending moment and shear force. The wall elements are configured by a combination of structural wall elements connected integrally to a floor diaphragm. The wall elements form the primary lateral load resisting structural system for the building, and resist the loads imposed on them through axial, shear and flexural actions, and through coupling actions offered by the connecting link elements if provided.

E-3.12.2 *Moment Frame System* — A structural system comprising (beam-column) frames and resisting the vertical and lateral loads.

E-3.12.3 *Moment Frame-Structural Wall System* — A structural system comprising (beam-column) frames and structural walls resisting the vertical and lateral loads. The relative share of the lateral load resisted between these systems is dependent on their relative lateral stiffnesses.

E-3.12.4 *Structural Wall System with Flat Slab Floor System* — A structural system comprising structural walls, a beam-less floor system, and columns resisting the vertical and lateral loads. The relative share of the lateral load resisted between these systems is dependent on their relative lateral stiffnesses.

E-3.12.5 *Core and Outrigger Structural System* — A structural system comprising wall element(s) and perimeter columns, resisting the vertical and lateral loads. Essentially, the perimeter columns are for resisting gravity loads only. The core structure is connected to select perimeter column element(s) (often termed outrigger columns) by beam elements, known as outriggers, at discrete floor locations along the height of the building. This type of structure is an extension of the core structure, to enhance the lateral stiffness for taller structures, which mobilizes the perimeter columns, and offers increased leverage for push pull-action through the framing action offered by the deep beam(s) connecting the core to the outrigger columns. The global lateral stiffness is sensitive to: flexural stiffness of the core element, the flexural stiffness of the outrigger element(s) and the axial stiffness of the outrigger column(s).

E-3.12.6 *Core, Outrigger and Belt Wall System* — A structural system, which is an extension to the core and outrigger structure to enhance the lateral stiffness further, where the outrigger column(s) is linked to the adjacent columns by deep beam elements (often known as belt truss), typically at the same level as the outrigger elements. The sharing of loads between multiple columns has the dual function of enhancing the axial stiffness and mobilizing greater number of gravity columns to counteract the induced tension loads generated by the overall lateral loads.

E-3.12.7 *Framed-Tube System* — A structural system comprising closely spaced columns and deep beams in the perimeter frame for efficient tube action. The internal vertical elements, comprising core or columns are primarily utilized to resist gravity loads only. Effective utilization of the perimeter of the building maximizes the overall stiffness for a given building plan shape; this system is effective for very tall buildings.

E-3.12.8 *Tube-in-Tube System* — A structural system, which is an extension of the tube structure, where there is an internal tube, often a core element, supplementing the external perimeter described as the tube structure above, to enhance the overall lateral global stiffness. Just as the tube structure, typically, even this system is suited for very tall buildings.

E-3.12.9 *Multiple-Tube System* — A structural system, which is an extension of the tube structure and/or the tube-in-tube structure, where the architectural plan of the tower facilitates multiple tubes to be connected together, to enhance the lateral stiffness of the structure. Just as the tube structure and the tube-in-tube structure, typically, this suited is reserved for very tall buildings.

E-3.13 Super Tall Building — A building of height greater than 250 m.

E-3.14 Tall Building — A building of height greater than 50 m, but less than or equal to 250 m.

E-3.15 Transfer Structure — A structure, comprising of horizontal deep beams, trusses or thick slabs that transfers load actions and supports vertical elements above to vertical elements below that are not aligned with each other, through flexural and shear actions. Alternatively, it can be a trussed structure that fulfils the task through axial actions in the truss members.

E-4 SYMBOLS

For the purpose of this Annex, the following letter symbols shall have the meaning indicated against each; where other symbols are used, they are explained at appropriate places. All dimensions are in metres (m), loads in Newton (N), stresses in mega Pascals (MPa) and time in seconds (s), unless otherwise specified.

a — Major axis of elliptic plan shape of the building

A_{cr} — Cracked area of section

A_{g} — Gross area of section

b — Minor axis of elliptic plan shape of the building

h_{i} — Inter-storey height of i^{th} floor in the building

l_{s} — Clear span of coupling beam

B — Smaller plan dimension of the building at its base

B_{t} — Width of tower above podium level

D — Dimension of the building in plan along the considered direction of earthquake shaking

d — Overall depth of coupling beam

H — Building height from its base to roof level:

a) excluding the height of basement storeys, if basement walls are connected with the ground floor slab or basement walls are fitted between the building columns, but;

b) including the height of basement storeys, if basement walls are not connected with the ground floor slab and basement walls are not fitted between the building columns

H_{t} — Height of tower above podium level

h_w — Unsupported height of structural wall

I_{eff} — Effective or cracked moment of inertia of section

I_{g} — Gross moment of inertia of section

L — Larger plan dimension of the building at its base

L_{t} — Length of the tower above podium level

M_u — Factored bending moment at a cross-section in a vertical member of the building

P_u — Factored axial load at a cross-section in the vertical member of the building

P_{uz} — Factored pure axial load capacity (at $M_u = 0$) of a vertical member of the building

T_a — Approximate fundamental translational lateral natural period

Δ_{max} — Maximum relative lateral displacement within the storey

E-5 GENERAL REQUIREMENTS

E-5.1 Elevation

E-5.1.1 *Height Limit for Structural Systems*

The maximum building height (in m) shall not exceed values given in Table 8 for buildings with different structural systems.

Table 8 Maximum values of Height *H* above Top of Base Level of Buildings with Different Structural Systems, in Metre

(*Clause* E-5.1.1)

Sl No.	Seismic Zones	Structural System				
		Moment Frame	Structural Wall Well Distributed$^{1)}$	Structural Wall + Moment Frame	Structural Wall + Perimeter Frame	Structural Wall + Framed Tube*
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	V	NA	120	150	150	180
ii)	IV	NA	150	200	200	225
Iii)	III	60	200	225	225	250
iv)	II	80	250	250	250	250

$^{1)}$ Structural walls are considered to be well-distributed when structural walls that are outside of the core are capable of carrying at least 25 percent of the lateral loads.

* This includes systems covered under **E-1.5 (g)**, **E-1.5 (h)** and **E-1.5 (k)**.

E-5.1.2 *Slenderness Ratio*

The maximum values of the ratio of height to minimum base width *B* shall not exceed values given in Table 9.

Table 9 Maximum Slenderness Ratio (H_t/B_t)

(*Clause* E-5.1.2)

Sl No.	Seismic Zones	Structural System				
		Moment Frame	Structural Wall Well Distributed	Structural Wall + Moment Frame	Structural Wall + Perimeter Frame	Structural Wall + Framed Tube*
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	V	NA	8	8	9	9

Table 9 (*Concluded*)

(*Clause* E-5.1.2)

Sl No.	**Seismic Zones**	**Structural System**				
		Moment Frame	Structural Wall Well Distributed	Structural Wall + Moment Frame	Structural Wall + Perimeter Frame	Structural Wall + Framed Tube*
(1)	(2)	(3)	(4)	(5)	(6)	(7)
ii)	IV	NA	8	8	9	9
iii)	III	4	8	8	9	10
iv)	II	5	9	9	10	10

* This includes systems covered under **E-1.5(g)**, **E-1.5(h)** and **E-1.5(k)**.

E-5.1.3 *Aerodynamic Effects*

Elevation profile, façade features of the building, and plan shape of the building shall be such as to attract minimum wind drag effects. Effects of features such as sharp corners, projected balconies, etc, shall be considered in design.

E-5.2 Plan

E-5.2.1 *Plan Geometry*

E-5.2.1.1 The plan shall preferably be rectangular (including square) or elliptical (including circular). In buildings with said plan geometries, structural members participate efficiently in resisting lateral loads without causing additional effects arising out of re-entrant corners and others.

E-5.2.2 *Plan Aspect Ratio*

The maximum plan aspect ratio (L_t/B_t) of the overall building shall not exceed 5.0. In case of an L-shaped building, L_t and B_t shall refer to the respective length and width of each leg of the building.

E-5.3 Storey Stiffness and Strength

Parameters influencing stiffness and strength of the building should be so proportioned, that the following are maintained:

a) Lateral stiffness of any storey shall not be less than 70 percent of that of the storey above; and

b) Lateral strength of any storey shall not be less than 90 percent that of the storey above.

E-5.4 Deformations

E-5.4.1 *Lateral Drift*

When design lateral forces are applied on the building, the maximum inter-storey lateral drift ratio (Δmax/h_i) under serviceability loads (including wind load with return period of 20 years), which is estimated based on the sectional properties for serviceability loads mentioned in **E-7.2**, shall be limited to 1/500. Total drift at the topmost usable floor shall be limited to H/500. For a single storey the drift limit may be relaxed to h_i/400.

E-5.5 Natural Modes of Vibration

E-5.5.1 The natural period of fundamental torsional mode of vibration shall not exceed 0.9 times the smaller of the natural periods of the fundamental translational modes of vibration in each of the orthogonal directions in plan.

E-5.5.2 The fundamental translational lateral natural period in any of the two horizontal plan directions, shall not exceed 8 s, considering sectional properties as per **E-7.2(c)** corresponding to serviceability loads.

E-5.6 Floor Systems

E-5.6.1 *Material*

All floor slabs shall be cast in-situ. For precast floor systems a minimum structural topping of 75 mm concrete with reinforcing mesh shall be used in Seismic Zones III and above, but can be reduced to 50 mm in Seismic Zone II.

E-5.6.2 *Openings*

E-5.6.2.1 Openings in floor diaphragm shall not be permitted along any floor diaphragm edge, unless perimeter members are shown to have stability and adequate strength.

E-5.6.2.2 The maximum area of openings in any floor diaphragm shall not exceed 30 percent of the plan area of diaphragm. Transfer of lateral forces from diaphragm to lateral load resisting vertical elements shall be ensured using collector elements, if required.

E-5.6.2.3 At any storey, the minimum width of floor slab along any section after deduction of openings shall not be less than 5 m, if there is no perimeter beam. Further, the cumulative width of the slab at any location shall preferably not be less than 50 percent of the floor width.

E-5.6.3 *Natural Frequency of Floor System*

The natural vertical vibration frequency of any floor system shall not be less than 3 Hz without demonstration of acceptability using rational procedures.

E-5.7 Materials

E-5.7.1 *Concrete*

E-5.7.1.1 The minimum grade of concrete shall be M 30.

E-5.7.1.2 The maximum grade of concrete shall be M 70. When higher grades are required, the designer shall ensure through experimentation that such concretes shall have at least a minimum crushing strain in compression of 0.002.

E-5.7.2 *Reinforcing Steel*

E-5.7.2.1 Reinforcing seel shall conform to provisions of good practice [C-5(5)].

E-5.7.2.3 Lapping of longitudinal bars shall be avoided in RC columns and walls that form a part of the lateral load resisting system; when diameter of bars is 20 mm or higher; mechanical couplers as per accepted standard [C-5(33)] shall be used to extend bars.

E-5.8 Progressive Collapse

Following are general guidelines to avoid progressive collapse of structure.

E-5.8.1 Possibilities of progressive collapse shall be precluded by:

a) Selecting structural systems that are appropriate for ensuring structural integrity;

b) Adopting rigorous structural investigations that verify acceptable structural behaviour, even when select critical members do not play their intended role; and

c) Providing adequate redundancy and integrity to the structure.

E-5.8.2 *Requirements of Key Elements*

E-5.8.2.1 Key elements are members, joints or other components, whose failure would result in a disproportionate deterioration of the building and whose presence is vital to ensure ductile behaviour of the building. Vertical and lateral resistance of key elements shall be improved in many ways, including by the use of higher partial safety factors for loads and materials, to ensure that they do not yield before the designated ductile elements.

E-5.8.2.2 Elements adjoining key elements and capable of providing an alternative load transfer path, shall be suitably designed and detailed.

E-6 LOADS AND LOAD COMBINATIONS

E-6.1 The loads and load combinations specified in Part C 'Structural Design/Section 1 Loads and Load Effects' of this NBCS, the good practice [C-5(2)] and good practice [C-5(5)]shall be applicable for tall buildings also. In addition, requirements given in subsequent clauses shall be applicable.

E-6.2 Wind Effects

E-6.2.1 For buildings (a) with height greater than 150 m, or (b) with complexities in plan or elevation geometry, or (c) sited on complex topography with group effect or interference effect (existing and future potential),or (d) whose natural period is greater than 5 s, wind effects shall be determined by site-specific wind tunnel studies.

E-6.2.2 *Site-Specific Wind Tunnel Studies*

E-6.2.2.1 When wind tunnels studies result in higher storey shears and overturning moments than those calculated at based on **4** of Part C 'Structural Design/Section 1 Loads and Load Effects' of this NBCS, the results of wind tunnel studies may be used in design.

E-6.2.2.2 When wind tunnel studies result in lower story shears and moments than those calculated based on **4** of Part C/Section 1 of this NBCS,

a) The minimum design wind base shear shall be at least 70 percent of that derived based on **4** of Part C/ Section 1 of this NBCS; and

b) The relative distribution of storey shears shall be as obtained from wind tunnel studies.

E-6.2.2.3 When wind tunnel studies indicate torsional motion, structural system of the building should be modified suitably to mitigate the torsional effects, so as to bring the torsional velocity below 0.003 rad/s for 10 year return period.

E-6.2.2.4 The damping ratio considered shall not be greater than 2 percent of critical for concrete buildings.

E-6.2.3 *Lateral Acceleration*

From serviceability considerations, under standard wind loads with return period of 10 years, the maximum structural peak combined horizontal acceleration a_{max} in the building for along and across wind actions at any floor level shall not exceed values given in Table 10, without or with the use of wind dampers in the building.

Table 10 Permissible Peak Combined Acceleration

(*Clause* E-6.2.3)

Sl No. (1)	**Building Use** (2)	**Maximum Peak Combined Acceleration, a_{max}** m/s^2 (3)
i)	Residential	0.18
ii)	Mercantile	0.25

E-6.3 Seismic Effects

E-6.3.1 Vertical shaking shall be considered simultaneously with horizontal shaking for tall buildings in Seismic Zone V.

E-6.3.2 For buildings in Seismic Zone V, deterministic site-specific design spectra may preferably be estimated and used in design. When site-specific investigations result in higher hazard estimation, site-specific investigation results shall be used.

E-6.3.3 Design base shear coefficient of a building under design lateral forces, shall not be taken less than that given in Table 11.

Table 11 Minimum Design Base Shear Coefficient (Percent of Seismic Weight)

(*Clause* E-6.3.3)

Sl No.	Building Height, *H*	Seismic Zone			
		II	III	IV	V
(1)	(2)	(3)	(4)	(5)	(6)
i)	$H \leq 120$ m	0.7	1.1	1.6	2.4
ii)	$H \geq 200$ m	0.5	0.75	1.25	1.75

NOTE — For buildings of intermediate height in the range 120 m to 200 m, linear interpolation shall be used.

E-6.3.4 *Approximate Fundamental Natural Period*

For buildings of height 50 m and more, the fundamental period T (in s) for a structure shall be determined by accounting for all structural properties and inherent stiffness of the building through rigorously validated structural analysis procedures. The fundamental period shall however not exceed the value obtained from the approximate fundamental translational natural period T_a (in s) of oscillation, estimated by following expression:

$$T_a = 0.0644 H^{0.9} \text{ for concrete moment resisting frame systems}$$

and

$$T_a = 0.0672 H^{0.75} \text{ for all other concrete structural systems}$$

E-7 STRUCTURAL ANALYSIS

E-7.1 Software

Structural analysis shall be carried out using standard 3-D computer model using well-established structural analysis software.

E-7.2 Considerations

Computer modelling shall consider the following:

a) Rigid end offsets of linear members in the joint region, when centerline modelling is adopted;

b) Floor diaphragm flexibility, as applicable;

c) Cracked cross sectional area properties as per Table 12; and

d) The load combination for the initial analysis considering *P-Δ* effects shall be taken as: 1.2 DL + 0.5 IL ± 1.5 EL/WL.

E-7.3 Modelling

E-7.3.1 Modelling of buildings shall follow a simple approach, which reflects the distribution of mass and stiffness properties to properly account for all significant inertial forces under seismic actions and deformation shapes.

E-7.3.2 Analytical model of a building shall reflect the true behaviour of its members as well of the whole structure. One can adopt lumped modelling that is frame element modelling, distributed modelling that is finite element modelling or a combination of the two.

Table 12 Cracked Section Properties of RC Members

(*Clauses* E-7.2 *and* E-7.3.6)

Sl No.	Structural Element	Serviceability Design		Strength Design	
		Cross-Sectional Area	Moment of Inertia	Cross-Sectional Area	Moment of Inertia
(1)	(2)	(3)	(4)	(5)	(6)
i)	Slabs	$1.0\ A_g$	$0.35 I_g$	$1.00\ A_g$	$0.25\ I_g$
ii)	Beams	$1.0\ A_g$	$0.7\ I_g$	$1.00\ A_g$	$0.35\ I_g$
iii)	Columns	$1.0\ A_g$	$0.9\ I_g$	$1.00\ A_g$	$0.70\ I_g$
iv)	Walls	$1.0\ A_g$	$0.9\ I_g$	$1.00\ A_g$	$0.70\ I_g$

E-7.3.3 In-plane stiffness of floor slabs shall be modelled, unless it is demonstrated that it is extremely stiff and sufficiently strong to remain elastic under seismic actions. *See* **5** of Part C 'Structural Design/Section 1 Loads and Load Effects' of this NBCS to identify when a floor slab may be considered to be extremely stiff in its own plane.

E-7.3.4 In moment frame buildings, when buildings with unreinforced masonry infill panels contribute to storey lateral stiffness, their effect shall be modelled as equivalent diagonal struts as per relevant provisions of **5** of Part C/Section 1 of this NBCS.

E-7.3.5 The analytical model for performing dynamic analysis of buildings with irregular configuration shall adequately represent irregularities in the configuration of the building.

E-7.3.6 Cracked sectional properties shall be used when representing concrete elements as per Table 12.

E-7.3.7 In reinforced concrete buildings, lateral deflections resulting from unfactored lateral loads shall be estimated using section properties intended for use with unfactored lateral loads, and lateral deflections resulting from factored lateral loads using section properties intended for use with factored lateral loads.

E-7.3.8 Buildings may be considered to be fixed at their bases for determining lateral effects on buildings. When modelling flexibility of foundations, reference shall be made to **E-8** and **E-9**.

When foundation flexibility is included in linear analysis, load-deformation characteristics of foundation-soil system shall be accounted for by equivalent linear stiffness, using soil properties that are consistent with soil strain levels associated with the design forces. A 50 percent increase and decrease in stiffness shall be incorporated in dynamic analysis, unless smaller variation can be justified; the largest value of response shall be used in the raft design.

E-7.3.9 Second order deformation effects (P-Δ effects) shall be considered.

E-7.3.10 The flexibility of the building shall be such that the inter-storey drift stability coefficient θ satisfies

$$\theta = \frac{P_i \Delta_i}{V_i h_{i-1} R} \le 0.2$$

where

P_i = total design vertical load at level i;

Δ_i = design storey drift at level i;

V_i = design shear force at level i;

h_{i-1} = storey height below level i; and

R = response reduction factor.

E-7.3.11 Stiffness of frames with flat slabs as horizontal members (that is, slab-column frames) shall be ignored in lateral load resistance, in all Seismic Zones. These shall be designed as gravity elements for deformation compatibility.

E-7.3.12 The model used in structural analysis of solid, coupled, perforated or punched structural walls shall represent stiffness, strength and deformation capacities of structural wall, structural wall segments and coupling beams or spandrel connections between structural walls. Stiffness of coupling beams and spandrel connections shall capture aspect ratio of these coupling beam and spandrel connections, extent of cracking anticipated, and reinforcement provided in them.

E-7.3.13 Effects shall be considered of construction sequence in buildings taller than 150 m.

E-7.3.14 Tower(s) connected by a podium shall be modelled separately and integrally.

E-7.4 Building Movements

For buildings taller than 150 m, and for buildings taller than 100 m with mass asymmetry, analysis shall be carried out for both vertical and horizontal long-term building movements.

E-7.4.1 Measures shall be taken in concrete and composite buildings to minimize adverse effects of shrinkage, creep, temperature variation and foundation settlement during the design life of the building (not less than 30 years).

E-7.4.2 Non-structural elements, such as curtain walls, cladding, partitions and finishes and service installations (for example, elevators, vertical pipes, ducts and cables), shall be required to withstand long-term movements of the building and associated differential effects.

E-7.4.3 Details of connections of non-structural elements with the structural elements of the building shall be planned, such that their relative movements are allowed without causing distress to both structural and non-structural elements.

E-7.4.4 Appropriate vertical compensation and sway compensation shall be accounted for during construction to minimize long term building movements for concrete and composite structures.

E-7.4.5 In gravity load analysis, internal forces shall be considered, which are developed due to differential vertical movement of vertical structural elements, due to shrinkage, creep, temperature, foundation settlement and construction compensation. In any case the total shrinkage strain of concrete shall not exceed 0.04 percent.

E-7.4.6 To calculate the effect of creep and shrinkage, selected strain prediction models of concrete shall be based on established principles of mechanics elaborated in specialist literature.

E-8 STRUCTURAL DESIGN

E-8.1 General Requirements

E-8.1.1 *Method of Design*

Limit state design method (as given in [C-5(2)]) shall be used in the design of RC members.

E-8.1.2 *Staircase*

Staircases built integrally with the structural system of the building and not confined by structural walls, shall be included in the three-dimensional structural model, and its elements designed as per forces induced in them under various load combinations. Alternately a sliding joint may be provided.

E-8.1.3 *Multiple Tall Buildings connected with a Common Podium*

E-8.1.3.1 This section deals with requirements for the following tall buildings with podium:

a) Tall building with single tower and podium (*see* Fig. 7A); and

b) Tall building with multiple towers and common podium (*see* Fig. 7B).

E-8.1.3.2 *Modelling*

E-8.1.3.2.1 *Sensitivity analyses*

a) As part of collapse prevention evaluation, two sets of backstay sensitivity analyses shall be carried out using upper-bound and lower-bound cracked section properties of floor diaphragms and the stiffness parameters for those diaphragms and perimeter walls of podium and below the level of the backstay are given in Table 13. These analyses shall be in addition to those required to be carried out using other cracked section properties described in **E-7.2(c)**.

Table 13 Stiffness Parameters

[*Clauses* E-8.1.3.2.1(a) *and* E-8.1.3.3.3(d)(2)]

Sl No.	**Stiffness Parameter**	**Values to be Adopted**	
		Upper-Bound	Lower-Bound
(1)	(2)	(3)	(4)
i)	$I_{\text{eff}} / I_{\text{g}}$	0.5	0.15
ii)	$A_{\text{cr}} / A_{\text{g}}$	0.5	0.15

b) Besides that of the floor diaphragms, flexibility of following structural elements in the structural analysis with appropriate modification to their stiffness:

1) Perimeter walls and their foundation supports; and

2) Foundation supports under the tower lateral load resisting system.

E-8.1.3.3 *Buildings with multiple towers*

E-8.1.3.3.1 *Backstay*

Backstay transfers the forces from lateral load-resisting elements in the tower to additional structural elements provided within the podium and the basement, typically through one or more floor diaphragms. Lateral load resistance in the podium levels with assured force transfer path through floor diaphragms at these levels, helps the tall building to resist lateral overturning forces. This component of overturning resistance, referred as the backstay effect (also called shear reversal), is critical because shear force changes direction within the podium levels, and the same lateral load-resisting element helps resist the changing shear force.

The following shall be considered:

a) In estimating backstay effects, two lateral load paths shall be considered (*see* Fig. 8), namely:

1) *Direct load path* — where overturning resistance is provided by the tower core elements and foundation directly beneath the tower; and

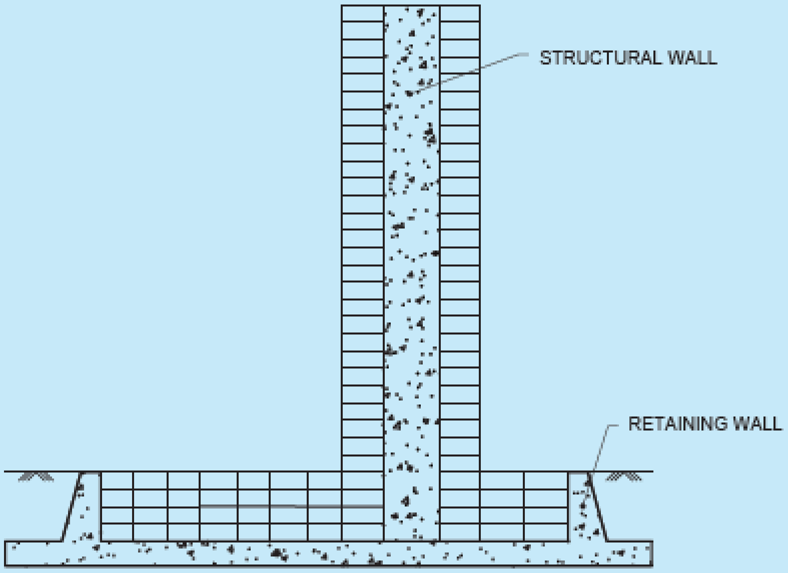
2) *Backstay load path* — where overturning resistance provided by in-plane forces in the backstay elements (lower floor diaphragm and perimeter walls).

In some tall buildings, backstay effects may not be considered. These include the following configurations:

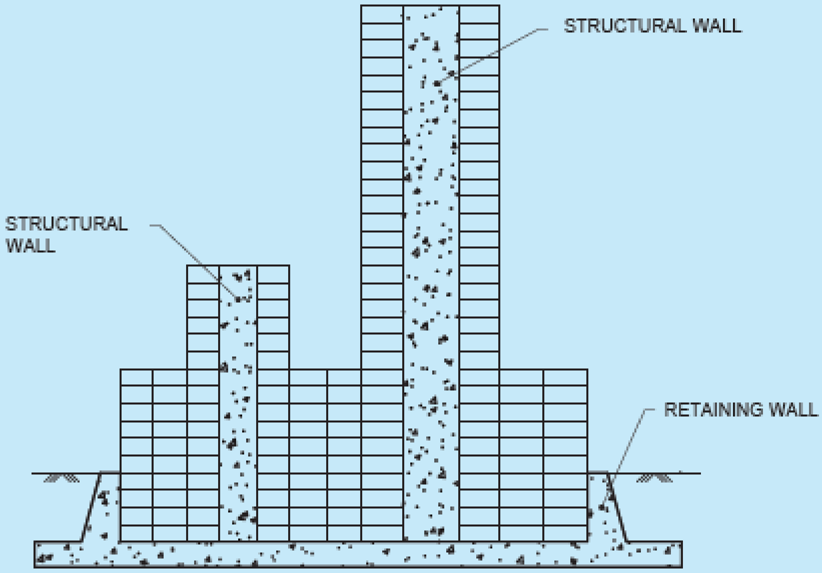
i) Buildings without below grade levels or buildings without significantly increased lateral load resisting systems at the base;

ii) Buildings that extend below grade, but have structural separations between the superstructure and the podium portions of the building, and that accommodate lateral load deformations without transfer of lateral forces from superstructure portion to podium portion; and

iii) Buildings with perimeter basement walls, where the walls are located directly below the lateral load resisting elements of the superstructure above. Here, there may be a marked change in lateral strength and stiffness at this level, but lateral forces will not be transferred through the floor diaphragms.



7A SINGLE TOWER



7B MULTIPLE TOWERS

FIG.7 TALL BUILDINGS WITH PODIUMS, CORE STRUCTURAL WALL AND BELOW-GRADE PERIMETER RETAINING WALL

b) Backstay floor diaphragms shall be modelled considering their in-plane and out-of-plane floor flexibility. Any large discontinuity present in the slab shall be modelled;

c) In direct load path case, vertical stiffness shall be considered of the piles, foundation and supporting soil;

d) In backstay load path case, relative stiffness shall be considered of floor diaphragms and perimeter walls, along with vertical in-plane rocking stiffness of soil below the walls. Also, horizontal pressure imposed by soil on retaining walls shall be considered. Axial stiffness of elements (representing backstay) along load path shall be reduced to account for cracking, bond slip, interface slip and other such effects;

e) In tall buildings with backstay diaphragms, collector elements shall be provided (*see* Fig. 8), which are capable of transferring forces from the lateral load-resisting system of the tower to the additional elements providing the resistance and in turn to those forces of the podium. Such collector elements shall be provided for transferring lateral forces originating in the other portions of the structure;

f) The backstay diaphragms shall be designed in accordance with the following:

  1) They shall be designed for the maximum of forces derived from sensitivity analysis;

  2) When the lateral force resisting system of a tall building has plan irregularity as per **5** of Part C 'Structural Design/Section 1 Loads and Load Effects' of this NBCS of Type I (torsion irregularity), Type II (re-entrant corners) and Type IV (out of plane offsets), and vertical irregularity as per **5** of Part C/Section 1 of this NBCS of Type IV (in-plane discontinuity of vertical elements resisting lateral forces), seismic forces shall be amplified by a factor of 1.5 in the design of:

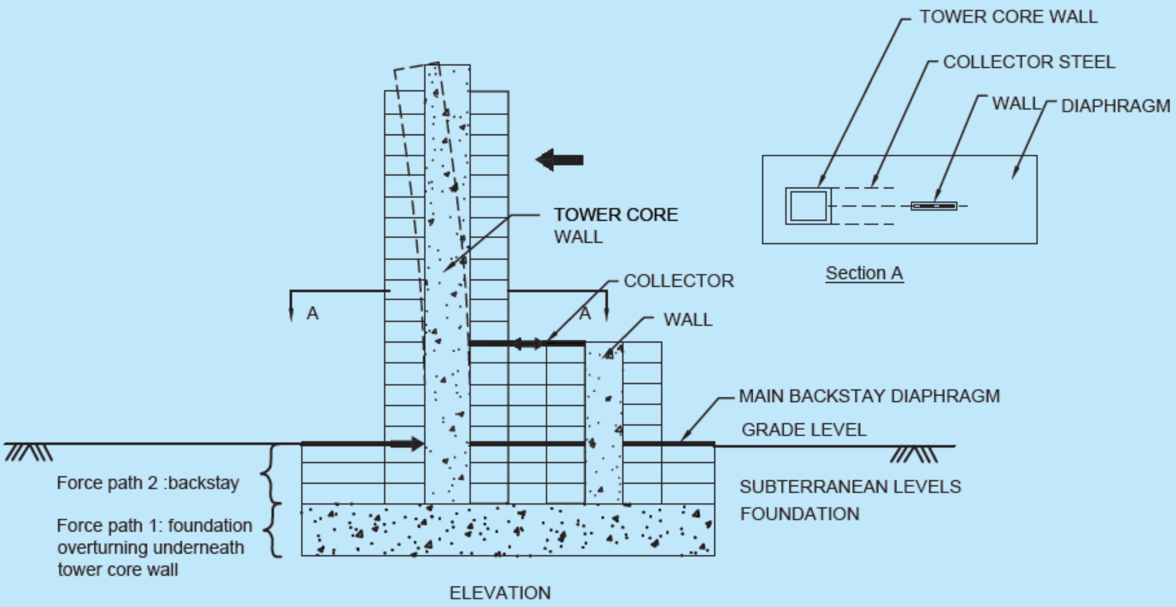
    i) Connections of diaphragms to vertical elements and to collectors; and

    ii) Collectors and their connections, including connections to vertical elements, of the seismic forces resisting system.

  3) When the lateral force resisting system of a tall building has plan irregularity of Type III (diaphragm discontinuity) as per **5** of Part C/Section 1 of this NBCS at the backstay diaphragm levels, collector elements and their connections to vertical elements shall be designed to resist seismic forces amplified by an over-strength factor of 2.5;

  4) Backstay diaphragm floor shall be at least 150 mm thick, with double mesh reinforcement not less than 0.25 percent of cross section area in each direction (including both layers of reinforcement steel); and

  5) Adequate measures shall be taken to prevent shear sliding failure at connections of diaphragm to structural walls; here, the inclination of the strut shall be taken as 45°. Additional reinforcements shall be provided to resist the shear force at the interface between diaphragm and structural walls.



a) **Path 1**: *Direct Load Path* through Tower Elements, and

b) **Path 2**: *Indirect Load Path* through Backstay Elements

FIG. 8 LOAD PATHS IN LATERAL OVERTURNING RESISTANCE OF TALL BUILDINGS WITH PODIUMS

E-8.1.3.3.2 *Structural walls*

a) Structural walls shown in Fig. 8 can sustain plastic hinges at the level of the backstay diaphragm also. Such walls shall also be designed and detailed for plastic hinge development at that level; and

b) All peripheral columns of the tower (irrespective of whether they are gravity columns or not) shall be provided with confinement reinforcements throughout the storeys adjoining (above and below) the backstay diaphragm level, as per the requirements of good practice [C-5(5)].

E-8.1.3.3.3 *Towers connected by common podium*

When buildings have two or more towers, they shall be designed considering the following:

a) Such buildings shall be modelled as separate towers as well as integral towers. The podium shall be designed based on the worst of the two results;

b) The estimation of natural period (for calculation of base shear) shall be based on individual building model;

c) In the integral tower modelling:

    1) directional effects for all worst possibilities (that is, tower shaking in the same and in the opposite directions) should be considered in the design load combinations; and

    2) equivalent static seismic forces can be used, provided they are scaled to match base overturning moments obtained from response spectrum analysis.

d) Where significant changes occur to mass or stiffness between the floors, the floor diaphragms of upper and lower levels shall be modelled to capture:

    1) diaphragm forces. Equivalent beam approach, finite element approach or strut and tie approach may be adopted to model the diaphragms; and

    2) potential cracking in the diaphragm by considering an upper bound and a lower bound axial stiffness. The lower and upper bound values of axial and flexural stiffnesses given in Table 13 for sensitivity analysis, may be considered for the cracked section properties, to arrive at the design level earthquake demand on the RC diaphragms.

e) Plan irregularities of Type I (torsion irregularity) and Type III (diaphragm discontinuity) as per **5** of Part C 'Structural Design/Section 1 Loads and Load Effects' of this NBCS, shall not be present in the first topmost connected floor and the first floor of the tower above the connected floor;

f) Vertical irregularities of Type I (soft story) as per **5** of Part C/Sec 1 of this NBCS shall not be present in the first connected level and the level above it;

g) Topmost slab between the towers of connected podium shall be at least 150 mm thick with double mesh reinforcements not less than 0.25 percent of cross-sectional area in each direction;

h) Peripheral columns of the tower shall be provided with confinement reinforcements as per good practice [C-5(5)] at the first connected level and a level above;

j) Structural walls of the tower shall be provided with boundary elements as per good practice [C-5(5)] at the uppermost connected level and a level above; and

k) A transfer structure shall not be provided at the first connected floor.

E-8.2 Ductility

Notwithstanding any of the clauses of this standard, the designer shall take all measures to ensure that the building has:

a) sufficient ductility capacity;

b) acceptable energy dissipation mechanism; and

c) desirable sequence of initiation of ductile behaviour in members.

E-8.3 Frame Buildings

Frame structure for seismic design shall have at least two planar frames with minimum 3 bays in the direction where the lateral load resistance is provided by the moment frames.

E-8.4 Moment Frame — Structural Wall Systems

E-8.4.1 Frame structural wall systems shall be designed as dual systems as per 5 of Part C/Section 1 of this NBCS.

E-8.4.2 In a moment frame–structural wall system, the moment frame shall comply with the requirements of **E-8.3**, and the structural wall with the requirements of **E-8.5**. In addition, the moment frames and structural walls shall comply with the requirements of good practice [C-5(5)].

E-8.4.3 *Special Requirements for Seismic Zone* IV *and above*

Special moment frame and shear walls shall not be discontinued in lower storeys and supported on less stiff and brittle elements.

E-8.5 Structural Wall Systems

E-8.5.1 The thickness of structural wall shall not be less than 160 mm or $h_i/20$, whichever is larger.

E-8.5.2 Opening in structural walls and the associated coupling beams shall meet the following requirements:

a) For walls, when the opening size is less than 800 mm or one-third length of wall, whichever is lesser, in height or length, the influence of the opening may not be taken into account in the overall stiffness of the building;

b) For beams, the opening size shall be less than one-third of the height or length of beam and location of the opening shall be such that the top and bottom one-third of height of the coupling beam is not disturbed; and

c) In either case, all four sides of the opening shall be strengthened with additional reinforcements, and shall comply with requirements of good practice [C-5(5)]. Diameter of reinforcement bars used in this reinforcement shall not be less than 12 mm.

E-8.5.3 Gravity columns in structural wall buildings shall be designed as per requirements of deformation compatibility on non-seismic members given in **5** of Part C/Section 1 of this NBCS.

E-8.5.4 Beams carrying predominant vertical load shall not be supported on coupling beams. Also, columns or structural walls carrying predominant vertical load shall not be supported on coupling beam.

E-8.5.5 In a structural wall system, the structural wall shall comply with the requirements of good practice [C-5(5)].

E-8.5.6 Concentrated gravity loads applied on the wall above the design flexural section shall be assumed to be distributed over a width equal to the bearing width, plus a width on each side that increases at a slope of 2 vertical to 1 horizontal down to the design section, but:

a) not greater than the spacing of the concentrated loads; and

b) not extending beyond the edges of the wall panel.

E-8.5.7 Design of coupling beam shall comply with requirements of good practice [C-5(5)], unless it can be shown that loss of stiffness and strength of the coupling beams will not impair the vertical load carrying ability of the structure, the egress from the structure, or the integrity of non-structural components and their connections to the structure.

E-8.5.8 The nominal design shear stress shall be limited to $\tau_{c,\max}$ in structural walls that do not sustain tensile axial stress under any load combination, while the nominal design shear stress shall be limited to $0.5\tau_{c,\max}$ in structural walls under tension in any load combination and coupling beams in structural walls under factored design loads, where $\tau_{c,max}$ is as per Table 20 in the good practice [C-5(2)].

E-8.5.9 The amount and distribution of the minimum reinforcement in structural walls shall be as per good practice [C-5(5)].

E-8.5.10 At locations where yielding of longitudinal reinforcements is likely to occur as a result of lateral displacement, development length of longitudinal reinforcement shall be 1.25 times the values calculated for the bar yielded in tension, that is at a stress level of f_y.

E-8.5.11 The maximum longitudinal reinforcement ratio in coupling beam shall be as given in Table 14.

Table 14 Maximum Longitudinal Reinforcement in Coupling Beams (Each at Top and Bottom Surface)

(*Clause* E-8.5.11)

Sl No.	**Span to Depth Ratio**	**Maximum Reinforcement,** Percent
(1)	(2)	(3)
i)	$L_s/D \leq 1.0$	0.6
ii)	$1.0 \leq L_s/D < 2.0$	1.2
iii)	$2.0 \leq L_s/D$	1.5

E-8.5.12 *Requirements for Each Storey Resisting more than* 35 *percent of Design Base Shear*

Structural wall with a height-to-length ratio greater than 1.0 may be removed in any storey above, if it accounts for less than one-third of the storey shear strength. Further, the resulting structural system must not have any torsional irregularity as per **5** of Part C 'Structural Design/Section 1 Loads and Load Effects' of this NBCS .

E-8.5.13 *Special Requirements for Seismic Zones IV and Above*

a) Structural walls shall be continuous to the base without being transferred in plane or out of plane at any level;

b) The minimum longitudinal reinforcement in structural walls shall not be less than 0.4 percent of gross cross-sectional area;

c) The minimum transverse reinforcement in structural walls shall not be less than 0.25 percent of gross cross-sectional area;

d) The reinforcements shall be distributed in two curtains in each direction;

e) Structural walls shall be fully embedded and anchored at their base in adequate basements or foundations, so that the wall does not rock. In this respect, walls supported by slabs or beams are not permitted; and

f) All openings in structural walls shall preferably be aligned vertically. Random openings, arranged irregularly, shall not be permitted in coupled walls, unless their influence is insignificant.

E-8.6 Flat Slab — Structural Wall Systems

In structures with flat slab system as gravity load carrying system, structural walls shall carry all lateral loads on the building, and column strips of the flat slab system shall not be included in the lateral load resisting system. All requirements related to structures with flat slabs mentioned in **5** of Part C 'Structural Design/Section 1 Loads and Load Effects' of this NBCS shall be met with.

E-8.7 Framed Tube System, Tube-in-Tube System and Multiple Tube System

E-8.7.1 The plan shape of a tube-in-tube system shall be regular with a length to width ratio not more than 2 and, the inner tube shall be centered with the outer tube.

E-8.7.2 Reentrant corners and sharp changes to tubular form should be avoided.

E-8.7.3 Column spacing of framed tube shall preferably be not more than 5 m.

E-8.7.4 In a framed-tube system:

a) Area of corner column shall be 1 to 2 times that of internal column; and

b) Height to width ratio of the opening shall be similar to ratio of storey height to column spacing.

E-8.7.5 Due consideration shall be given to shear lag effects in the design of tube structures.

E-8.7.6 In Seismic Zones III and above:

a) Single span frame shall not be adopted; and

b) Axial compression ratio of columns shall be as per good practice [C-5(5)].

E-8.7.7 Beams carrying predominantly gravity load shall be directly supported on columns or on walls and not on frame beams.

E-8.7.8 The minimum requirements for reinforcement bar diameters in beams of moment frames of framed-tube structures are given in Table 15.

Table 15 Reinforcement Requirements in Beams

(*Clause* E-8.7.8)

All dimensions in millimetres.

Sl No.	Reinforcement Type	Seismic Zone	
		II	III and above
(1)	(2)	(3)	(4)
i)	Stirrup diameter	≥ 8	≥ 10
ii)	Stirrup spacing	≤ 150	≤ 100
iii)	Main (longitudinal) reinforcements	≥ 16	≥ 16

E-9 FOUNDATIONS

E-9.1 Load paths and mechanisms shall be ensured explicitly for transferring vertical and lateral loads between structure and soil system underneath.

E-9.2 A factor of safety of 1.5 shall be provided against overturning and sliding under, (a) unfactored design wind load, gravity load and other permanent imposed load; and (b) 2.5 times design earthquake load, unfactored gravity load and other permanent imposed load .

E-9.3 Geotechnical Investigations

E-9.3.1 All geotechnical investigations needed to establish the safety of the building shall be conducted including for liquefaction potential analysis, and estimation of soil spring constants and modulus of subgrade reaction.

E-9.3.2 For geotechnical investigations, the good practice [C-5(39)] shall be referred.

E-9.4 Depth of Foundation

The embedded depth of the building shall be at least 1/15 of height of building for raft foundation and 1/20 of the height of building for pile and piled raft foundation (excluding pile length). But, this requirement may be relaxed:

a) when the foundation rests on hard rock; or

b) when there is no uplift under any portion of the raft in any service load combination, and provided the minimum competent founding strata requirement is fulfilled.

E-9.5 Podium and basement roof slab shall be capable of transferring in-plane shear from the tower to the foundation.

E-9.6 Expansion joints shall preferably be avoided in basements of tall buildings. If provided such joints shall be suitably detailed for water tightness.

E-9.7 Modelling of Soil

E-9.7.1 While modelling raft foundations through spring constant or modulus of sub-grade reaction, zoned spring constants or zoned modulus of sub-grade reaction shall be utilized for design, at least for the case of (dead load + live load) condition. For design of rafts for buildings taller than 150 m, a soil-structure interaction study shall be conducted, using actual column loads and column locations to obtain the zoned spring constants.

E-9.7.2 For piled raft foundations designed with settlement reducing piles, soil-structure interaction study shall be conducted with actual column loads and column locations. This analysis shall be conducted at a minimum for combinations of following loads:

a) Dead;

b) Imposed;

c) Wind in X-direction;

d) Wind in Y-direction;

e) Seismic in X-direction; and

f) Seismic in Y-direction.

where X and Y are orthogonal axes in plan.

E-9.8 Settlements of Foundations

Maximum vertical settlement of raft or piled raft foundations under gravity loads shall comply with requirements of good practice [C-5(40)] and good practice [C-5(41)]. The maximum vertical settlement is limited to 125 mm in raft or raft-pile foundation subject to maximum angular distortion of raft not exceeding 1/500 and 50 mm in rock.

E-10 RECOMMENDATIONS FOR NON-STRUCTURAL ELEMENTS

The non-structural elements (NSEs) of tall buildings shall comply with all relevant existing national standards and guidelines as laid down by the various statutory and non-statutory bodies as well as the client/owner of the building.

E-11 MONITORING DEFORMATIONS IN BUILDINGS

E-11.1 Earthquake Shaking

All tall buildings in Seismic Zone V and tall buildings exceeding 150 m in Seismic Zone III and IV shall be instrumented with tri-axial accelerometers to capture translational and twisting behavior of buildings during strong earthquake shaking.

E-11.2 Wind Oscillations

Buildings over 150 m in height may be instrumented with anemometers and accelerometers to measure wind speed, acceleration and direction on top of the buildings.

E-11.3 Foundation Settlement and Pressure Measurement

E-11.3.1 Permanent settlement markers (at corners and center) shall be provided at raft top level and referenced to a permanent benchmark. Records of settlement shall be maintained till completion of the building and preferably even after completion.

E-11.3.2 Raft or Piled-raft shall be instrumented for monitoring long-term pressure imposed by soil on the raft, at appropriate number (at least 5) of pressure pads below the raft. Alternatively, piles can be instrumented with strain gauges at their top to measure the load on them.

LIST OF STANDARDS

The following list records those standards which are acceptable as ‘good practice’ and ‘accepted standards’ in the fulfilment of the requirements of this NBCS. The latest version of a standard shall be adopted at the time of enforcement of this NBCS. The standards listed may be used as a guide in conformance with the requirements of the referred clauses in this NBCS.

In the following list, the number appearing in the first column within parentheses indicates the number of the reference in this Part C/Section 5.

Sl No.	*IS No.*	*Title*
(1)	IS 4845 : 1968	Definitions and terminology relating to hydraulic cement
	IS 6461	Cement concrete — Glossary of terms:
	(Part 1) : 2024	Concrete aggregates (*first revision*)
	(Part 2) : 2024	Materials (other than cement and aggregate) (*first revision*)
	(Part 3) : 2024	Concrete reinforcement (*first revision*)
	(Part 4) : 2024	Types of concrete (*first revision*)
	(Part 5) : 2024	Formwork for concrete (*first revision*)
	(Part 6) : 2024	Equipment, tool and plant (*first revision*)
	(Part 7) : 2024	Mixing, laying, compaction, curing and other construction aspect (*first revision*)
	(Part 8) : 2024	Properties of concrete (*first revision*)
	(Part 9) : 2024	Structural aspects (*first revision*)
	(Part 10) : 2024	Tests and testing apparatus (*first revision*)
	(Part 11) : 2024	Prestressed concrete (*first revision*)
	(Part 12) : 2024	Miscellaneous terms (*first revision*)
(2)	IS 456 : 2000	Plain and reinforced concrete — Code of practice (*fourth revision*)
(3)	IS 1343 : 2012	Prestressed concrete — Code of practice (*second revision*)
(4)	IS 16700 : 2023	Criteria for structural safety of tall concrete buildings (*first revision*)
(5)	IS 13920 : 2016	Ductile design and detailing of reinforced concrete structures subjected to seismic forces — Code of Practice (*first revision*)
(6)	IS 383 : 2016	Coarse and fine aggregate for concrete — Specification (*third revision*)
(7)	IS 9142 (Part 2) : 2018	Artificial lightweight aggregate for concrete — Specification: Part 2 Sintered fly ash coarse aggregate (*first revision*)
(8)	IS 269 : 2015	Ordinary Portland cement — Specification (*sixth revision*)
(9)	IS 455 : 2015	Portland slag cement — Specification (*fifth revision*)
(10)	IS 1489	Portland pozzolana cement — Specification
	Part 1 : 2015	Part 1 Fly ash based (*fourth revision*)

Sl No.	*IS No.*	*Title*
	Part 2 : 2015	Part 2 Calcined clay based (*fourth revision*)
(11)	IS 16415 : 2015	Composite cement — Specification
(12)	IS 18189 : 2023	Portland calcined clay limestone cement — Specification
(13)	IS 12330 : 1988	Specification for sulphate resisting Portland cement
(14)	IS 16993 : 2018	Microfine ordinary Portland cement — Specification
(15)	IS 8043 : 1991	Hydrophobic Portland cement — Specification (*second revision*)
(16)	IS 12600 : 1989	Portland cement, low heat — Specification
(17)	IS 8041 : 1990	Rapid hardening Portland cement — Specification (*second revision*)
(18)	IS 6452 : 1989	High alumina cement for structural use — Specification (*first revision*)
(19)	IS 6909 : 1990	Supersulphated cement — Specification (*first revision*)
(20)	IS 8042 : 2015	White Portland cement — Specification (*third revision*)
(21)	IS 10500 : 2012	Drinking water— Specification (*second revision*)
(22)	IS 3025 (Part 18) : 2022	Methods of sampling and test (physical and chemical) for water and wastewater: Part 18 Volatile and fixed solids (total, filterable and non-filterable at 550 C (*second revision*)
(23)	IS 3025 (Part 24/Sec 1) : 2022	Methods of sampling and test (physical and chemical) for water and wastewater: Part 24 Sulphates, Section 1 Gravimetric and turbidity methods (*second revision*)
(24)	IS 3025 (Part 32) :1988	Methods of sampling and test (physical and chemical) for water and wastewater: Part 32 Chloride (*first revision*)
(25)	IS 3025 (Part 17) : 2022	Methods of sampling and test (physical and chemical) for water and wastewater Part 17 Non- filterable residue total suspended solids at 103 °C to 105 °C (*second revision*)
(26)	IS 3812 (Part 1) : 2013	Pulverized fuel ash — Specification: Part 1 For use as pozzolana in cement, cement mortar and concrete (*third revision*)
(27)	IS 15388 : 2003	Silica fume — Specification
(28)	IS 16354 : 2015	Metakaolin for use in cement, cement mortar and concrete — Specification
(29)	IS 16714 : 2018	Ground granulated blast furnace slag for use in cement, mortar and concrete — Specification
(30)	IS 16715 : 2018	Ultrafine ground granulated blast furnace slag — Specification
(31)	IS 19058 : 2024	Ultrafine fly ash — Specification
(32)	IS 9103 : 1999	Concrete admixtures — Specification (*first revision*)
(33)	IS 16172 : 2023	Reinforcement couplers for mechanical splices of steel bars in concrete — Specification (*first revision*)
(34)	IS 18256 : 2023	Solid round glass fibre reinforced polymer (GFRP) bars for concrete reinforcement — Specification
(35)	IS 1566 : 1982	Specification for hard-drawn steel wire fabric for concrete reinforcement (*second revision*)
(36)	IS 1199 (Part 6) : 2018	Fresh concrete — methods of sampling, testing and analysis: Part 6 Tests on fresh self compacting concrete (*first revision*)
(37)	IS 10262 : 2019	Concrete mix proportioning — Guidelines (*second revision*)
(38)	IS 4031 (Part 5) : 1988	Methods of physical tests for hydraulic cement: Part 5 Determination of initial and final setting times (*first revision*)

Sl No.	*IS No.*	*Title*
(39)	IS 1892 : 2021	Subsurface investigation for foundations — Code of practice (*second revision*)
(40)	IS 1904 : 2021	General requirements for design and construction of foundations in soils — Code of practice (*fourth revision*)
(41)	IS 12070 : 1987	Code of practice for design and construction of shallow foundations on rocks

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART C STRUCTURAL DESIGN

SECTION 6 STEEL AND COMPOSITE CONSTRUCTION

SUBSECTION 6(A) STEEL

BUREAU OF INDIAN STANDARDS

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National Building Code Sectional Committee, CED 46

FOREWORD

This NBCS (Part C/Subsection 6A) covers the structural design aspects of steel structures in buildings.

This Section covers the use of hot-rolled structural steel sections and steel tubes in buildings. It covers the design by limit state method and plastic theory.

This Section was first published in 1970 and revised in 1983, 2005 and 2016 as a chapter of the National Building Code of India. In the second revision of 2005, the detailed design provisions were not included as IS 800 : 1984 'Code of practice for general construction in steel (*second revision*)' was under revision at that time. This Section, therefore, then referred to the 1984 version of IS 800 with the remarks that the latest version would prevail, as and when published. It, however, covered the philosophical aspects of limit state design which was being introduced in the revision of IS 800. IS 800 was subsequently revised and published as IS 800 : 2007 and hence, became the prevailing version for use under this Section. In the 2016 version of the Code, this Section was brought it in line with the revised version of IS 800 : 2007 read with its Amendment No. 1 and to take care of further improvements and incorporations required.

In the current revision, this publication has been renamed as National Building Construction Standards (NBCS).

This revision of the Section is intended to bring it in line with the revised version of IS 800 : 2026 (*under publication*) to take care of further improvements and incorporations required. In this revision, therefore, the following major modifications have been made:

a) The working stress design has been discontinued due to the increasing familiarity of designers with the limit state design of steel structures;

b) The table on tensile properties of structural steel products has been updated by including the latest Indian Standards relating to structural steels and aligning the corresponding provisions;

c) Fire-resistant steel as per IS 15103 : 2002 'Fire resistant steel — Specification', structural weather-resistant steels as per IS 11587 : 1986 'Structural weather resistant steels — Specification', and structural steels for buildings and structures with improved seismic resistance as per IS 15962 : 2012 'Structural steels for buildings and structures with improved seismic resistance — Specification' have been included in the table of tensile properties of structural steel products;

d) Provisions related to the requirement of temperature stress analysis have been updated;

e) Provisions related to the requirement of fire load have been updated;

f) Table 2 Limiting width thickness ratio of elements has been updated;

g) Provisions related to the consideration of second order effects have been updated;

h) Provisions related to design for earthquake loads relating to load and load combinations, various types of frames and connections in the critical zones of frames have been updated;

j) Provisions related to bracing connections have been updated;

k) Provisions related to fabrication procedures have been updated;

m) Certain terminologies, symbols and figures have been updated based on the changes incorporated;

n) Buckling class of cross section table has been updated;

p) Imperfection parameter for lateral torsional buckling of beam has been added;

q) A new clause on sustainable steel construction has been added. This provision covers the following:

    1) Requirements from Engineers, contractors and supply chain members;

    2) Sustainable design process by minimizing the materials, fabrication; and avoidance of maintenance; and

    3) Design for adaptability and deconstruction, etc.

r) The detailed provision relating to design of corrugated web girder have been introduced in Annex G.

The revised Section will enhance the confidence of designers, engineers, contractors, technical institutions, professional bodies and the industry and will open a new era in safe and economic construction in steel.

The provisions relating to using steel tubes in general building construction are based on IS 806 : 1968 'Code of practice for the use of steel tubes in general building construction', which is complementary to IS 800. The design using tubular steel in structural applications may be carried out using the limit state design provisions in this Section until IS 806 is revised as per the limit state design method.

The design of cold-formed steel members is based on the provisions of IS 801 : 1975 'Code of practice for use of cold formed light gauge steel structural members in general building construction'. The standard is currently under revision to be based on the limit state design practice. Until the revised IS 801 is published, the cold formed steel members may be designed using the current IS 801, based on the working stress method.

All standards, whether given herein above or cross-referred to in the main text of this section, are subject to revision. The parties to agreement based on this Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 'Rules for rounding of numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

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Important Explanatory Note for Users of the NBCS

In any Part/Section of this NBCS, where reference is made to **'good practice'** in relation to design, constructional procedures or other related information, and where reference is made to **'accepted standard'** in relation to material specification, testing, or other related information, the Indian Standards listed at the end of the Part/Section shall be used as a guide to the interpretation.

At the time of publication, the editions indicated in the standards were valid. All standards are subject to revision and parties to agreements based on any Part/ Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

In the list of standards given at the end of a Part/Section, the number appearing within parentheses in the first column indicates the number of the reference of the standard in the Part/Section. For example:

a) Good practices [C-6A(1)] refers to the Indian Standard(s) give at serial number (1) of the list of standards given at the end of this Part C/Subsection 6A, that is, IS 786 : 1967 'Conversion factors and conversion tables (*first revision*)'.

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART C STRUCTURAL DESIGN

SECTION 6 STEEL AND COMPOSITE CONSTRUCTION

SUBSECTION 6(A) STEEL

1 SCOPE

1.1 This NBCS (Part C/Subsection 6A) covers the structural design aspects of steel structures in buildings. This Section applies to general construction using hot rolled steel sections and steel tubes joined using riveting, bolting, and welding. Cold formed light gauge steel sections are covered in separate standards. This Section covers the design by limit state method and plastic theory.

1.2 This Section gives only general guidance as regards to the various loads to be considered in the design. For the actual loads, such as dead, imposed, snow, wind and earthquake loads and load combinations to be used, reference may be made to Part C 'Structural Design/Section 1 Loads and Load Effects' of this NBCS.

1.3 Fabrication and erection requirements covered in this Section are general and the minimum necessary quality of material and workmanship consistent with assumptions in the design rules. The actual requirements may be further developed as per other standards or the project specification, the type of structure and the method of construction.

1.4 For seismic design, recommendations pertaining to steel frames only are covered in this section. For more detailed information on seismic design of other structural and non-structural components, reference be made to **5** of Part C 'Structural Design/Section 1 Loads and Load Effects' of this NBCS and other special publications on the subject.

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NOTE — This clause is intentionally left blank.

3 TERMINOLOGY

For the purpose of this standard, the following definitions shall apply.

3.1 Accidental Loads — Loads due to explosion, impact of vehicles, or other rare loads for which the structure is susceptible as per user.

3.2 Accompanying Load — Imposed load acting along with leading imposed load but Causing action/deflection lesser than the leading load.

3.3 Action Effect or Load Effect — Internal response of a structural element, including axial force, shear force, bending moment, and torsional moment, resulting from applied external loads, temperature variations, and other environmental influences such as seismic activity, settlement effects, and residual stresses.

3.4 Action — The primary cause for stress or deformations in a structure such as dead, imposed, wind, seismic or temperature loads.

3.5 Actual Length — The distance measured from centre to centre of intersection points with supporting members, applicable to beams, trusses, or other structural elements. In the case of a cantilevered member, it refers to the full projection from the fixed support.

3.6 Beam — A member subjected predominantly to bending.

3.7 Bearing Type Connection — A connection made using bolts in 'snug-tight' condition, or rivets where the load is transferred by bearing of bolts or rivets against plate inside the bolt hole.

3.8 Braced Member — A member in which the relative transverse displacement is effectively prevented by bracing.

3.9 Brittle Cladding — Claddings, such as cement fibre boards which get damaged before undergoing considerable deformation.

3.10 Buckling Load — The load at which an element, a member or a structure as a whole, either collapses in service or buckles in a load test and develops excessive lateral (out of plane) deformation or instability.

3.11 Buckling Strength or Resistance — Force or moment, which a member can withstand without buckling.

3.12 Built-up Section — A member fabricated by interconnecting more than one element to form a compound section acting as a single member.

3.13 Camber — Intentionally introduced pre-curving (usually upwards) in a system, member or any portion of a member with respect to the straight line joining the end points in place. Frequently, camber is introduced to compensate for deflections at a specific level of loads.

3.14 Characteristic Load (Action) — The value of specified load (action), above which not more than a specified percentage (usually 5 percent) of samples of corresponding load are expected to be encountered.

3.15 Characteristic Yield/Ultimate Stress — The minimum value of stress, below which not more than a specified percentage (usually 5 percent) of corresponding stresses of samples tested are expected to occur.

3.16 Column — A member in upright (vertical) position which supports a roof or floor system and predominantly subjected to compression.

3.17 Compact Section — A cross section, which can develop plastic moment, but has inadequate plastic rotation capacity needed for formation of a plastic collapse mechanism of the member or structure.

3.18 Constant Stress Range — The amplitude between which the stress ranges under cyclic loading is assumed to be constant during the life of the structure or a structural element.

3.19 Corrosion — An electrochemical process over the surface of steel, leading to oxidation of the metal.

3.20 Crane Load — The horizontal and vertical forces exerted by a crane on a structure, including dynamic effects due to crane movement, acceleration, and braking caused by its due to its self-weight and load lifted.

3.21 Cumulative Fatigue — Total damage due to fatigue loading of varying stress ranges.

3.22 Cut-off Limit — The stress range, corresponding to the particular detail, below which cyclic loading need not be considered in cumulative fatigue damage evaluation (corresponds to 10^8 number of cycles in most cases).

3.23 Dead Loads — The self-weights of all permanent constructions and installations including the self-weight of all walls, partitions, floors, roofs, and other permanent fixtures acting on a member.

3.24 Deflection — The deviation from the standard position of a member or structure.

3.25 Design Life — Time period for which a structure or a structural element is required to perform its function without damage.

3.26 Design Load/Factored Load — A load value obtained by multiplying the characteristic load with the partial safety factor for loads.

3.27 Design Spectrum — Frequency distribution of the stress ranges from all the nominal loading events during the design life (stress spectrum).

3.28 Detail Category — Designation given to a particular detail to indicate the S-N curve to be used in fatigue assessment.

3.29 Discontinuity — A sudden change in cross section of a loaded member, causing a stress concentration at the location.

3.30 Ductility — The property of the material or a structure indicating the extent to which it can deform beyond the limit of yield deformation before failure or fracture. The ratio of ultimate to yield deformation is usually termed as ductility.

3.31 Durability — The ability of a material to resist deterioration over long periods of time.

3.32 Earthquake effects — The inertia forces and relative deformations induced in a structure due to the ground shaking during an earthquake.

3.33 Edge Distance — Distance from the centre of a fastener hole to the nearest edge of an element measured perpendicular to the direction of load transfer.

3.34 Effective Lateral Restraint — Restraint that produces sufficient resistance to prevent deformation in the lateral direction.

3.35 Effective Length — Actual length of a member between points of effective restraint or effective restraint and free end, multiplied by a factor to take account of the end conditions in buckling strength calculations.

3.36 Elastic Cladding — Claddings, such as metal sheets that can undergo considerable deformation without damage.

3.37 Elastic Critical Moment — The elastic moment, which initiates lateral-torsional buckling of a laterally unsupported beam.

3.38 Elastic Design — Design, which assumes elastic behaviour of materials throughout the service load range.

3.39 Elastic Limit — The stress below which the material regains its original size and shape when the load is removed. In steel design, it is taken as the yield stress.

3.40 End Distance — Distance from the centre of a fastener hole to the edge of an element measured parallel to the direction of load transfer.

3.41 Erection Loads — The actions (loads and deformations) experienced by the structure exclusively during erection.

3.42 Erection Tolerance — Amount of deviation related to the plumbness, alignment, and level of the element as a whole in the erected position. The deviations are determined by considering the locations of the ends of the element.

3.43 Exposed Surface Area to Mass Ratio — The ratio of the surface area exposed to the fire (in mm^2) to the mass of steel (in kg).

NOTE — In the case of members with fire protection material applied, the exposed surface area is to be taken as the internal surface area of the fire protection material.

3.44 Fabrication Tolerance — Amount of deviation allowed in the nominal dimensions and geometry in fabrication activities, such as cutting to length, finishing of ends, cutting of bevel angles, etc.

3.45 Factor of Safety — The factor by which the yield stress of the material of a member is divided to arrive at the permissible stress in the material.

3.46 Fatigue — Damage caused by repeated fluctuations of stress, leading to progressive cracking of a structural element.

3.47 Fatigue Loading — Set of nominal loading events, cyclic in nature, described by the distribution of the loads, their magnitudes and the numbers of applications in each nominal loading event.

3.48 Fatigue Strength — The stress range for a category of detail, depending upon the number of cycles it is required to withstand during design life.

3.49 Fire Exposure Condition

3.49.1 *Three-Sided Fire Exposure Condition* — Steel member incorporated in or in contact with a concrete or masonry floor or wall (at least against on surface); and

NOTES

1 Three-sided fire exposure condition is to be considered separately unless otherwise specified (*see* **22.9**).

2 Members with more than one face in contact with a concrete or masonry floor or wall may be treated as three-sided fire exposure.

3.49.2 *Four-Sided Fire Exposure Condition* — Steel member, which may be exposed to fire on all sides.

3.50 Fire Protection System — The fire protection material and its method of attachment to the steel member.

3.51 Fire Resistance — The ability of an element, component or structure, to fulfil for a stated period of time, the required stability, integrity, thermal insulation and/or other expected performance specified in a standard fire test.

3.52 Fire Resistance Level — The fire resistance grading period for a structural element or system, in minutes, which is required to be attained in the standard fire test.

3.53 Flexural Stiffness — Stiffness of a member against rotation as evaluated by the value of bending deformation moment required to cause a unit rotation while all other degrees of freedom of the joints of the member except the rotated one are assumed to be restrained.

3.54 Friction Type Connection — Connection effected by using pre-tensioned high strength bolts where shear force transfer is due to mobilization of friction between the connected plates due to clamping force developed at the interface of connected plates by the bolt pre-tension.

3.55 Gauge — The spacing between adjacent parallel lines of fasteners, transverse to the direction of load/stress.

3.56 Gravity Load — Loads arising due to gravitational effects.

3.57 Gusset Plate — The plate to which the members intersecting at a joint are connected.

3.58 High Shear — High shear condition is caused when the actual shear due to factored load is greater than a certain fraction of design shear resistance (*see* **16.2.2**).

3.59 Imposed (Live) Load — The load assumed to be produced by the intended use or occupancy including distributed, concentrated, impact, vibration and snow loads but excluding, wind, earthquake and temperature effects.

3.60 Instability — The phenomenon which disables an element, member or a structure to carry further load due to excessive deflection lateral to the direction of loading and vanishing stiffness.

3.61 Lateral Restraint for a Beam — *See* **3.34**.

3.62 Leading Imposed Load — Imposed load causing higher action and/or deflection.

3.63 Limit State — Any limiting condition beyond which the structure ceases to fulfill its intended function (*see* also **3.86**).

3.64 Live Load — *See* **3.59**.

3.65 Load — An externally applied force or action (*see also* **3.4**).

3.66 Main Member — A structural member, which is primarily responsible for carrying and distributing the applied load or action.

3.67 Mill Tolerance — Amount of variation allowed from the nominal dimensions and geometry, with respect to cross sectional area, non-parallelism of flanges, and out of straightness such as sweep or camber, in a product, as manufactured in a steel mill.

3.68 Normal Stress — Stress component acting normal to the face, plane or section.

3.69 Partial Safety Factor — The factor normally greater than unity by which either the loads (actions) are multiplied or the resistances are divided to obtain the design values.

3.70 Period of Structural Adequacy under Fire — The time (t), in minutes, for the member to reach the limit state of structural inadequacy in a standard fire test.

3.71 Permissible Stress — When a structure is being designed by the working stress method, the maximum stress that is permitted to be experienced in elements, members or structures under the nominal/service load (action).

3.72 Pitch — The centre to centre distance between individual fasteners in a line, in the direction of load/stress.

3.73 Plastic Collapse — The failure stage at which sufficient number of plastic hinges have formed due to the loads (actions) in a structure leading to a failure mechanism.

3.74 Plastic Design — Design against the limit state of plastic collapse.

3.75 Plastic Hinge — A yielding zone with significant inelastic rotation, which forms in a member, when the plastic moment is reached at a section.

3.76 Plastic Moment — Moment capacity of a cross section when the entire cross section has yielded due to bending moment.

3.77 Plastic Section — Cross section, which can develop a plastic hinge and sustain plastic moment over sufficient plastic rotation required for formation of plastic failure mechanism of the member or structure.

3.78 Poisson’s Ratio — The absolute value of the ratio of lateral strain to longitudinal strain under uniaxial loading.

3.79 Proof Stress — The stress to which high strength friction grip (HSFG) bolts are pre-tensioned.

3.80 Proof Testing — The application of test loads to a structure, sub-structure, member or connection to ascertain the structural characteristics of only that specific unit.

3.81 Prototype Testing — Testing of structure, sub-structure, members or connections to ascertain the structural characteristics of that class of structures, sub-structures, members or connections that are nominally identical (full scale) to the units tested.

3.82 Prying Force — Additional tensile force developed in a bolt as a result of the flexing of a connection component such as a beam end plate or leg of an angle.

3.83 Rotation — The change in angle at a joint between the original orientation of two linear member and their final position under loading.

3.84 Secondary Member — Member which is provided for overall stability and or for restraining the main members from buckling or similar modes of failure.

3.85 Semi-compact Section — Cross section, which can attain the yield moment, but not the plastic moment before failure by plate buckling.

3.86 Serviceability Limit State — A limit state of acceptable service condition exceedance of which causes serviceability failure.

3.87 Shear Force — The in-plane force at any transverse cross section of a straight member of a column or beam.

3.88 Shear lag — The in plane shear deformation effect by which concentrated forces tangential to the surface of a plate gets distributed over the entire section perpendicular to the load over a finite length of the plate along the direction of the load.

3.89 Shear Stress — The stress component acting parallel to a face, plane or cross section.

3.90 Slender Section — Cross section in which the elements buckle locally before reaching yield moment.

3.91 Slenderness Ratio — The ratio of the effective length of a member to the radius of gyration of the cross section about the axis under consideration.

3.92 Slip Resistance — Limit shear that can be applied in a friction grip connection before slip occurs.

3.93 S-N Curve — The curve defining the relationship between the number of stress cycles to failure (N_{sc}) at a constant stress range (S_c), during fatigue loading of a structure.

3.94 Snow Load — Load on a structure due to the accumulation of snow and ice on surfaces such as roof.

3.95 Snug Tight — The tightness of a bolt achieved by a few impacts of an impact wrench or by the full effort of a person using a standard spanner.

3.96 Stability Limit State — A limit state corresponding to the loss of static equilibrium of a structure by excessive deflection transverse to the direction of predominant loads.

3.97 Stickability — The ability of the fire protection system to remain in place as the member deflects under load during a fire test.

3.98 Stiffener — An element used to retain or prevent the out-of-plane deformations of plates.

3.99 Strain — Deformation per unit length or unit angle.

3.100 Strain Hardening — The phenomenon of increase in stress with increase in strain beyond yielding.

3.101 Strength — Resistance to failure by yielding or buckling.

3.102 Strength Limit State — A limit state of collapse or loss of structural integrity.

3.103 Stress — The internal force per unit area of the original cross section.

3.104 Stress Analysis — The analysis of the internal force and stress condition in an element, member or structure.

3.105 Stress Cycle Counting — Sum of individual stress cycles from stress history arrived at using any rational method.

3.106 Stress Range — Algebraic difference between two extremes of stresses in a cycle of loading.

3.107 Stress Spectrum — Histogram of stress cycles produced by a nominal loading event design spectrum, during design life.

3.108 Structural Adequacy for Fire — The ability of the member to carry the test load exposed to the standard fire test.

3.109 Structural Analysis — The analysis of stress, strain, and deflection characteristics of a structure.

3.110 Strut — A compression member, which may be oriented in any direction.

3.111 Sway — The lateral deflection of a frame.

3.112 Sway Member — A member in which the transverse displacement of one end, relative to the other is not effectively prevented.

3.113 Tensile Stress — The characteristic stress corresponding to rupture in tension, specified for the grade of steel in the appropriate Indian Standard, as listed in Table 1.

3.114 Test Load — The factored load, equivalent to a specified load combination appropriate for the type of test being performed.

3.115 Transverse — Direction along the stronger axes of the cross section of the member.

3.116 Ultimate Limit State — The state which, if exceeded can cause collapse of a part or the whole of the structure.

3.117 Ultimate Stress — *See* **3.113**.

3.118 Wind Loads — Load experienced by member or structure due to wind pressure acting on the surfaces.

3.119 Yield Stress — The characteristic stress of the material in tension before the elastic limit of the material is exceeded, as specified in the appropriate Indian Standard, as listed in Table 1.

3.120 Terms Relating to Sustainable Steel Design

3.120.1 *Embodied Carbon* — Life-cycle greenhouse gas emissions (expressed as carbon dioxide equivalents – CO2e) that occur during the manufacture and transport of construction materials and components, as well as the construction process itself and end-of-life aspects of the building.

NOTE — In recent years, the term embodied carbon of construction materials and products has become synonymous with the term carbon footprint.

3.120.2 *Deconstruction* (*or Disassembly, or Demounting*) — Deconstruction is the process of taking a building apart into its components in such a way that they can be more readily reused; it minimizes the destructive aspects of the process of removing buildings, preserving components and materials not wasting them, and treating them as a resource.

3.120.3 *Design for Deconstruction* (*DfD*) — Designing for deconstruction is considering, at the design stage, how a building can be taken apart.

3.120.4 *Environmental Product Declaration* (*EPD*) — An EPD communicates verifiable, accurate, non-misleading environmental information for products and their applications; EPD information is expressed in information modules, which allow easy organization and expression of data packages throughout the life cycle of the product.

3.120.5 *Material Efficiency* — Optimizing the use of the steel by avoiding waste during fabrication and avoiding over specification of steel in the design.

3.120.6 *Recycling* — Steel involves re-melting of scrap to form new semi-finished products.

3.120.7 *Responsible Sourcing* — Management of sustainable development in the provision or procurement of a product.

3.120.8 *Reuse* — Use of previously used components with little or no reprocessing, largely in their original form; they may be reused for the original function (a conventional reuse scenario), or repurposed.

3.120.9 *Sustainable Development* — An enduring, balanced approach to economic activity, environmental responsibility and social progress.

3.120.10 *Traceability* — Ability to trace the history, application or location of an object.

4 SYMBOLS

For the purpose of this Subsection, the symbols (other than those used for load categorization) given in Annex A are applicable.

5 UNITS

For the purpose of design calculations the following units are recommended:

a) forces and loads, in kN, kN/m, kN/m^2;

b) unit mass, in kg/m^3;

c) unit weight, in kN/m^3;

d) stresses and strengths, in N/mm^2 (= MN/m^2 or MPa); and

e) moments (bending, etc), in kNm.

For conversion of one system of units to another system, [C-6A(1)] may be referred.

6 STANDARD DIMENSIONS, FORM AND WEIGHT

The dimensions, form, weight, tolerances of all rolled shapes, all rivets, bolts, nuts, studs, and welds and other members used in any steel structure shall conform to accepted standards [C-6A(2)], wherever applicable.

7 PLANS AND DRAWINGS

7.1 Plans, drawings and stress sheet shall be prepared according to accepted standards [C-6A(3)].

7.1.1 *Plans*

The plans (design drawings) shall show the sizes, sections, and the relative locations of the various members. Floor levels, column centres, and offsets shall be dimensioned. Plans shall be drawn to a scale large enough to convey the information adequately. Plans shall indicate the type of construction to be employed; and shall be supplemented by such data on the assumed loads, shears, moments and axial forces to be resisted by all members and their connections, as may be required for the proper preparation of shop drawings. Any special precaution to be taken in the erection of structure, from the design consideration shall also be indicated in the drawing.

7.1.2 *Shop Drawings*

Shop drawings, giving complete information necessary for the fabrication of the component parts of the structure including the location, type, size, length and detail of all welds and fasteners shall be prepared in advance of the actual fabrication. They shall clearly distinguish between shop and field rivets, bolts and welds. For additional information to be included on drawings for designs based on the use of welding, reference shall be made to appropriate Indian Standards. Shop drawings shall be made in conformity with accepted standard [C-6A(4)]. A marking diagram allotting distinct identification marks to each separate part of steel work shall be prepared. The diagram shall be sufficient to ensure convenient assembly and erection at site.

7.2 Symbols used for welding on plans and shop drawings shall be according to good practice [C-6A(5)].

8 CONVENTION FOR MEMBER AXES

Unless otherwise specified convention used for member axes is as follows (Fig. 1):

a) *x-x* along the member;

b) *y-y* an axis of the cross section:

  1) perpendicular to the flanges; and

  2) perpendicular to the smaller leg in an angle section.

c) *z-z* an axis of the cross-section:

    1) axis parallel to flanges; and
    2) axis parallel to smaller leg in angle section.
- d) *u-u* major axis (when it does not coincide with *z-z* axis); and
- e) *v-v* minor axis (when it does not coincide with *y-y* axis).

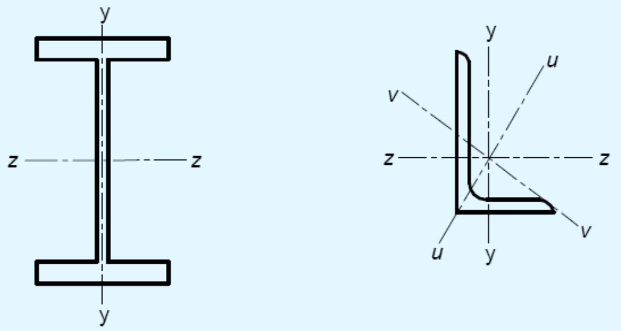

FIG. 1 AXES OF MEMBERS

9 MATERIALS

9.1 General

The material properties given in this clause are nominal values, to be accepted as characteristic values in design calculations.

9.2 Structural Steel

9.2.1 The provisions in this Section are applicable to the steels commonly used in steel construction namely, structural mild steel and high tensile structural steel.

9.2.2 All the structural steel used in general construction, coming under the purview of this standard shall before fabrication conform to accepted standard [C-6A(6)].

9.2.3 Structural steel other than those specified in 9.2.2 may also be used provided that the permissible stresses and other design provisions are suitably modified and the steel is also suitable for the type of fabrication adopted.

9.2.3.1 Steel that is not supported by mill test result may be used only in unimportant members and details, where their properties such as ductility and weldability would not affect the performance requirements of the members and the structure as a whole.

However, such steels may be used in structural system after confirming their quality by carrying out appropriate tests in accordance with the method specified in accepted standard [C-6A(7)].

9.2.4 *Properties*

The properties of structural steel for use in design may be taken as given in 9.2.4.1 and 9.2.4.2.

9.2.4.1 Physical properties of structural steel irrespective of its grade may be taken as:

- a) unit mass of steel, ρ = 7 850 kg/m^3;
- b) modulus of elasticity, $E = 2.0 \times 10^5$ N/mm^2 (MPa);
- c) Poisson's ratio, $\mu = 0.3$;
- d) modulus of rigidity, $G = 0.769 \times 10^5$ N/mm^2 (MPa); and

e) coefficient of thermal expansion $\alpha_t = 12 \times 10^{-6}$ /°C

9.2.4.2 *Mechanical properties of structural steel*

The principal mechanical properties of the structural steel important in design are the yield stress, f_y; the tensile or ultimate stress, f_u; the maximum percent elongation on a standard gauge length and notch toughness. Except for notch toughness, the other properties are determined by conducting tensile tests on samples cut from the plates, sections, etc, in accordance with accepted standard [C-6A(7)]. Commonly used properties for the common steel products of different specifications are summarized in Table 1.

9.2.4.2.1 *Steel tubes* — Steel tubes used in building construction shall be hot finished tubes conforming to the requirements specified in accepted standard [C-6A(8)].

9.2.4.2.2 Tubes made by other than hot finishing processes, or which have been subjected to cold working, shall be regarded as hot finished if they have subsequently been heat-treated and are supplied in the normalized conditions.

9.2.4.3 *Electrodes* — The electrodes used for welding steel tubes shall conform to the requirements of accepted standard [C-6A(9)] or [C-6A(10)], as appropriate.

9.3 Rivets

9.3.1 Rivets shall be manufactured from steel conforming to accepted standard [C-6A(11)]. They may also be manufactured from steel conforming to accepted standard [C-6A(6)] provided that the steel meets the requirements given in accepted standard [C-6A(12)].

9.3.2 Rivets shall conform to accepted standards [C-6A(13)] as appropriate.

9.3.3 *High Tensile Steel Rivets*

High tensile steel rivets, shall be manufactured from steel conforming to accepted standard [C-6A(12)].

9.4 Bolts, Nuts and Washers

Bolts, nuts and washers shall conform as appropriate to accepted standards [C-6A(14)]. The recommendations in good practice [C-6A(15)] shall be followed.

9.5 Steel Casting

Steel casting shall conform to accepted standard [C-6A(16)] or accepted standard [C-6A(17)].

9.6 Welding Consumable

9.6.1 Covered electrodes shall conform to accepted standard [C-6A(9)] or [C-6A(10)], as appropriate.

9.6.2 Filler rods and wires for gas welding shall conform to accepted standard [C-6A(18)].

9.6.3 The supply of solid filler wires for submerged arc welding of structural steels shall conform to accepted standard [C-6A(19)].

9.6.4 The bare wire electrodes for submerged arc welding and the combination of wire and flux shall satisfy the requirements of accepted standard [C-6A(20)].

9.6.5 Filler rods and bare electrodes for gas shielded metal arc welding shall conform to accepted standards [C-6A(21)], as appropriate.

9.7 Other Materials

Other materials used in association with structural steel work shall conform to appropriate Indian standards.

Table 1 Tensile Properties of Structural Steel Products

(*Clauses* 3.113, 3.119 *and* 9.2.4.2)

Sl No.	**Accepted Standard**	**Grade/ Classification**	**Properties**												
			Yield Stress, MPa *Min*				Ultimate Tensile Stress, MPa *Min*	Elongation, Percent *Min*						
(1)	(2)	(3)	(4)				(5)	(6)						
i)	[C-6A(22)]							Gauge Length						
								80 mm				50 mm		
		CR1	280				410	27				28		
		CR2	240				370	30				31		
		CR3	220				350	34				35		
		CR4	210				350	36				37		
		CR5	190				350	38				40		
			thickness, *t*, mm					Gauge Length-50mm and thickness, *t*, mm						
			< 0.40	≥ 0.40 and < 0.80	≥ 0.80 and < 1.00	≥ 1.00		< 0.40	≥ 0.40 and < 0.60	≥ 0.60 and <0.80	≥ 0.80 and < 1.00	≥ 1.00 and < 1.20	≥ 1.20 and < 1.60	≥ 1.60 and < 2.00 or ≥ 2.00 and < 2.50 or > 2.50
		ISC590LA	—	430 to 580	420 to 570	410 to 560	590	—	—	17 to 32	17 to 32	18 to 33	18 to 33	≥18
		ISC490W	—	305 to 410	295 to 400	295 to 400	490	—	—	23 to 35	23 to 35	24 to 36	24 to 36	≥ 24
		ISC540W	—	335 to 440	325 to 430	325 to 430	540	—	—	20 to 32	20 to 32	21 to 33	21 to 33	≥ 21
		ISC590W	—	365 to 470	355 to 460	355 to 460	590	—	—	17 to 29	17 to 29	18 to 30	18 to 30	≥ 18
		ISC450Y	—	270 to 360	260 to 370	250 to 340	450	—	—	26 to 42	27 to 43	28 to 44	29 to 45	≥ 29
		ISC490Y	—	310 to 410	300 to 400	290 to 390	490	—	—	22 to 38	23 to 39	24 to 40	25 to 41	≥ 25
		ISC540Y	—	340 to 450	330 to 440	320 to 430	540	—	—	18 to 35	19 to 36	20 to 37	21 to 38	≥ 21

Table 1 (*Continued*)

Sl No.	**Accepted Standard**	**Grade / Classification**	**Properties**		
			Yield Stress, MPa *Min*	Ultimate Tensile Stress, MPa *Min*	Elongation, Percent *Min*
(1)	(2)	(3)	(4)	(5)	(6)
ii)	[C-6A(9)]				
		Ex40xx	330	410 to 540	16
		Ex41xx	330	410 to 540	20
		Ex42xx	330	410 to 540	22
		Ex43xx	330	410 to 540	24
		Ex44xx	330	410 to 540	24
		Ex50xx	360	510 to 610	16
		Ex51xx	360	510 to 610	18
		Ex52xx	360	510 to 610	18
		Ex53xx	360	510 to 610	20
		Ex54xx	360	510 to 610	20
		Ex55xx	360	510 to 610	20
		Ex56xx	360	510 to 610	20

Table 1 (*Continued*)

Sl No.	**Accepted Standard**	**Grade/ Classification**	**Properties**								
			Yield Stress, MPa *Min*			Ultimate Tensile Stress, MPa *Min*	Elongation, Percent *Min*				
(1)	(2)	(3)	(4)			(5)	(6)				
iii)	[C-6A(23)]						$t \leq 3$		$t > 3$		
							GL $L_0 = 80$ mm	GL $L_0 = 50$ mm	GL $L_0 = 5.65\sqrt{S_0}$		GL $L_0 = 50$ mm
		HR1	—			440	23	24	28		29
		HR2	—			420	25	26	30		31
		HR3	—			400	28	29	33		34
		HR4	—			380	31	32	36		37
			$t < 2$	$2 \leq t < 3.2$	$t \geq 3.2$		$t < 2$	$2 \leq t < 3.2$	$t \geq 3.2$	$t < 3$	$t > 3$
							GL Lo = 50 mm			GL Lo = 80 mm	GL $L0 = 5.65\sqrt{S_0}$
		ISH270C	170, Min			270 to 420	26	26	31	25	30
		ISH270D	170, Min		165, Min	270 to 400	29	29	34	28	33
		ISH270E	165, Min	155, Min	145, Min	270 to 380	32	32	37	31	36

Table 1 (*Continued*)

Sl No.	**Accepted Standard**	**Grade/Classification**	**Properties**		
			Yield Stress, MPa *Min*	Ultimate Tensile Stress MPa *Min*	Elongation, Percent *Min*
(1)	(2)	(3)	(4)	(5)	(6)
iv)	[C-6A(24)]	3.6	180	330	25
		4.6	240	400	22
		4.8	320	420	—
		5.6	300	500	20
		5.8	400	520	—
		6.8	480	600	—
		8.8 ($d \leq 16$ mm)	640 1)	800	12
		8.8 ($d > 16$ mm)	660 1)	830	12
		9.8	720 1)	900	10
		10.9	940 1)	1 040	9
		12.9	1 100 1)	1 220	8
v)	[C-6A(25)]	1	200	370	26
		1A	220	410	25
		2	230	430	24
		2A	250	460	22
		3	270	490	21
		3A	280	540	20
		4	320	620	15
		5	350	710	13
		6	370	740	10

Table 1 (*Continued*)

Sl No.	**Accepted Standard**	**Grade/Classification**	**Properties**									
			Yield Stress, MPa *Min*					Ultimate Tensile Stress, MPa *Min*			Elongation, Percent *Min*	
(1)	(2)	(3)	(4)					(5)			(6)	
vi)	[C-6A(26)]		*d* or *t*									
			≤ 20	> 20								
		S_t 37	220	200				360 to 440			26	
		S_t 42	250	240				410 to 500			23	
vii)	[C-6A(27)]		*t*					*t*			*t*	
			≤ 16	> 16 and ≤ 40	> 40 and ≤ 60	> 60 and ≤ 100	>100 and ≤ 350	≤60	> 60 and ≤ 100	> 100 and ≤ 350	≤ 60	> 60 and ≤ 350
		1	235	225	215	200	185	360 to 480	360 to 480	350 to 480	24	23
		2	265	255	245	215	200	410 to 530	410 to 530	400 to 530	22	21
		3	290	285	280	255	230	460 to 580	450 to 570	440 to 570	21	20

Table 1 (*Continued*)

Sl No.	**Accepted Standard**	**Grade/Classification**	**Properties**				
			Yield Stress, MPa *Min*			Ultimate Tensile Stress, MPa *Min*	Elongation Percent, *Min*
(1)	(2)	(3)	(4)			(5)	(6)
			d or *t*				
			<20	20 to 40	> 40		
viii)	[C-6A(6)]	E250 (A, BR, B0, C)	250	240	230	410	23
		E275 (A, BR, B0, C)	275	265	255	430	22
		E300 (A, BR, B0, C)	300	290	280	440	22
		E350 (A, BR, B0, C)	350	330	320	490	22
		E410 (A, BR, B0, C)	410	390	380	540	20
		E450 (A, BR)	450	430	420	570	20
ix)	[C-6A(28)]						$L_o = 5.65\sqrt{S_o}$
		A	235			400 to 520[2]	22[3]
		B	235			400 to 520[2]	22[3]
		D	235			400 to 520[2]	22[3]
		E	235			400 to 520[2]	22[3]
x)	[C-6A(29)]	—	240			350 to 450	25

Table 1 (*Continued*)

Sl No.	**Accepted Standard**	**Grade/Classification**	**Properties**					
			Yield Stress, MPa *Min*				Ultimate Tensile Stress, MPa *Min*	Elongation Percent, *Min*
(1)	(2)	(3)	(4)				(5)	(6)
xi)	[C-6A(11)]	Annealed Condition	160				330 to 410	30
		As-Drawn Condition	190				410 to 490	20
xii)	[C-6A(30)]	HFC 210/CDS 210/ERW210	210				330	20
		HFC 240/CDS 240/ERW240	240				410	18
		HFC 310/CDS 310/ERW310	310				450	15
xiii)	[C-6A(31)]	1	170				290	30
		2	210				330	28
		3	240				410	25
		4	275				430	20
		5	310				490	15
xiv)	[C-6A(32)]		< 12	12 to 25	25 to 40	> 40		
		WR-Fe 480A	345	325	325	–	345	21
		WR-Fe 480B	345	345	345	340	345	21
		WR-Fe 500	355	–	–	–	355	20

Table 1 (*Concluded*)

Sl No.	Accepted Standard	Grade/Classification	Properties					
			Yield Stress, MPa *Min*				Ultimate Tensile Stress, MPa *Min*	Elongation Percent, *Min*
(1)	(2)	(3)	(4)				(5)	(6)
xv)	[C-6A(33)]		<12	12 to 25	25 to 40	> 40		
		Grade A (FR-Fe 410)	300	280	260	240	410	21
		Grade B (FR-Fe 490)	350	330	310	290	490	18
xvi)	[C-6A(34)]		< 20	20 to 40	> 40			
		E250S	250	240	230		410	23
		E300S	300	290	280		440	22
		E350S	350	330	320		490	22
		E450S	450	430	420		570	20

NOTE — Percentage of elongation shall be taken over the gauge length of 5.65 $\sqrt{S_0}$, where S_0 = original cross-sectional area of the test specimen.

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[1] Stress at 0.2 percent non-proportional elongation, Min.

[2] For Grade A sections and bars, the upper limit of the tensile strength may be 550 MPa or as agreed between the purchaser and the manufacturer/the supplier.

[3] For full thickness flat test pieces with width 25 mm and gauge length 200 mm, the minimum elongation (percent) may be reduced as per specified in good practice [C-6A(**29**)].

10 GENERAL DESIGN REQUIREMENTS

10.1 Basis for Design

10.1.1 *Design Objective*

The objective of design is the achievement of an acceptable probability that structures will perform satisfactorily for the intended purpose during the design life. With an appropriate degree of safety, they should sustain all the loads and deformations, during construction and use and have adequate resistance to certain expected accidental loads and fire. Structure should be stable and have alternate load paths to prevent disproportionate overall collapse under accidental loading.

10.1.2 *Methods of Design*

Structure and its elements shall normally, be designed by the limit state method. Account should be taken of accepted theories, experimental information and experience and the need to design for durability. Calculations alone may not produce safe, serviceable and durable structures. Suitable materials, quality control, adequate detailing and good supervision are equally important.

10.1.3 *Design Process*

Structural design, including design for durability, construction and use should be considered as a whole. The realization of design objectives requires compliance with clearly defined standards for materials, fabrication, erection and in-service maintenance.

10.2 Loads and Forces

10.2.1 For the purpose of designing any element, member or a structure, the following loads (actions) and their effects shall be taken into account, where applicable, with partial safety factors for loads and their combinations given in Part C 'Structural Design/Section 1 Loads and Load Effects' of this NBCS (*see* **12.3.3**).

a) Dead loads;

b) Imposed loads (imposed load, crane load, snow load, dust load, wave load, earth pressures, etc);

c) Wind loads;

d) Earthquake effects;

e) Fire Load, forces induced due to restraint against expansion during a fire;

f) Erection loads;

g) Accidental loads such as those due to blasts, impact of vehicles, etc; and

h) Secondary effects due to contraction or expansion resulting from temperature changes, differential settlements of the structure as a whole or of its components, eccentric connections, rigidity of joints differing from design assumptions.

10.2.1.1 Dead loads should be assumed in design as specified in **2** of Part C 'Structural Design/Section 1 Loads and Load Effects' of this NBCS.

10.2.1.2 Imposed loads for different types of occupancy and function of structures shall be taken as recommended in **3** of Part C 'Structural Design/Section 1 Loads and Load Effects' of this NBCS. Imposed loads arising from equipment, such as cranes and machines should be assumed in design as per manufacturers/suppliers data (*see* **10.6.4**). Snow load shall be taken as per in **6** of Part C 'Structural Design/Section 1 Loads and Load Effects' of this NBCS.

10.2.1.3 Wind loads on structures shall be taken as per the recommendations of **4** of Part C 'Structural Design/Section 1 Loads and Load Effects' of this NBCS.

10.2.1.4 Earthquake effects shall be assumed as per the recommendations of **5** of Part C 'Structural Design/Section 1 Loads and Load Effects' of this NBCS.

10.2.1.5 The fire loads, erection loads and temperature effects shall be considered as specified in **10.3**, **10.4** and **10.5**, respectively.

10.3 Fire Loads

During a fire, the structural members around the fire experience higher temperatures. This causes expansion in members that is restrained by rest of the structure, inducing forces in the members. Simultaneously, due to high temperature both strength and stiffness of the members experiencing the higher temperature degrade. The forces in members during fire including that due to dead load and imposed load are checked against the reduced capacity of the members. As it is an extreme event, the design is done for loads without extra partial safety factors. The imposed load is taken as 100 percent of the characteristic Imposed loads in case of storage areas and otherwise taken as 50 percent of the characteristic Imposed load value, during fire.

Due to proper fire protection, the temperature felt by the members may be less than the ambient temperature, and this may be taken into consideration in evaluating temperature effects due to fire.

10.4 Erection Loads

All loads required to be carried by the structure or any part of it due to storage or positioning of construction material and erection equipment, including all loads due to operation of such equipment shall be considered as erection loads. Proper provision shall be made, including temporary bracings, to take care of all stresses developed during erection. Dead load, wind load and also such parts of the imposed load as would be imposed on the structure during the period of erection shall be taken as acting together with the erection loads. The structure as a whole and all parts of the structure in conjunction with the temporary bracings shall be capable of sustaining these loads during erection.

10.5 Temperature Effects

10.5.1 Expansion and contraction due to changes in temperature of the members and elements of a structure shall be considered and adequate provision made for such effect.

10.5.2 The temperature range varies for different localities and under different diurnal and seasonal conditions. The absolute maximum and minimum temperatures, which may be expected at the site, may be obtained from the Indian Metrological Department and used in assessing the maximum variations of temperature for which provision for expansion and contraction has to be made in the structure.

10.5.3 The range of variation in temperature of the building materials may be appreciably greater or lesser than the variation of air temperature and is influenced by the condition of exposure and the rate at which the materials composing the structure absorb or radiate heat. This difference in temperature variations of the material and air shall be given due consideration. The effect of differential temperature within an element or member, due to part exposure to direct sunlight shall also be considered.

10.5.4 The coefficient of thermal expansion for steel is as given in **9.2.4.1**(e).

10.6 Load Combinations

10.6.1 Load combinations for design purposes shall be those that produce maximum forces and effects and, consequently maximum stresses and deformations. The combination of loads with appropriate partial safety factors may be as per Part C/Section 1 of this NBCS.

NOTE — In the case of structures supporting cranes, imposed loads shall include the crane effects as given in **10.6.4**.

10.6.2 Wind load and earthquake effects shall not be assumed to act simultaneously. The effect of each shall be considered separately.

10.6.3 The effect of cranes to be considered under imposed loads shall include the vertical loads, eccentricity effects induced by the vertical loads, impact factors, lateral (surge) and longitudinal (horizontal) thrusts, not acting simultaneously across and along the crane rail, respectively [*see* **3** of Part C 'Structural Design/Section 1 Loads and Load Effects' of this NBCS].

10.6.4 The crane loads and their combinations to be considered shall be as indicated by the customer. In the absence of any specific indications, the load combinations shall be in accordance with the provisions in **3** of Part C 'Structural Design/Section 1 Loads and Load Effects' of this NBCS or as given below:

a) Vertical loads with full impact from one loaded crane or two cranes in case of tandem operation, together with vertical loads without impact from as many loaded cranes as may be positioned for maximum effect, along with maximum horizontal thrust from one crane only or two in case of tandem operation;

b) Loads as specified in **10.6.4**(a), subject to cranes in maximum of any two bays of the building cross section shall be considered for multi-bay multi-crane gantries;

c) The longitudinal thrust on a crane track rail shall be considered for a maximum of two loaded cranes on the track; and

d) Lateral thrust (surge) and longitudinal thrust acting across and along the crane rail, respectively, shall be assumed not to act simultaneously. The effect of each force, shall however be investigated separately.

10.6.5 While investigating the effect of earthquake, the resulting effect from dead loads of all cranes parked in each bay, positioned to cause maximum effect shall be considered.

10.6.6 The crane runway girders supporting bumpers shall be checked for bumper impact loads also, as specified by the manufacturers.

10.6.7 Stresses developed due to secondary effects such as handling; erection, temperature and settlement of foundations, if any, shall be appropriately added to the stresses calculated from the combination of loads stated in **10.6.1**, with appropriate partial safety factors.

10.7 Geometrical Properties

10.7.1 *General*

The geometrical properties of the gross and the effective cross sections of a member or part thereof, shall be calculated on the following basis:

a) the properties of the gross cross section shall be calculated from the specified size of the member or part thereof or read from appropriate table; and

b) the properties of the effective cross section shall be calculated by deducting from the area of the gross cross section, in the following:

1) The sectional area in excess of effective plate width, in case of slender sections [*see* **10.8.2 (d)**]; and

2) The sectional areas of all holes in the section except for parts in compression. In case of punched holes, hole size 2 mm in excess of the actual diameter may be deducted.

10.8 Classification of Cross Sections

10.8.1 Plate elements of a cross section may buckle locally due to compressive stresses. The local buckling can be avoided before the limit state is achieved by limiting the width to thickness ratio of each element of a cross section subjected to compression due to axial force, moment or shear.

10.8.1.1 When plastic analysis is used, the members shall be capable of forming plastic hinges with sufficient rotation capacity (ductility) without local buckling, to enable the redistribution of bending moment required before formation of the failure mechanism.

10.8.1.2 When elastic analysis is used, the member shall be capable of developing the yield stress under compression without local buckling.

10.8.2 On basis of the above, four classes of sections are defined as follows:

a) *Class* 1 (*Plastic*) — Cross sections, which can develop plastic hinges and have the rotation capacity required for failure of the structure by formation of plastic mechanism. The width to thickness ratio of plate elements shall be less than that specified under class 1 (Plastic), in Table 2;

b) *Class* 2 (*Compact*) — Cross sections, which can develop plastic moment of resistance, but have inadequate plastic hinge rotation capacity for formation of plastic mechanism, due to local buckling. The width to thickness ratio of plate elements shall be less than that specified under class 2 (compact), but greater than that specified under class 1 (plastic), in Table 2;

c) *Class* 3 (*Semi-compact*) — Cross sections, in which the extreme fiber in compression can reach yield stress, but cannot develop the plastic moment of resistance, due to local buckling. The width to thickness ratio of plate elements shall be less than that specified under class 3 (semi-compact), but greater than that specified under class 2 (compact), in Table 2; and

d) *Class* 4 (*Slender*) — Cross sections in which the elements buckle locally even before reaching yield stress. The width to thickness ratio of plate elements shall be greater than that specified under class 3 (semi-compact), in Table 2. In such cases, the effective sections for design shall be calculated either by following the provisions of good practice [C-6A(35)] to account for the post-local-buckling strength or by conservatively deducting width of the compression plate element in excess of the semi-compact section limit [*see* Fig. 2(C)].

The design of slender web elements in flexural members may be done as given in **15.2.1.1** for flexure and **15.4.2.2** for shear.

When different elements of a cross section fall under different classes, the section shall be classified as governed by the most critical element.

The maximum value of limiting width to thickness ratios of elements for different classifications of sections are given in Fig. 2(A). The effective section in case of class 4 (slender elements) may be conservatively taken as shown in Fig. 2(C).

10.8.3 *Types of Elements*

a) *Internal elements* — These are elements attached along both longitudinal edges to other elements or to longitudinal stiffeners connected at suitable intervals to transverse stiffeners; for example, web of I-section and flanges and web of box section;

b) *Outside elements or outstands* — These are elements attached along only one of the longitudinal edges to an adjacent element, the other edge being free to displace out of plane, for example flange overhang of an I-section, stem of T-section and legs of an angle section; and

c) *Tapered elements* — These may be treated as flat elements having average thickness as defined in accepted standard [C-6A(36)].

The design of slender compression element (Class 4) considering the strength beyond elastic local buckling of element is outside the scope of this section. Reference may be made to in good practice [C-6A(35)] for such design provisions. The design of slender web elements may be made as given in **15.2.1.1** for flexure and **15.4.2.2** for shear.

10.8.4 *Compound Elements in Built-up Section* (*see* Fig. 2)

In case of compound elements consisting of two or more elements bolted or welded together, the limiting width to thickness ratios as in Table 2 should be considered on basis of the following:

a) Outstanding width of compound element (b_e) to its own thickness;

b) The internal width of each added plate between the lines of welds or fasteners connecting it to the original section to its own thickness; and

c) Any outstand of the added plates beyond the line of welds or fasteners connecting it to original section to its own thickness.

10.9 Maximum Effective Slenderness Ratio

The maximum effective slenderness ratio, KL/r, values of a beam, strut or tension member shall not exceed those given in Table 3. 'KL' is the effective length of the member and 'r' is appropriate radius of gyration based on the effective section as defined in **10.8**.

Table 2 Limiting Width to Thickness Ratio

(*Foreword* *and Clauses* 10.8.2(a), 10.8.2(b), 10.8.2(c), 10.8.2(d),10.8.4, 11.5.2.2, 14.3.1 *and* 15.6.3.1)

Sl No.	Compression Element			Ratio	Class of Section		
					Class 1 Plastic	Class 2 Compact	Class 3 Semi-compact
(1)	(2)			(3)	(4)	(5)	(6)
i)	Outstanding element	Under uniform compression		b/t_f	8.7ε	9.7ε	13.6ε (*a* in Fig. 2C)
		Non uniform stress	Tip in compression	b/t_f	$\frac{8.7\,\varepsilon}{r_1}$	$\frac{9.7\,\varepsilon}{r_1}$	$21\varepsilon\sqrt{k_\sigma}$
			Tip in tension	b/t_f	$\frac{8.7\,\varepsilon}{r_1\sqrt{r_1}}$	$\frac{9.7\,\varepsilon}{r_1\sqrt{r_1}}$	$21\varepsilon\sqrt{k_\sigma}$
ii)	Web of I, Channel, H, box or RHS	Axial compression		d/t_w	27ε	33 ε	37ε (*b* in Fig. 2C)
		Non uniform stress	Neutral axis at mid-depth	d/t_w	70ε	80ε	117ε
			$r_1 > 0.5$ (or) $r_2 > -1$	d/t_w	$\frac{122\,\varepsilon}{5.5\,r_1 - 1}$	$\frac{182\,\varepsilon}{6.53\,r_1 - 1}$	$\frac{37\,\varepsilon}{0.608 + 0.343\,r_2 + 0.049\,r_2^2}$
			$r_1 \le 0.5$ (or) $r_2 \le -1$	d/t_w	$\frac{35\,\varepsilon}{r_1}$	$\frac{40\,\varepsilon}{r_1}$	$59\,\varepsilon\,(1 - r_2)$
iii)	Angle, compression due to bending (Both criteria should be satisfied)			b/t d/t	8.7 ε 8.7 ε	9.7 ε 9.7 ε	14.5 ε 14.5 ε
iv)	Single angle, or double angles with the components separated, axial compression (All three criteria should be satisfied)			b/t d/t $(b+d)/t$	Not applicable		14.5 ε 14.5 ε 22.3 ε
v)	Outstanding leg of an angle in contact back-to-back in a double angle member or with another component			d/t	8.7ε	9.7ε	14.5 ε
vi)	Circular, elliptical hollow tube (*see* Note 6), including welded tube	a) bending moment		D_e/t	48 ε^2	68 ε^2	87 ε^2
		b) axial compression		D_e/t	Not applicable		87 ε^2

NOTES

1 Elements which exceed semi-compact limits are to be taken as of slender cross section

2 $\varepsilon = \sqrt{(250 / fy)}$

3 Webs shall be checked for shear buckling in accordance with **15.4.2** when $d/t > 67\varepsilon$. Where, *b* is the width of the element may be taken as clear distance between lateral supports or between lateral support and free edge, as appropriate, *t* is the thickness of element, *d* is the depth of the web, *D* is the outer diameter of the element (*see* Fig 2, **10.8.3** and **10.8.4**).

4 Different elements of a cross section can be in different classes. In such cases the section is classified based on the least favourable classification.

5 The stress ratio r_1 and r_2 are defined as:

$$r_1 = \frac{\text{depth under compression}}{\text{Overall depth}}$$

$$r_2 = \frac{\text{Minimum compressive stress (tensile if negative)}}{\text{Maximum design compressive stress of web alone}}$$

6 (a) for circular sections $D_e = D$,

(b) Elliptical sections: (h = major axis, b = minor axis)

in compression: $D_e = h\left[1 + \left(1 - 2.3\left(\frac{t}{h}\right)^{0.6}\right)\left(\frac{h}{b} - 1\right)\right]$

conservatively $D_e = \frac{h^2}{b}$

In bending about the strong (minor) axis

For h/b ≤ 1.36: $D_e = \frac{b^2}{h}$

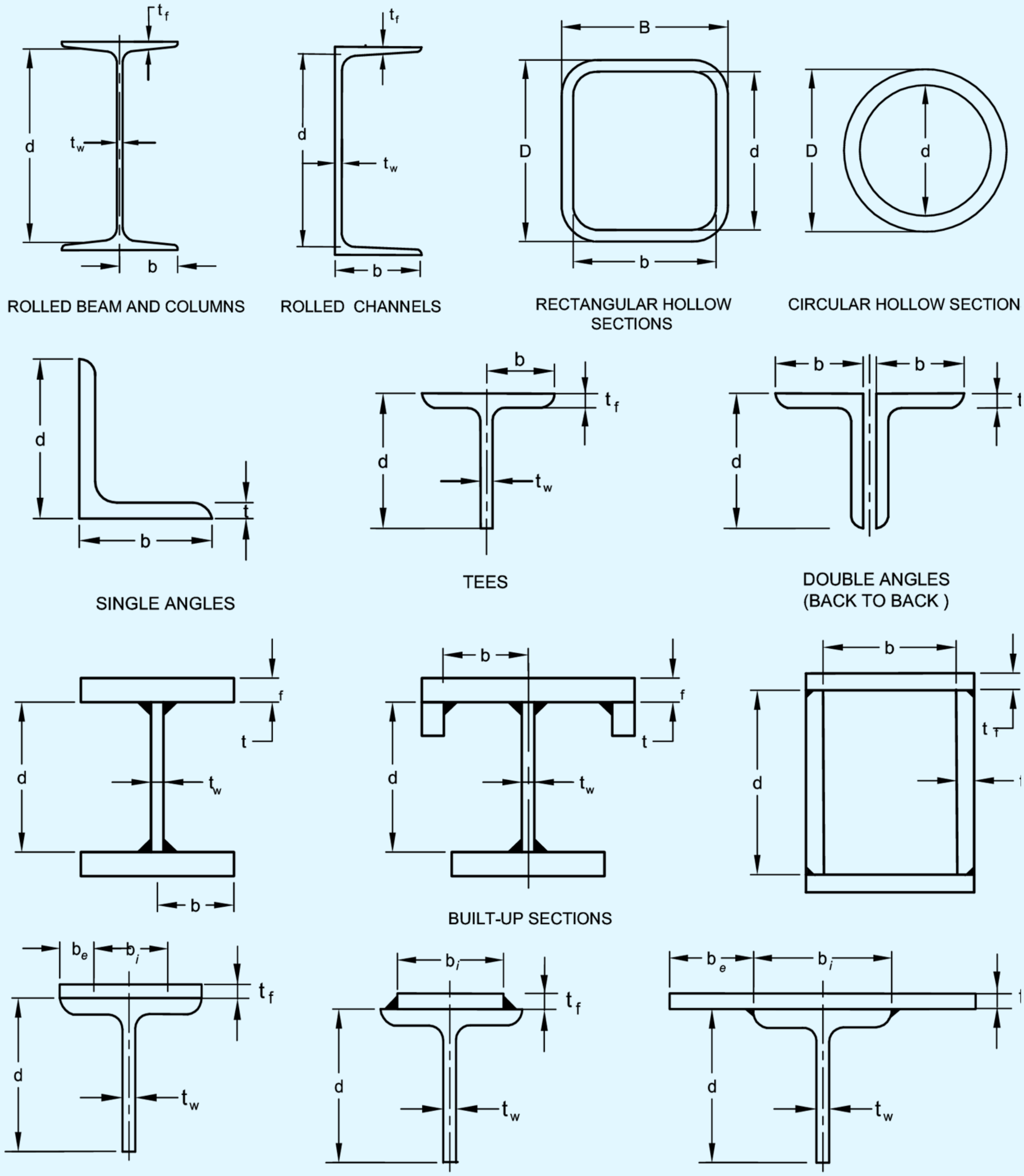
For h/b > 1.36: $D_e = 0.4\,\frac{h^2}{b}$

In compression and or bending about weak axis:

$D_e = \frac{h^2}{b}$

7 k_σ is the buckling factor given by:

Maximum compression at free edge	r_2	1	0	–1	–1 to – 3
	K_σ	0.43	0.57	0.85	$0.57 - 0.21k_2 + 0.07r_2$
Maximum Compression at supported edge	r_2	1	$0 < r_2 < 1$	0	$-1 < r_2 < 0$
	K_σ	0.43	$0.578/(r_2 + 0.34)$	1.70	$1.7 - 5\,r_2 + 17.1\,r_2^2$


t_f
d
t_w
b
ROLLED BEAM AND COLUMNS
t_f
d
t_w
b
ROLLED CHANNELS
B
D
d
b
RECTANGULAR HOLLOW SECTIONS
D
d
CIRCULAR HOLLOW SECTION
d
t
b
SINGLE ANGLES
b
t_f
d
t_w
TEES
b
b
t
d
DOUBLE ANGLES (BACK TO BACK)
f
t
d
t_w
b
b
f
t
d
t_w
b
t_f
d
BUILT-UP SECTIONS
b_e
b_i
t_f
d
t_w
b_i
t_f
d
t_w
b_e
b_i
d
t_w

b_i – INTERNAL ELEMENT WIDTH

b_e – EXTERNAL ELEMENT WIDTH

FIG. 2(A) DIMENSIONS OF SECTIONS

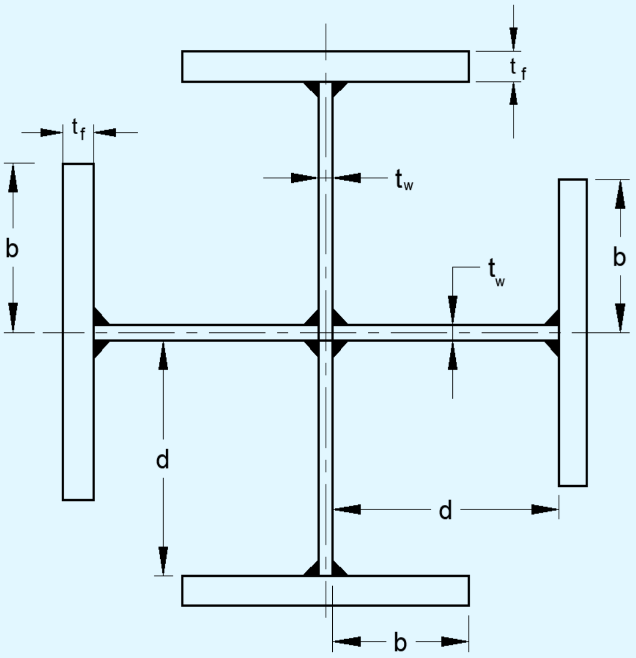
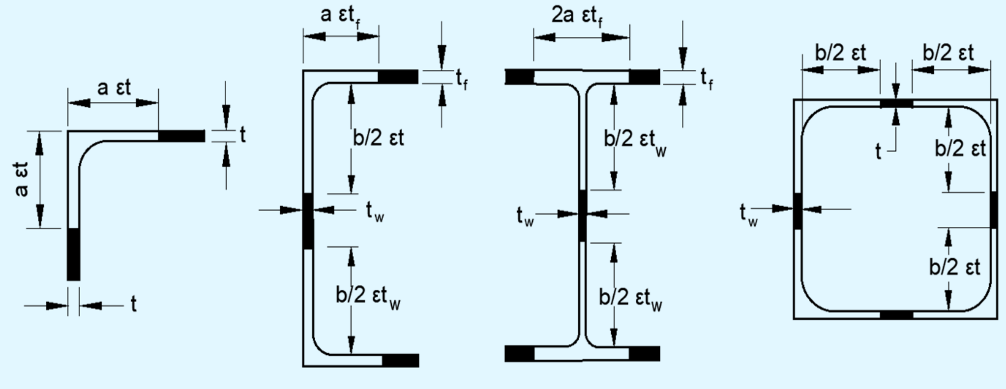

t f
t f
t w
b
t w
b
d
d
b

Fig. 2(B) Built-Up Steel Column Cruciform, Flanged


a εt
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2a εtf
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b/2 εt

VALUES OF (a) AND (b) ARE TO BE TAKEN FROM TABLE 2.

Fig. 2(C) Effective Section of Slender Elements

Fig.2 Classification of Sections

Table 3 Maximum Values of Effective Slenderness Ratios

(*Clause* 10.9)

Sl No. (1)	**Member** (2)	**Maximum Effective Slenderness Ratio *KL/r*** (3)
i)	A member carrying compressive loads resulting from dead loads and imposed loads	180
ii)	A tension member in which a reversal of direct stress occurs due to loads other than wind or seismic forces	180
iii)	A member subjected to compression forces resulting only from combination with wind/earthquake effects, provided the deformation of such member does not adversely affect the stress in any part of the structure	250
iv)	Compression flange of a beam against lateral torsional buckling	300
v)	A member normally acting as a tie in a roof truss or a bracing system not considered effective when subject to possible reversal of stress into compression resulting from the action of wind or earthquake effects[1)]	350
vi)	Members always under tension[1)] (other than pre-tensioned members)	400

[1)] Tension members, such as bracings, where sag is avoided, need not satisfy the maximum slenderness ratio limits.

10.10 Resistance to Horizontal Forces

10.10.1 In designing the steel frame work of a building, provision shall be made (by adequate moment connections or by a system of bracing) to effectively transmit to the foundations all the horizontal forces, giving due allowance for the stiffening effect of the walls and floors, where applicable.

10.10.2 When the walls, or walls and floors and/or roofs are capable of effectively transmitting all the horizontal forces directly to the foundations, the structural steel framework may be designed without considering the effects of wind or earthquake.

10.10.3 Wind and earthquake effects are reversible and therefore call for initial stiffness and strength under force reversal in both longitudinal and transverse directions. To resist torsional effects of wind and earthquake forces, bracings in plan should be provided and integrally connected with the longitudinal and transverse bracings, to impart adequate torsional resistance to the structure.

10.10.3.1 In shed type steel mill buildings, adequate bracings shall be provided to transfer the wind or earthquake loads from their points of action to the appropriate supporting members. Where the connections to the interior columns or frames are designed such that the wind or earthquake loads will not be transferred to the interior columns, the exterior columns or frames shall be designed to resist the total wind or earthquake loads. Where the connections to the interior columns and frames are designed such that the wind or earthquake effects are transferred to the interior columns also, and where adequate rigid diaphragm action can be mobilized as in the case of the cast-in place RC slab, both exterior and interior columns and frames may be designed on the assumption that the wind or earthquake load is divided among them in proportion to their relative stiffness. Columns also should be designed to withstand the net uplifting effect caused by excessive wind or earthquake shaking. Additional axial forces arising in adjacent columns due to the vertical component of bracings or due to frame action shall also be accounted for.

10.10.3.2 Earthquake forces are proportional to the seismic mass as defined in 5 of Part C 'Structural Design/Section 1 Loads and Load Effects' of this NBCS. Earthquake forces should be applied at the centre of mass of all such components and their transfer to the foundation should be ensured. Other construction details, stipulated in good practice [C-6A(37)] should also be followed.

10.10.3.3 In buildings where high-speed traveling cranes are supported or where a building or structure is otherwise subjected to vibration or sway, triangulated bracing or rigid portal systems shall be provided to reduce the vibration or sway to an acceptable minimum.

10.10.4 *Foundations*

The foundations of a building or other structures shall be designed to provide the rigidity and strength that has been assumed in the analysis and design of the superstructure.

10.10.5 *Eccentrically Placed Loads*

Where a wall, or other gravity load, is placed eccentrically upon the flange of a supporting steel beam, the beam and its connections shall be designed for torsion, unless the beam is restrained laterally in such a way as to prevent the twisting of the beam.

10.11 Expansion Joints

Expansion joints in case of low-rise buildings (up to three storeys) shall comply with **10.11.1** to **10.11.4**. For requirement of expansion joints in high-rise buildings, specialist literature shall be referred to.

10.11.1 In view of the large number of factors involved in deciding the location, spacing and nature of expansion joints, the decision regarding provision of expansion joints shall be left to the discretion of the designer.

10.11.2 Structures in which marked changes in plan dimensions take place abruptly, shall be provided with expansion joints at the section where such changes occur. Expansion joints shall be so provided that the necessary movement occurs with minimum resistance at the joint. The gap at the expansion joint should be such that:

a) it accommodates the expected expansion/contraction due to seasonal and diurnal variation of temperature; and

b) it avoids pounding of adjacent units under earthquake shaking. The structure adjacent to the joint should preferably be supported on separate columns but not necessarily on separate foundations.

10.11.3 The details as to the length of a structure where expansion joints have to be provided may be determined after taking into consideration various factors such as temperature, exposure to weather and structural design. The provisions in **10.11.3.1** to **10.11.3.3** are given as general guidance. The provision for expansion may be made by providing double framing at the joint or providing for expansion at the connection to the single framing in detailing.

10.11.3.1 If one bay of longitudinal bracing is provided at the centre of the building or building section, the length of the building section may be restricted to 180 m in case of covered buildings and 120 m in case of open gantries (*see* Fig. 3).

10.11.3.2 If more than one bay of longitudinal bracing is provided near the centre of the building/section, the maximum centre line distance between the two lines of bracing may be restricted to 50 m for covered buildings (and 30 m for open gantries) and the maximum distance between the centre of the bracing to the nearest expansion joint/end of building or section may be restricted to 90 m (60 m in case of open gantries). The maximum length of the building section thus may be restricted to 230 m for covered buildings (150 m for open gantries). Beyond this, suitable expansion joints shall be provided (*see* Fig.4).

10.11.3.3 The maximum width of the covered building section should preferably be restricted to 150 m beyond which suitable provisions for the expansion joint may be made.

10.11.4 When the provisions of these sections are met for a building or open structure made only of steel frame with elastic steel claddings, the stress analysis due to temperature is not required. However, for buildings, specialist literature may be referred to decide on thermal stress design.

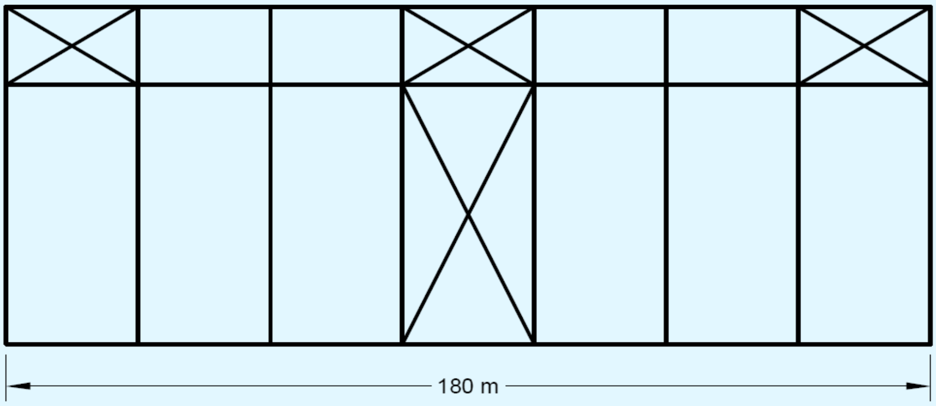

FIG. 3 MAXIMUM LENGTH OF BUILDING WITH ONE BAY OF BRACING

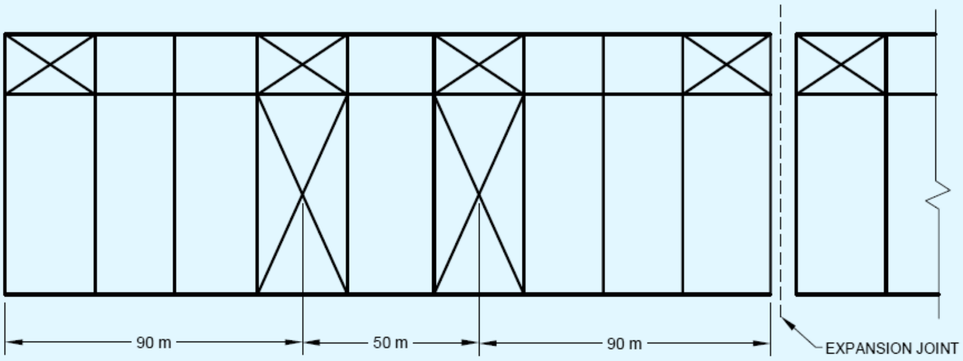

FIG. 4 MAXIMUM LENGTH OF COVERED BUILDING/SECTION WITH TWO BAYS OF BRACINGS

11 METHODS OF STRUCTURAL ANALYSIS

11.1 Methods of Determining Action Effects

11.1.1 *General*

For the purpose of complying with the requirements of the limit states of stability, strength and serviceability specified under Section **12** on the effects of design actions on a structure and its members and connections, shall be determined by structural analysis using the assumptions of **11.2** and **11.3** and one of the following methods of analysis:

a) elastic analysis in accordance with **11.4**;

b) plastic analysis in accordance with **11.5**;

c) advanced analysis in accordance with Annex B; or

d) dynamic analysis in accordance with **5** of Part C 'Structural Design/Section 1 Loads and Load Effects' of this NBCS.

The effects of design earthquake shaking specified in Section **18** shall be estimated by elastic analysis. Plastic analysis shall not be employed to obtain member forces corresponding to design earthquake shaking specified in Section **18**. More information on analysis to resist earthquake effects is given in **5** of Part C 'Structural Design/ Section 1 Loads and Load Effects' of this NBCS.

11.1.2 *Non-sway and Sway Frames*

For the purpose of analysis and design, the structural frames are classified as non-sway and sway frames as given below:

a) *Non-sway frame* — One in which the transverse displacement of one end of the member relative to the other end is effectively prevented. This applies to triangulated frames and trusses or to frames where in-plane stiffness is provided by bracings, or by shear walls, or by floor slabs and roof decks secured horizontally to walls or to bracing systems parallel to the plane of loading and bending of the frame;

b) *Sway frame* — One in which the transverse displacement of one end of the member relative to the other end is not effectively prevented. Such members and frames occur in structures which depend on flexural action of members to resist lateral loads and sway, as in moment resisting frames; and

c) A rigid jointed multi-storey frame may be considered as a non-sway frame if in every individual storey, the deflection δ, over a storey height h_s, due to the notional horizontal loading given in **11.3.6** satisfies the following criteria:

   1) For clad frames, when the stiffening effect of the cladding is not taken into account in the deflection calculations:

$$\delta \leq \frac{h_s}{2\,000}$$

   2) For unclad frame or clad frames, when the stiffening effect of the cladding is taken into account in the deflection calculations:

$$\delta \leq \frac{h_s}{4\,000}$$

   3) A frame, which when analyzed considering all the lateral supporting system does not comply with the above criteria, should be classified as a sway frame, even if it is braced or otherwise laterally stiffened.

11.2 Forms of Construction Assumed for Structural Analysis

11.2.1 The effects of design action in the members and connections of a structure shall be determined by assuming singly or in combination of the following forms of construction (*see* **17.6.1**).

11.2.1.1 *Rigid construction*

In rigid construction, the connections between members (beam and column) at their junction shall be assumed to have sufficient rigidity to hold the original angles between the members connected at a joint unchanged under loading.

11.2.1.2 *Semi-rigid construction*

In semi-rigid construction, the connections between members (beam and column) at their junction may not have sufficient rigidity to hold the original angles between the members at a joint unchanged, but shall be assumed to have the capacity to furnish a dependable and known degree of flexural restraint. The relationship between the degree of flexural restraint and the level of the load effects shall be established by any rational method or based on test results (*see* Annex F).

11.2.1.3 *Simple construction*

In simple construction, the connections between members (beam and column) at their junction will not resist any appreciable moment and shall be assumed to be hinged.

11.2.2 *Design of connections*

The design of all connections shall be consistent with the form of construction, and the behaviour of the connections shall not adversely affect any other part of the structure beyond what is allowed for in design. Connections shall be designed in accordance with provisions under **17**.

11.3 Assumptions in Analysis

11.3.1 The structure shall be analyzed in its entirety except as follows:

a) Regular building structures, with orthogonal frames in plan, may be analyzed as a series of parallel two-dimensional sub-structures (part of a structure), the analysis being carried out in each of the two directions, at right angles to each other, except when there is significant load redistribution between the sub-structures (part of a structure);

b) For vertical loading in a multi-storey building structure, provided with bracing or shear walls to resist all lateral forces, each level thereof, together with the columns immediately above and below, may be considered as a substructure, the columns being assumed fixed at the ends remote from the level under consideration; and

c) Where beams at a floor level in a multi-bay building structure are considered as a substructure (part of a structure), the bending moment at the support of the beam due to gravity loads may be determined based on the assumption that the beam is fixed at the far end support, one span away from the span under consideration, provided that the floor beam is continuous beyond that support point.

11.3.2 *Span Length*

The span length of a flexural member in a continuous frame system shall be taken as the centre-to-centre distance between the supports.

11.3.3 *Arrangements of Imposed Loads in Buildings*

For building structures, the various arrangements of imposed loads considered for the analysis, shall include at least the following:

a) Where the loading pattern is fixed, the arrangement concerned;

b) Where the imposed load is variable and not greater than three-quarters of the dead load, the imposed load may be taken to be acting on all spans; and

c) Where the imposed load is variable and exceeds three-quarters of the dead load, arrangements of imposed load acting on the floor under consideration shall include the following cases:

    1) imposed load on alternate spans;

    2) imposed load on two adjacent spans; and

    3) imposed load on all the spans.

11.3.4 *Base Stiffness*

In the analysis of all structures, the appropriate base stiffness about the axis under consideration shall be used. In the absence of the knowledge of the pedestal and foundation stiffness, the following may be assumed:

a) When the column is rigidly connected to a suitable foundation, the stiffness of the pedestal shall be taken as the stiffness of the column above base plate. However, in case of very stiff pedestals and foundations the column may be assumed as fixed at base;

b) When the column is nominally connected to the foundation, a pedestal stiffness of 10 percent of the column stiffness may be assumed;

c) When an actual pin or rocker is provided in the connection between the steel column and pedestal, the column is assumed as hinged at base and the pedestal and foundation may be appropriately designed for the reactions from the column; and

d) In case of (a) and (b), the bottom of the pedestal shall be assumed to have the following boundary condition in the absence of any detailed procedure based on theory or tests:

    1) When the foundation consists of a group of piles with a pile cap, raft foundation or an isolated footing resting on rock or very hard soil, the pedestal shall be assumed to be fixed at the level of the bottom of footing or at the top of the pile cap. Pedestal to be considered as fixed at top of pile cap, where

the Single Piles are tied at Pile cap level by means of ground beams (in both orthogonal directions) with required stiffness;

2) When the foundation consists of an isolated footing resting on other soils, the pedestal shall be assumed to be hinged at the level of the bottom of the footing;

3) When the pedestal is supported by a single pile, which is laterally surrounded by soil providing passive resistance, the pile shall be assumed to be fixed at a depth of 5 times the diameter of the pile below the ground level in case of compact ground or the top level of compact soil in case of poor soil overlying compact soil. Single pile cap, connected flexurally to orthogonal beams having adequate stiffness, shall be assumed to be fixed at the top of pile cap; and

4) When the column is founded into rock, it may be assumed to be fixed at the interface of the column and rock.

11.3.5 *Simple Construction*

Bending members may be assumed to have their ends connected for shear only and to be free to rotate. In triangulated structures, axial forces may be determined by assuming that all members are pin-connected. The eccentricity for stanchion and column shall be assumed in accordance with **14.3.3**.

11.3.6 *Notional Horizontal Loads*

To analyze a frame subjected to gravity loads, considering the sway stability of the frame, notional horizontal forces should be applied. These notional horizontal forces account for practical imperfections and should be taken at each level as being equal to 0.5 percent of factored dead load plus vertical imposed loads applied at that level. The notional load should not be applied along with other lateral loads, such as wind and earthquake effects, in the analysis.

11.3.6.1 The notional forces should be applied on the whole structure, in both orthogonal directions, in one direction at a time, at roof and all floor levels or their equivalent. They should be taken as acting simultaneously with factored gravity loads.

11.3.6.2 The notional force should not be:

a) applied when considering overturning or overall instability;

b) combined with other horizontal (lateral) loads;

c) combined with temperature effects; and

d) taken to contribute to the net shear on the foundation.

11.3.6.3 The sway effect using notional load under gantry load case need not be considered if the ratio of height to lateral width of the building is less than unity.

11.4 Elastic Analysis

11.4.1 *Assumptions*

Individual members shall be assumed to remain elastic under the action of the factored design loads for all limit states.

The effect of haunching or any variation of the cross section along the axis of a member shall be considered, and where significant, shall be taken into account in the determination of the member stiffness.

11.4.2 *First-order Elastic Analysis*

In a first-order elastic analysis, the equilibrium of the frame in the undeformed geometry is considered, the changes in the geometry of the frame due to the loading are not accounted for, and changes in the effective stiffness of the members due to axial force are neglected. The conditions under which the first order elastic analysis results are adequate for design are given in Section **11.7**.

11.5 Plastic Analysis

11.5.1 *Application*

The effects of design action throughout or on part of a structure may be determined by a plastic analysis, provided that the requirements of **11.5.2** are met. The distribution of design action effects shall satisfy equilibrium and the boundary conditions.

11.5.2 *Requirements*

When a plastic method of analysis is used, all of the following conditions shall be satisfied, unless adequate ductility of the structure and plastic rotation capacity of its members and connections are established for the design loading conditions by other means of evaluation:

a) The yield stress of the grade of the steel used shall not exceed 450 MPa;

b) The stress-strain characteristics of the steel shall not be significantly different from those obtained for steels complying with the accepted standard [C-6A(6)] or equivalent and shall be such as to ensure complete plastic moment redistribution. The stress-strain diagram shall have a plateau at the yield stress, extending for at least six times the yield strain. The ratio of the tensile strength to the yield stress specified for the grade of the steel shall not be less than 1.2. The elongation on a gauge length complying with the accepted standard [C-6A(6)] shall not be less than 15 percent; and the steel shall exhibit strain-hardening capability. Steels conforming to the accepted standard [C-6A(6)] shall be deemed to satisfy the above requirements;

c) The members used shall be hot-rolled or fabricated using hot-rolled plates and sections;

d) The cross section of members not containing plastic hinges should be at least that of compact section (*see* **10.8.2**), unless the members meet the strength requirements from elastic analysis;

e) Where plastic hinges occur in a member, the proportions of its cross section should not exceed the limiting values for plastic section given in **10.8.2**;

f) The cross section should be symmetrical about its axis perpendicular to the axis of the plastic hinge rotation; and

g) The members shall not be subject to impact loading, requiring fracture assessment or fluctuating loading, requiring a fatigue assessment [*see* **19**].

11.5.2.1 *Restraints*

If practicable, torsional restraint (against lateral buckling) should be provided at all plastic hinge locations. Where not feasible, the restraint should be provided within a distance of $D/2$ of the plastic hinge location, where D is the total depth of section.

The torsional restraint requirement at a section as above, need not be met at the last plastic hinge to form, provided it can be clearly identified.

Within a member containing a plastic hinge, the maximum distance L_m from the restraint at the plastic hinge to an adjacent restraint should be calculated by any rational method or the conservative method given below, so as to prevent lateral buckling.

Conservatively L_m (in mm) may be taken as:

$$L_\mathrm{m} \le \frac{38 r_\mathrm{y}}{\left[\dfrac{f_\mathrm{c}}{130} + \left(\dfrac{f_\mathrm{y}}{250}\right)^2 \left(\dfrac{x_\mathrm{t}}{40}\right)^2\right]^{1/2}}$$

where

A = area of cross section;

f_c = actual, in N/mm^2, compressive stress on the cross section due to axial load;

f_y = yield, in N/mm^2, stress;

I_w, I_y, I_t = warping constant, second moment of the cross section about the minor axes and St. Venant's torsion constant, respectively;

r_y = radius, in mm, of gyration about the minor axis; and

x_t = torsional index, $x_t = 1.132(AI_w / I_y I_t)^{0.5}$.

Where the member has unequal flanges, r_y should be taken as the lesser of the values of the compression flange only or the whole section.

Where the cross section of the member varies within the length L_m, the maximum value of r_y and the minimum value of x_t should be used.

The spacing of restraints to member lengths not containing a plastic hinge should satisfy the recommendations of section on lateral buckling strength of beams (*see* **15.2.2**). Where the restraints are placed at the limiting distance L_m, no further checks are required.

11.5.2.2 *Stiffeners at plastic hinge locations*

Web stiffeners should be provided where a concentrated load, which exceeds 10 percent of the shear capacity of the member, is applied within *D/2* of a plastic hinge location, (*see* **15.2.1.2**). The stiffener should be provided within a distance of half the depth of the member on either side of the hinge location and be designed to carry the applied load in accordance with **15.7.4**. If the stiffeners are flat plates, the outstand width to the thickness ratio, *b*/*t*, should not exceed the values given in the plastic section (*see* **10.7** and Table 2). Where other sections are used, the ratio $\left(\frac{I_{so}}{I_t}\right)^{1/2}$, should not exceed the values given for plastic section (for simple outstand, as in **10.7**);

where

I_{so} = second moment of area of the stiffener about the face of the element perpendicular to the web; and

I_t = St. Venant's torsion constant of the stiffener.

11.5.2.3 The frame shall be adequately supported against sway and out-of-plane buckling, by bracings, moment resisting frame or an independent system such as shear wall.

11.5.2.4 *Fabrication restriction*

Within a length equal to the member depth, on either side of a plastic hinge location, the following restrictions should be applied to the tension flange and noted in the design drawings. Holes, if required, should be drilled or else punched 2 mm undersize and reamed. All sheared or hand flame cut edges should be finished smooth by grinding, chipping or planning.

11.5.3 *Assumptions in Analysis*

The design action effects shall be determined using a rigid-plastic analysis.

It shall be permissible to assume full strength or partial strength connections, provided the capacities of these are used in the analysis, and provided that:

a) In a full strength connection, the moment capacity of the connection shall be not less than that of the member being connected;

b) In a partial strength connection, the moment capacity of the connection may be less than that of the member being connected; and

c) In both cases the behavior of the connection shall be such as to allow all plastic hinges necessary for the collapse mechanism to develop, and shall be such that the required plastic hinge rotation does not exceed the rotation capacity at any of the plastic hinges in the collapse mechanism.

In the case of building structures, it is not normally necessary to consider the effect of alternating plasticity.

11.6 Frame Buckling Analysis

11.6.1 The elastic buckling load factor (λ_{cr}) shall be the ratio of the elastic buckling load set of the frame to the design load set for the frame, and shall be determined in accordance with **11.6.2**.

NOTE — The value of λ_{cr} depends on the load set and has to be evaluated for each possible set of load combination.

11.6.2 *In-plane frame buckling*

The elastic buckling load factor (λ_{cr}) of a rigid-jointed frame shall be determined by using:

a) One of the approximate methods of **11.6.2.1** and **11.6.2.2**; or

b) A rational elastic buckling analysis of the whole frame.

11.6.2.1 *Regular non-sway frames* (*see* **11.1.2**)

In a rectangular non-sway frame with regular loading and negligible axial forces in the beams, the Euler buckling stress $f_{cr,}$ for each column shall be determined in accordance with **14.1.2.1**. The elastic buckling load factor (λ_{cr}) for the whole frame shall be taken as the lowest of the ratio of (f_{cr}/f_{cd}) for all the columns, where f_{cd} is the axial compressive stress in the column from the factored load analysis.

11.6.2.2 *Regular sway frames*

In a rectangular sway frame with regular loading and negligible axial forces in the beams, the buckling load, P_{cr}, for each column shall be determined as $P_{cr} = A\, f_{cr}$, where f_{cr} is the elastic buckling stress of the column in the plane of frame, obtained in accordance with **14.1.2.1**. The elastic buckling load factor $\lambda_{cr,}$ for the whole frame shall be taken as the lowest of all the ratios, λ_{scr}, calculated for each storey of the building, as given below:

$$\lambda_{scr} = \frac{\sum (P_{cr}/L)}{\sum (P/L)}$$

where

L = column length and the summation includes all columns in the plane frame within a storey; and

P = member axial force from the factored load analysis, with tension taken as negative.

11.7 Consideration of Second Order Effects

11.7.1 Any second-order effects of the loads acting on the structure in its deformed configuration may be neglected and first order elastic analysis or plastic analysis results may be used provided the following are satisfied:

a) for clad frames, provided with the stiffening effects of masonry infill wall panels or diaphragms of profiled wall panel is not taken into account, and where elastic buckling load factor, λ_{cr} (*see* **11.6**) satisfies $\lambda_{cr}/\lambda_P \geq 10$;

If $10 > \lambda_{cr}/\lambda_P \geq 4.6$ the second-order effects may be considered by amplifying the design load effects obtained from elastic/plastic analysis by a factor as given in **11.7.3.1**.

If $\lambda_{cr}/\lambda_P < 4.6$, second-order elastic analysis or second-order plastic analysis (*see* **11.7.3**) is to be carried out.

b) for un-clad frames or for clad frames where the stiffening effects of masonry infill or diaphragms of profiled wall panel is taken into account, where elastic buckling load factor, λcr (see 11.6) satisfies $\lambda cr / \lambda_P \geq 20$.

If $20 > \lambda_{cr} / \lambda_P \geq 5.75$ the second-order effects may be considered by amplifying the design load effects obtained from plastic analysis by a factor as given in **11.7.3.2**.

If $\lambda_{cr}/\lambda_P < 5.75$, second-order elasto-plastic analysis or second-order elastic analysis (*see* **11.7.2**) shall be carried out.

where

λ_p = Ultimate load factor from elastic or plastic analysis.

11.7.2 *Second-order Elastic Analysis*

11.7.2.1 The analysis shall allow for the effects of the design loads acting on the structure and its members in their displaced and deformed configuration. These second-order effects shall be taken into account by using either:

a) a first-order elastic analysis with moment amplification in accordance with **11.7.3.1**, **11.7.3.2**, provided the moment amplification factors, K_y and K_z are not greater than 1.4; or

b) a second-order elastic analysis in accordance with Annex B.

11.7.3 Moment Amplification

11.7.3.1 *Moment amplification for members in non-sway frames*

For a member with zero axial compression or a member subject to axial tension, the design bending moment is that obtained from the first-order analysis for factored loads, without any amplification.

For a braced member with a design axial compressive force P_d as determined by the first-order analysis, the design bending moment shall be calculated considering moment amplification as in **16.3.2.2**.

11.7.3.2 *Moment amplification for members in sway frames*

The design bending moment shall be calculated as the product of moment amplification factor, [*see* **16.3.2.2** (K_y, K_z)] and the moment obtained from the first-order analysis of the sway frame, unless analysis considering second order effects is carried out (*see* **11.7.2**).

11.7.4 The calculated bending moments from the first order elastic analysis may be modified by redistribution up to 15 percent of the peak calculated moment of the member under factored load, provided that:

a) in which the moments are reduced shall belong to plastic or compact section classification (*see* **10.8**). the internal forces and moments in the members of the frame are in equilibrium with applied loads; and

b) all the members.

12 LIMIT STATE DESIGN

12.1 Basis for Design

12.1.1 In the limit state design method, the structure shall be designed to withstand safely all loads likely to act on it throughout its life. It shall not suffer total collapse under accidental loads such as from explosions or impact or due to consequences of human error to an extent beyond the local damages. The objective of the design is to achieve a structure that will remain fit for use during its life with acceptable target reliability. In other words, the probability of a limit state being reached during its lifetime should be very low. The acceptable limit for the safety and serviceability requirements before failure occurs is called a limit state. In general, the structure shall be designed on the basis of the most critical limit state and shall be checked for other limit states.

12.1.2 Steel structures are to be designed and constructed to satisfy the design requirements with regard to stability, strength, serviceability, brittle fracture, fatigue, fire, and durability such that they meet the following:

a) Remain fit with adequate reliability and be able to sustain all actions (loads) and other influences experienced during construction and use;

b) Have adequate durability under normal maintenance; and

c) Do not suffer overall damage or collapse disproportionately under accidental events like explosions, vehicle impact or due to consequences of human error to an extent beyond local damage. The potential for catastrophic damage shall be limited or avoided by appropriate choice of one or more of the following:

   1) Avoiding, eliminating or reducing exposure to hazards, which the structure is likely to sustain;

   2) Choosing structural forms, layouts and details and designing such that;

      i) the structure has low sensitivity to hazardous conditions; and

      ii) the structure survives with only local damage even after serious damage to any one individual element by the hazard.

   3) Choosing suitable material, design and detailing procedure, construction specifications, and control procedures for shop fabrication and field construction as relevant to the particular structure.

12.1.3 The following conditions may be satisfied to avoid a disproportionate collapse:

a) The building should be effectively tied together at each principal floor level and each column should be effectively held in position by means of continuous ties (beams) nearly orthogonal, except where the steel work supports only cladding weighing not more than 0.7 kN/m^2 along with imposed and wind loads. These ties must be steel members such as beams, which may be designed for other purposes, steel bar reinforcement anchoring the steel frame to concrete floor or steel mesh reinforcement in composite slab with steel profiled sheeting directly connected to beam with shear connectors. These steel ties and their end connections should be capable of resisting factored tensile force not less than the factored dead and imposed loads acting on the floor area tributary to the tie nor less than 75 kN. Such connection of ties to edge column should also be capable of resisting 1 percent of the maximum axial compression in the column at the level due to factored dead and imposed loads. All column splices should be capable of resisting a tensile force equal to the largest of a factored dead and imposed load reaction from a single floor level located between that column splice and the next column splice below that splice. Lateral load system to resist notional horizontal loads prescribed in **11.3.6** should be distributed throughout the building in nearly orthogonal directions so that no substantial portions is connected at only one point to such a system. Precast concrete or other heavy floor or roof units should be effectively anchored in the direction of their span either to each other over the support or directly to the support.

b) Where the above conditions to tie the columns to the floor adequately are not satisfied each storey of the building should be checked to ensure that disproportionate collapse would not precipitate by the notional removal, one at a time, of each column.

c) Where each floor is not laterally supported by more than one system, check should be made at each storey by removing one such lateral support system at a time to ensure that disproportionate collapse would not occur. The collapse is considered disproportionate, if more than 15 percent of the floor or roof area of 70 m^2 collapse at that level and at one adjoining level either above or below it, under a load equal to 1.05 or 0.9 times the dead load, 0.33 times temporary or full imposed load of permanent nature (as in storage buildings) and 0.33 times wind load acting together.

12.1.4 Structures designed for unusual or special functions shall comply with any other relevant additional limit state considered appropriate to that structure.

12.2 Limit State Design

12.2.1 For achieving the design objectives, the design shall be based on characteristic values for material strengths and applied loads (actions), which take into account the probability of variations in the material strengths and in the loads to be supported. The characteristic values shall be based on statistical data, if available. Where such data is not available, these shall be based on experience. The design values are derived from the characteristic values through the use of partial safety factors, both for material strengths and for loads. In the absence of special considerations, these factors shall have the values given in this Section according to the material, the type of load and the limit state being considered. The reliability of design is ensured by satisfying the requirement:

$$\text{Design action} \leq \text{Design strength}$$

12.2.2 Limit states are the states beyond which the structure no longer satisfies the performance requirements specified. The limit states are classified as:

a) limit state of strength; and

b) limit state of serviceability.

12.2.2.1 The limit states of strength are those associated with failures (or imminent failure), under the action of probable and most unfavourable combination of loads on the structure using the appropriate partial safety factors, which may endanger the safety of life and property. The limit state of strength includes:

a) loss of equilibrium of the structure as a whole or any of its parts or components;

b) loss of stability of the structure (including the effect of sway where appropriate and overturning) or any of its parts including supports and foundations;

c) failure by excessive deformation, rupture of the structure or any of its parts or components;

d) fracture due to fatigue; and

e) brittle fracture.

12.2.2.2 The limit state of serviceability include:

a) deformation and deflections, which may adversely affect the appearance or effective use of the structure or may cause improper functioning of equipment or services or may cause damages to finishes and non-structural members;

b) vibrations in the structure or any of its components causing discomfort to people, damages to the structure, its contents or which may limit its functional effectiveness. Special consideration shall be given to systems susceptible to vibration, such as large open floor areas free of partitions to ensure that such vibrations are acceptable for the intended use and occupancy (*see* Annex C).;

c) repairable damage or crack due to fatigue;

d) corrosion, durability; and

e) fire.

12.3 Actions

The actions (loads) to be considered in design include direct actions (loads) experienced by the structure due to self-weight, external actions, etc, and imposed deformations such as that due to temperature and settlements.

12.3.1 *Classification of Actions*

Actions are classified by their variation with time as given below:

a) *Permanent actions* (Q_p) — Actions due to self-weight of structural and non-structural components, fittings, ancillaries, and fixed equipment, etc;

b) *Variable actions* (Q_v) — Actions due to construction and service stage loads such as imposed (live) loads (crane loads, snow loads, etc), wind loads, and earthquake effects; and

c) *Accidental actions* (Q_a) — Actions expected due to explosions, and impact of vehicles, etc.

12.3.2 *Characteristic Actions* (*Loads*)

12.3.2.1 The characteristic actions, Q_c, are the values of the different actions that are not expected to be exceeded with more than 5 percent probability, during the life of the structure and they are taken as:

a) the self-weight, in most cases calculated on the basis of nominal dimensions and unit weights [*see* **2** of Part C ‘Structural Design/Section 1 Loads and Load Effects’ of this NBCS];

b) the variable loads, values of which are specified in relevant standard [(*see* Part C ‘Structural design/Section 1 Loads and Load Effects’ of this NBCS];

c) the upper limit with a specified probability (usually 5 percent) not exceeding during some reference period (design life); and

d) specified by client, or by designer in consultation with client, provided they satisfy the minimum provisions of the relevant loading standard.

12.3.2.2 The characteristic values of accidental loads generally correspond to the value specified by relevant code, standard or client. The design for accidental load is generally not required in building unless it is required by client or approving authority in which case, generally recommendation in **12.1.2 (c)** or specialist literature shall be followed.

12.3.3 *Design Actions*

The design action, Q_{d}, is expressed as:

$$Q_d = \sum_k \gamma_{\mathrm{Lk}} Q_{\mathrm{ck}}$$

where

$_{\mathrm{Lk}}$ = partial safety factor for different loads k, given in Table 4 to account for.

1) possibility of unfavourable deviation of the load from the characteristic value;

2) possibility of inaccurate assessment of the load;

3) uncertainty in the assessment of effects of the load; and

4) uncertainty in the assessment of the limit states being considered.

The loads, Load combinations and the relevant partial safety factors for loads in a combination shall be as given in Part C/Section 1 of this NBCS. The loads or load effects shall be multiplied by the relevant γ_{L} factors, given in Table 4, to get the design loads or design load effects, when such a value is not available in Part C/Section 1 of this NBCS.

12.4 Strength

The ultimate strength calculation may require consideration of the following:

a) Loss of equilibrium of the structure or any part of it, considered as a rigid body; and

b) Failure by excessive deformation, rupture or loss of stability of the structure or any part of it including support and foundation.

12.4.1 *Design Strength*

The design strength, S_{d}, is obtained as given below from ultimate strength, S_{u} and partial safety factors for materials, γ_{m} given in Table 5.

$$S_{\mathrm{d}} = S_{\mathrm{u}} / \gamma_{\mathrm{m}}$$

where partial safety factor for materials, γ_{m} account for:

a) possibility of unfavourable deviation of material strength from the characteristic value;

b) possibility of unfavourable variation of member sizes;

c) possibility of unfavourable reduction in member strength due to fabrication and tolerances; and

d) uncertainty in the calculation of strength of the members.

Table 4 Partial Safety Factors for Loads, γ_L, for Limit States

(*Clauses* 10.6.1, 12.3.3, 12.6, 12.6.1, 18.2 *and* 22.5)

Sl No.	Combination	Limit State of Strength						Limit State of Serviceability			
		DL	IL 1)		WL/EL	FL	AL	DL	IL 1)		WL/EL/FL
			Leading	Accompanying					Leading	Accompanying	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
i)	DL + IL + CL	1.5	1.5	1.05	—	—	—	1.0	1.0	1.0	—
ii)	DL + IL + CL + WL	1.2 1.2	1.2 1.2	1.05 0.53	0.6 1.2	—	—	1.0	0.8	0.8	0.8
iii)	DL + WL	1.5 (0.9) 2)	—	—	1.5	—	—	1.0	—	—	1.0
iv)	DL + IL + CL + EL	1.2 1.2	1.2 1.2	1.05 0.53	1.0 1.0	—	—	1.0	0.8	0.8	1.0
v)	DL + EL	1.5 (0.9) 2)	—	—	1.0	—	—	1.0	—	—	1.0
vi)	DL + ER	1.2 (0.9) 2)	1.2	—	—		—	—	—	—	—
vii)	DL + IL 3) + FL	1.0	1.0/0.5	—	—	1.0	—	1.0	1.0/0.5	—	1.0
viii)	DL + IL + AL	1.0	0.35 4)	0.35 4)	—		1.0	—	—	—	—

Abbreviations:

DL= Dead load, IL= Imposed load, WL= Wind load, CL= Crane load (Vertical/Horizontal), AL=Accidental load, ER= Erection load, EL= Earthquake effects, FL = Forces due to restraints during fire.

NOTE — The effects of actions (loads) in terms of stresses or stress resultants may be obtained from an appropriate method of analysis as in **11**.

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1) When action of different imposed loads is simultaneously considered, the leading imposed load shall be considered to be the one causing the higher load effects in the member/section.

2) This value is to be considered when the dead load contributes to stability against overturning is critical or the dead load causes reduction in stress due to other loads.

3) Imposed load shall be taken as the full characteristic specified values in case of storage loads and 50 percent of the specified characteristic values in other cases.

4) 0.35 shall not be used when the imposed load is not permeant load as in earth pressure.

Table 5 Partial Safety Factor for Materials, γ_m

(*Clauses* 12.4.1, 13.2, 13.3.1, 17.1.6 *and* 17.5.7.1.1)

Sl No. (1)	Definition (2)	Partial Safety Factor (3)	
i)	Resistance, governed by yielding, γ_{m0}	1.10	
ii)	Resistance of member to buckling, γ_{m0}	1.10	
iii)	Resistance, governed by ultimate stress, γ_{m1}	1.25	
iv)	Resistance of connection:	Shop Fabrications	Field Fabrications
	a) bolts-Friction Type, γ_{mf};	1.25	1.25
	b) bolts-Bearing Type, γ_{mb};	1.25	1.25
	c) rivets, γ_{mr}; and	1.25	1.25
	d) welds, γ_{mw}	1.25	1.50

12.5 Factors Governing the Ultimate Strength

12.5.1 *Stability*

Stability shall be ensured for the structure as a whole and for each of its elements. This should include, overall frame stability against overturning and sway, as given in **12.5.1.1** and **12.5.1.2**.

12.5.1.1 *Stability against overturning*

The structure as a whole or any part of it shall be designed to prevent instability due to overturning, uplift or sliding under factored load as given below:

a) The actions shall be divided into components aiding instability and components resisting instability;

b) The permanent and variable actions and their effects causing instability shall be combined using appropriate partial safety factors for loads as per the limit state requirements, to obtain maximum destabilizing effect;

c) The permanent actions (loads) and effects contributing to resistance shall be multiplied with a partial safety factor 0.9 and added together with design resistance (after multiplying with appropriate partial safety factor). Variable actions and their effects contributing to resistance shall be disregarded; and

d) The resistance effect shall be greater than or equal to the destabilizing effect. Combination of imposed and dead loads should be such as to cause most severe effect on overall stability.

12.5.1.2 *Sway stability*

The whole structure, including portions between expansion joints, shall be adequately stiff against sway. To ensure this, in addition to designing for applied horizontal loads, a separate check should be carried out for notional horizontal loads such as given in **11.3.6** to evaluate the sway under gravity loads.

12.5.2 *Fatigue*

Generally, fatigue need not be considered unless a structure or element is subjected to numerous significant fluctuations of stress. Stress changes due to fluctuations in wind loading normally need not be considered. Fatigue design shall be in accordance with the provisions under **19**. When designing for fatigue, the partial safety factor for load, γ_L, equal to unity shall be used for the load causing stress fluctuation and stress range.

12.5.3 *Plastic Collapse*

Plastic analysis and design may be used, if the requirement specified under the plastic method of analysis (*see* **11.5**) are satisfied.

12.6 Limit State of Serviceability

Serviceability limit state is related to the criteria governing normal use. Serviceability limit state is limit state beyond which the service criteria specified below, are no longer met:

a) deflection limit;

b) vibration limit;

c) durability consideration; and

d) fire resistance.

Unless specified otherwise (*see* Table 4), partial safety factor for loads, γ_L, of value equal to unity shall be used for all loads leading to serviceability limit states to check the adequacy of the structure under serviceability limit states.

12.6.1 *Deflection*

The deflection under serviceability loads of a building or a building component should not impair the strength of the structure or components or cause damage to finishing. Deflections are to be checked for the most adverse but realistic combination of service loads and their arrangement, by elastic analysis, using partial safety factors in Table 4 for loads, as required, in Table 6. Table 6 gives recommended limits of deflections for certain structural members and systems. In Table 6, imposed load should include all post construction loads including superimposed dead loads. Circumstances may arise where greater or lesser values would be more appropriate, depending upon the nature of material in element to be supported (vulnerable to cracking or not) and intended use of the structure, as required by client.

Where the deflection due to the combination of dead load and imposed load is likely to be excessive, consideration should be given to pre-camber the beams, trusses and girders. The value of desired camber shall be specified in design drawing. Generally, for spans greater than 25 m, a camber approximately equal to the deflection due to dead loads plus half the imposed load may be used. The deflection of a member shall be calculated without considering the impact factor or dynamic effect of the loads on deflection. Roofs, which are very flexible, shall be designed to withstand any additional load that is likely to occur as a result of ponding of water or accumulation of snow or ice.

12.6.2 *Vibration*

Suitable provisions in the design shall be made for the dynamic effects of imposed loads, impact loads and vibration due to machinery operating loads. In severe cases possibility of resonance, fatigue or unacceptable vibrations shall be investigated. Unusually flexible structures (generally the height to effective width of lateral load resistance system exceeding 5 : 1) shall be investigated for lateral vibration under dynamic wind loads. Structures subjected to large number of cycles of loading shall be designed against fatigue failure, as specified under **19**. Floor vibration effect shall be considered using specialist literature (*see* Annex C).

12.6.3 *Durability*

Factors that affect the durability of the buildings, under conditions relevant to their intended life, are listed below:

a) Environment;

b) Degree of exposure;

c) Shape of the member and the structural detail;

d) Protective measure; and

e) Ease of maintenance.

The durability of steel structures shall be ensured by following recommendations given under **21**. Specialist literature may be referred to for more detailed and additional information in design for durability.

Table 6 Deflection Limits

(*Clause* 12.6.1)

Sl No.	Type of Building	Deflection	Design Load	Member	Supporting	Maximum Deflection
(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Industrial buildings	Vertical	Imposed load and wind load	Purlins and Girts	Elastic cladding	Span/150
					Brittle cladding	Span/180
			Imposed load	Simple span	Elastic cladding	Span/240
					Brittle cladding	Span/300
			Imposed load	Cantilever span	Elastic cladding	Span/120
					Brittle cladding	Span/150
			Imposed load, wind load and crane load	Rafter supporting	Profiled metal sheeting	Span/180
					Plastered sheeting	Span/240
			Crane load (Manual operation)	Gantry	Wheels of crane	Span/500
			Crane load (Electric operation up to 50 t)	Gantry	Wheels of crane	Span/750
			Crane load (Electric operation over 50 t)	Gantry	Wheels of crane	Span/1000
		Lateral	No cranes (due to wind)	Column	Elastic cladding	Height/150
					Masonry/Brittle cladding	Height/240
			Crane load and wind load	Gantry (lateral)	(absolute)	Span/400
					Relative displacement between rails supporting wheels of crane	25 mm1)
			Crane load and wind load	Column/Frame	Gantry (Elastic cladding)	Height/200
					Gantry (Brittle cladding; cab operated)	Height/400
	Other Buildings	Vertical	Imposed load	Floor and roof	Elements not susceptible to cracking	Span/300
					Elements susceptible to cracking	Span/360
			Imposed load	Cantilever	Elements not susceptible to cracking	Span/150
					Elements susceptible to cracking	Span/180
		Lateral	Wind load	Building	Elastic cladding	Height/300
					Brittle cladding	Height/500
			Wind load	Inter-storey drift	—	Storey height/300

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1) Crane supplier may be consulted for higher values

12.6.4 *Fire Resistance*

Fire resistance of a steel member is a function of its mass, its geometry, and the actions to which it is subjected, its structural support condition, fire protection measures adopted and the fire to which it is exposed. Design provisions to resist fire are briefly discussed under **22**. Specialist literature may be referred to for more detailed information in design of fire resistance of steel structures.

13 DESIGN OF TENSION MEMBERS

13.1 Tension Members

Tension members are linear members in which axial forces act to cause elongation (stretch). Such members can sustain loads up to the ultimate load, at which stage they may fail by rupture at a critical section. However, if the gross area of the member yields over a major portion of its length before the rupture load is reached, the member may become non-functional due to excessive elongation. Plates and other rolled sections in tension may also fail by block shear of end bolted regions (*see* **13.4.1**).

The factored design tension T, in the members shall satisfy the following requirement:

$$T < T_d$$

where

T_d = Design strength of the member.

The design strength of a member under axial tension, T_d, is the lowest of the design strength due to yielding of gross section, T_{dg}; rupture strength of critical section, T_{dn}; and block shear T_{db}, given in **13.2**, **13.3** and **13.4**, respectively.

13.2 Design Strength Due to Yielding of Gross Section

The design strength of members under axial tension, T_{dg}, as governed by yielding of gross section, is given by:

$$T_{dg} = A_g f_y / \gamma_{m0}$$

where

A_g = gross area of cross section;

f_y = yield stress of the material; and

γ_{m0} = partial safety factor for failure in tension by yielding (*see* Table 5).

13.3 Design Strength Due to Rupture of Critical Section

13.3.1 *Plates*

The design strength in tension of a plate, T_{dn}, as governed by rupture of net cross sectional area, A_n, at the holes is given by:

$$T_{dn} = 0.9\, A_n f_u / \gamma_{m1}$$

where

A_n = net effective area of the member given by;

f_u = ultimate stress of the material; and

γ_{m1} = partial safety factor for failure at ultimate stress (*see* Table 5).

$$A_n = \left[b - nd_h + \sum \frac{p_{si}^2}{4g_i} \right] t$$

where

b, t = width and thickness of the plate, respectively;

d_h = diameter of the bolt hole (2 mm in addition to the diameter of the hole, in case of directly punched holes);

g = gauge length between the bolt holes, as shown in Fig. 5;

i = subscript for summation of all the inclined legs;

n = number of bolt holes in the critical section; and

p_s = staggered pitch length between line of bolt holes, as shown in Fig. 5.

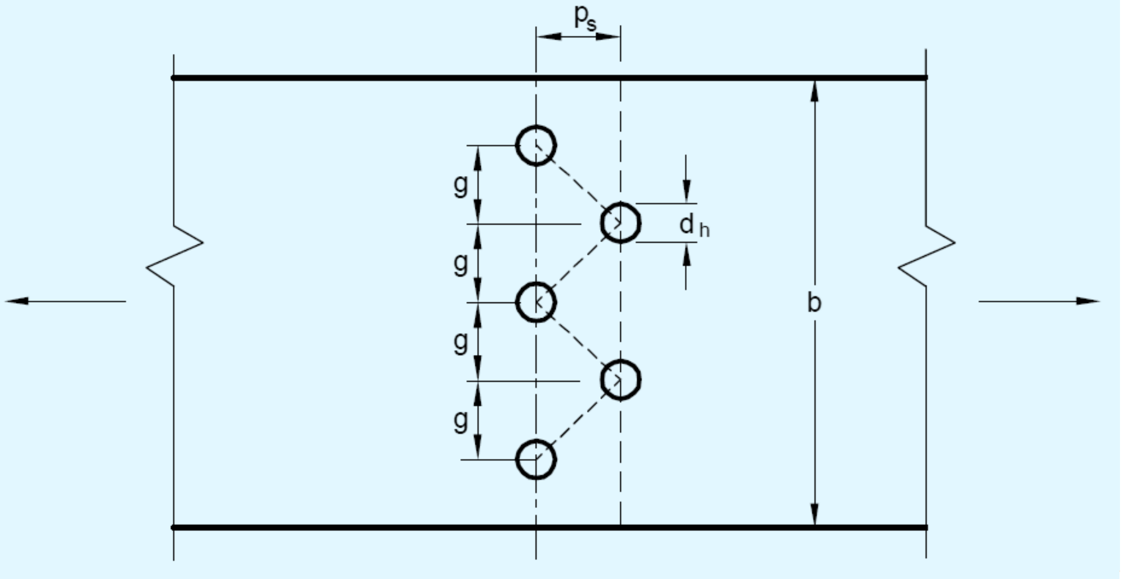


FIG. 5 PLATES WITH BOLTS HOLES IN TENSION

13.3.2 *Threaded Rods*

The design strength of threaded rods in tension, T_{dn}, as governed by rupture is given by:

$$T_{dn} = 0.9 A_c f_u / \gamma_{m1}$$

where

A_c = net root area at the threaded section.

13.3.3 *Single Angles*

The rupture strength of an angle connected through one leg is affected by shear lag. The design strength, $T_{dn,}$ as governed by rupture at net section is given by:

$$T_{dn} = 0.9 A_{nc} f_u / \gamma_{m1} + \beta A_{go} f_y / \gamma_{m0}$$

where

$$\beta = 1.4 - 0.076\,(w/t)\,(f_y/f_u)\,(b_s/L_c) \leq (0.9 f_u \gamma_{m0}/f_y \gamma_{m1}) \geq 0.7$$

where

A_{go} = gross area of the outstanding leg;

A_n = net area of the total cross section

A_{nc} = net area of the connected leg;

b_s = shear lag width, as shown in Fig. 6;

L_c = length of the end connection, that is the distance between the outermost bolts in the end joint measured along the load direction or length of the weld along the load direction;

t = thickness of the leg; and

w = outstand leg width.

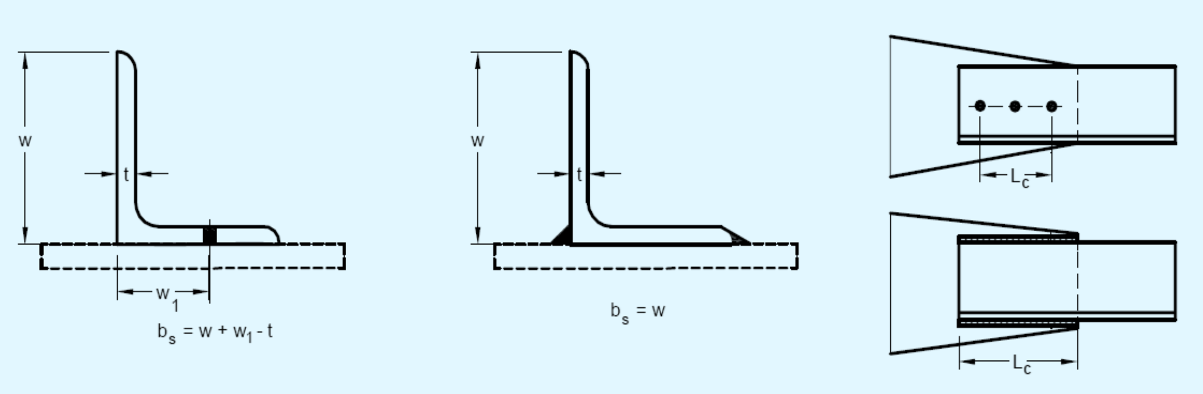


FIG. 6 ANGLES WITH SINGLE LEG CONNECTIONS

13.3.4 *Other Section*

The rupture strength, T_{dn}, of the double angles, channels, I-sections and other rolled steel sections, connected by one or more elements to an end gusset is also governed by shear lag effects. The design tensile strength of such sections as governed by tearing of net section may also be calculated using equation in **13.3.3**, where β is calculated based on the shear lag distance, b_s, taken from the farthest edge of the outstanding leg to the nearest bolt/weld line in the connected leg of the cross section.

13.4 Design Strength Due to Block Shear

The strength as governed by block shear at an end connection of plates and angles is calculated as given in **13.4.1**.

13.4.1 *Bolted Connections*

The block shear strength, T_{db} of connection shall be taken as the smaller of,

$$T_{db} = \left[A_{vg}\, f_y/(\sqrt{3}\,\gamma_{m0}) + 0.9 A_{tn}\, f_u/\gamma_{m1} \right]$$

or

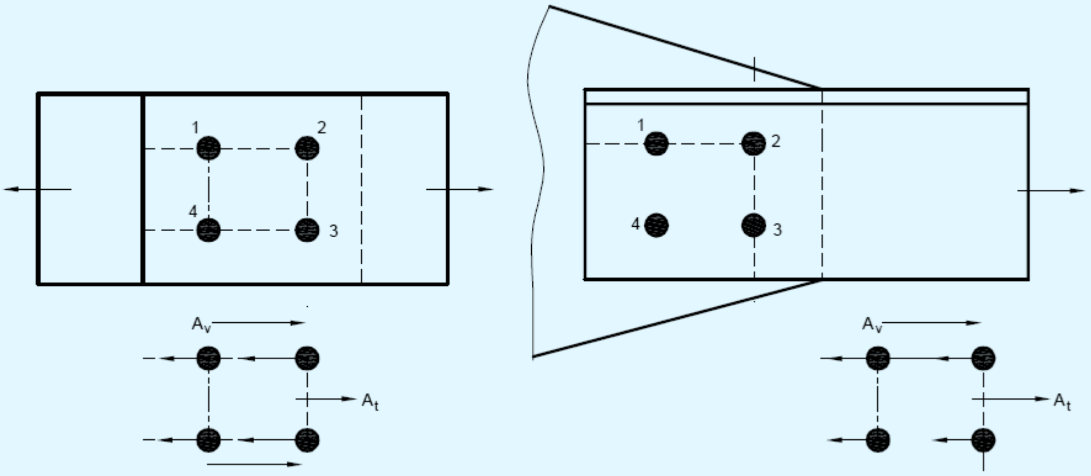
$$T_{db} = \left[0.9 A_{vn}\, f_u/(\sqrt{3}\,\gamma_{m1}) + A_{tg}\, f_y/\gamma_{m0} \right]$$

where

A_{tg}, A_{tn} = minimum gross and net area in tension from the bolt hole to the toe of the angle, end bolt line, perpendicular to the line of force, respectively (2-3 as shown in Fig. 7(B);

A_{vg}, A_{vn} = minimum gross and net area in shear along bolt line parallel to external force, respectively (1-2 and 3-4 as shown in Fig. 7(A) and 1-2 as shown in Fig. 7(B); and

f_u, f_y = ultimate and yield stress of the material, respectively.



7A PLATE

7B ANGLE

FIG. 7 BLOCK SHEAR FAILURE

13.4.2 *Welded Connection*

The block shear strength, T_{db} shall be checked for welded end connections by taking an appropriate section in the member around the end weld, which can shear off as a block.

14 DESIGN OF COMPRESSION MEMBERS

14.1 Design Strength

14.1.1 Common hot rolled and built-up steel members used for carrying axial compression, usually fail by flexural buckling. The buckling strength of these members is affected by residual stresses, initial bow and accidental eccentricities of load. To account for all these factors, the strength of members subjected to axial compression is defined by buckling class a_0, a, b, c, or d as given Table 7.

14.1.2 The factored design compression, P in members shall satisfy the following requirement:

$$P < P_d$$

$$P_d = A_e f_{cd}$$

where

P_d = design strength of the member

A_e = effective sectional area as defined in **14.3.2**; and

f_{cd} = design compressive stress, given by.

$$f_{\mathrm{cd}} = \frac{\chi f_y}{\gamma_{\mathrm{m0}}} \leq f_y / \gamma_{\mathrm{m0}}$$

χ = stress reduction factor for different buckling class, slenderness ratio and yield stress and mode of buckling as given in **14.1.2.1** or **14.1.2.2**, as applicable (*see* Table 8); and

γ_{m0} = partial safety factor for material strength.

NOTE — Calculated values of design compressive stress, f_{cd} for different buckling classes are given in Table 9.

14.1.2.1 *Reduction factor for flexural buckling* (*See also* Table 8)

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 + \lambda^2}}$$

$\phi = 0.5[1 + \alpha(\lambda - 0.2) + \lambda^2]$

λ = non-dimensional effective slenderness ratio:

$$= \sqrt{f_y / f_{\mathrm{cr}}} = \sqrt{f_{\mathrm{y}} \left(\frac{KL}{r}\right)^2 / \pi^2 E}$$

f_{cr} = Euler buckling stress about the relevant axis $= \dfrac{\pi^2 E}{(KL/r)^2}$

where

KL/r = effective slenderness ratio or ratio of effective length, KL to appropriate radius of gyration, r; and

α = imperfection factor given in Table 7.

14.1.2.2 *Reduction factor for torsional and torsional flexural buckling*

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 + \lambda_{\mathrm{TF}}^2}}$$

$$\phi = 0.5\left[1 + \left(\frac{\lambda_{\mathrm{TF}}}{\lambda_{\mathrm{y}}}\right)^2 . \alpha_{\mathrm{TF}}\left(\lambda_{\mathrm{y}} - 0.2\right) + \lambda_{\mathrm{TF}}^2\right]$$

$$\alpha_{\mathrm{TF}} = \alpha \sqrt{\frac{A\, f_{\mathrm{y}}(i_{\mathrm{p}}^2 + d_{\mathrm{y}}^2)}{6.25\, G\, I_{\mathrm{T}}}}$$

$$\lambda_{\mathrm{TF}} = \sqrt{f_y / f_{\mathrm{crTF}}}$$

$$\lambda_{\mathrm{Y}} = \sqrt{f_y / f_{\mathrm{cr,y}}}$$

where

α = is the imperfection factor given in Table 7;

d_y = is the distance between intermediate lateral support and shear centre at the section;

i_p = is the polar radius of gyration given by;

i_{p}^2 = $(I_{\mathrm{y}} + I_z)/A$;

I_{T} = is the torsional constant of the cross section;

I_y, I_z = is the moment of inertia about y and z axis, respectively and shear centre;

λ_{TF} = non-dimensional effective slenderness ratio; and

λ_y = non-dimensional effective slenderness ratio.

f_{cry} = flexural buckling stress about the y axis ; and

f_{crTF} = torsional flexural buckling stress at the extreme compression fibre (Annex E).

14.1.2.3 The classification of different sections under different buckling class a_0, a, b, c or d, is given in Table 10. The stress reduction factor χ, and the design compressive stress f_{cd}, for different buckling class, yield stress, and effective slenderness ratio is given in Table 8 and Table 9 for convenience. The curves corresponding to different buckling class are presented in non-dimensional form, in Fig. 8.

Table 7 Imperfection Factor, α

(*Clauses* 14.1.1, 14.1.2.1 *and* 14.1.2.2)

Sl No.	Buckling Class	a_0	a	b	c	d
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	α	0.13	0.21	0.34	0.49	0.76

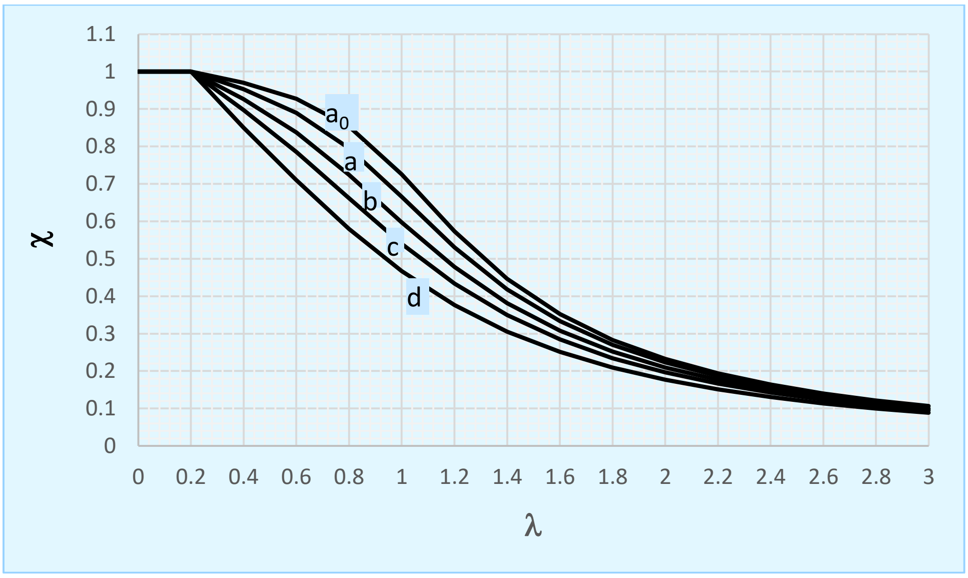


FIG. 8 COLUMN BUCKLING CURVES

14.2 Effective Length of Compression Members

14.2.1 The effective length *KL,* is calculated from the actual length *L*, of the member, considering the rotational and relative translational boundary conditions at the ends. The actual length shall be taken as the length from centre to centre of its intersections with the supporting members in the plane of the buckling deformation. In the case of a member with a free end, the free standing length from the centre of the intersecting member at the supported end, shall be taken as the actual length.

14.2.2 *Effective Length*

Where the boundary conditions in the plane of buckling can be assessed, the effective length, *KL* can be calculated on the basis of Table 11. Where frame analysis does not consider the equilibrium of a framed structure in the deformed shape (second-order analysis or advanced analysis), the effective length of compression members in such cases can be calculated using the procedure given in **D-1**. The effective length of stepped column in single storey buildings can be calculated using the procedure given in **D-2**.

14.2.3 *Eccentric Beam Connection*

In cases where the beam connections are eccentric in plan with respect to the axes of the column, the same conditions of restraint as in concentric connection shall be deemed to apply, provided the connections are carried across the flange or web of the columns as the case may be, and the web of the beam lies within, or in direct contact with the column section. Where practical difficulties prevent this, the effective length shall be taken as equal to the distance between points of restraint in non-sway frames.

14.2.4 *Compression Members in Trusses*

In the case of bolted, riveted or welded trusses and braced frames, the effective length, KL, of the compression members shall be taken as 0.7 to 1.0 times the distance between centres of connections, depending on the degree of end restraint provided. In the case of members of trusses buckling in the plane perpendicular to the plane of the truss, the effective length, KL shall be taken as the distance between the centres of intersection. The design of angle struts shall be as specified in **14.5**.

14.3 Design Details

14.3.1 *Thickness of Plate Elements*

Classification of members on the basis of the thickness of constituent plate elements shall satisfy the width-thickness ratio requirements specified in Table 2.

14.3.2 *Effective Sectional Area, A_e*

Except as modified in **10.8.2** (Class 4), the gross sectional area shall be taken as the effective sectional area for all compression members fabricated by welding, bolting and riveting so long as the section is semi-compact or better. Holes not fitted with rivets, bolts or pins shall be deducted from gross area to calculate effective sectional area.

14.3.3 *Eccentricity for Stanchions and Columns*

14.3.3.1 For the purpose of determining the stress in a stanchion or column section, the beam reactions or similar loads shall be assumed to be applied at an eccentricity of 100 mm from the face of the section or at the centre of bearing whichever dimension gives the greater eccentricity, and with the exception of the following two cases:

a) In the case of cap connection, the load shall be assumed to be applied at the face of the column or stanchion section or at the edge of packing, if used towards the span of the beam; and

b) In the case of a roof truss bearing on a cap, no eccentricity be taken for simple bearings without connections capable of developing any appreciable moment. In case of web member connection with face, actual eccentricity is to be considered.

Table 8(A) Stress Reduction Factor, χ for Flexural Column Buckling Class, a_0

(*Clauses* 14.1.2.1 *and* 14.1.2.3)

KL/r	**Yield Stress, f_y** (MPa)																		
↓	200	210	220	230	240	250	260	280	300	320	340	360	380	400	420	450	480	510	540
10	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
20	1.000	0.999	0.998	0.998	0.997	0.997	0.996	0.995	0.994	0.992	0.991	0.990	0.989	0.988	0.987	0.986	0.984	0.983	0.981
30	0.986	0.985	0.983	0.982	0.981	0.980	0.979	0.977	0.975	0.973	0.971	0.969	0.967	0.965	0.964	0.961	0.958	0.955	0.952
40	0.970	0.968	0.966	0.965	0.963	0.961	0.960	0.956	0.953	0.949	0.946	0.943	0.939	0.936	0.932	0.927	0.921	0.915	0.909
50	0.951	0.948	0.945	0.943	0.940	0.937	0.934	0.929	0.923	0.917	0.911	0.905	0.899	0.892	0.885	0.874	0.863	0.852	0.840
60	0.927	0.922	0.918	0.914	0.909	0.905	0.900	0.891	0.881	0.870	0.860	0.848	0.837	0.824	0.812	0.792	0.772	0.752	0.731
70	0.895	0.888	0.881	0.874	0.867	0.859	0.852	0.836	0.819	0.802	0.784	0.766	0.747	0.728	0.710	0.682	0.655	0.629	0.605
80	0.851	0.841	0.830	0.819	0.808	0.796	0.784	0.760	0.736	0.712	0.687	0.664	0.641	0.619	0.598	0.568	0.540	0.515	0.491
90	0.792	0.777	0.762	0.747	0.731	0.716	0.701	0.670	0.641	0.614	0.587	0.563	0.539	0.518	0.498	0.470	0.445	0.422	0.401
100	0.721	0.702	0.683	0.665	0.647	0.629	0.612	0.580	0.550	0.523	0.498	0.475	0.453	0.434	0.416	0.391	0.369	0.349	0.332
110	0.643	0.622	0.602	0.583	0.564	0.547	0.530	0.499	0.471	0.446	0.423	0.403	0.384	0.366	0.350	0.329	0.310	0.293	0.278
120	0.568	0.547	0.527	0.509	0.491	0.475	0.459	0.431	0.405	0.383	0.363	0.344	0.328	0.312	0.299	0.280	0.264	0.249	0.236
130	0.500	0.480	0.462	0.445	0.429	0.414	0.399	0.374	0.351	0.331	0.313	0.297	0.282	0.269	0.257	0.241	0.227	0.214	0.203
140	0.441	0.423	0.406	0.390	0.376	0.362	0.350	0.327	0.307	0.289	0.273	0.259	0.246	0.234	0.223	0.209	0.197	0.186	0.176
150	0.391	0.374	0.359	0.345	0.332	0.319	0.308	0.288	0.270	0.254	0.240	0.227	0.216	0.205	0.196	0.183	0.172	0.163	0.154
160	0.348	0.333	0.319	0.306	0.294	0.283	0.273	0.255	0.239	0.225	0.212	0.201	0.191	0.181	0.173	0.162	0.152	0.144	0.136
170	0.311	0.298	0.285	0.273	0.263	0.253	0.244	0.227	0.213	0.200	0.189	0.179	0.170	0.161	0.154	0.144	0.135	0.128	0.121
180	0.280	0.268	0.256	0.246	0.236	0.227	0.219	0.204	0.191	0.179	0.169	0.160	0.152	0.145	0.138	0.129	0.121	0.114	0.108
190	0.253	0.242	0.231	0.222	0.213	0.205	0.197	0.184	0.172	0.162	0.152	0.144	0.137	0.130	0.124	0.116	0.109	0.103	0.097
200	0.230	0.219	0.210	0.201	0.193	0.186	0.179	0.166	0.156	0.146	0.138	0.131	0.124	0.118	0.112	0.105	0.099	0.093	0.088
210	0.209	0.200	0.191	0.183	0.176	0.169	0.163	0.151	0.142	0.133	0.125	0.119	0.113	0.107	0.102	0.095	0.090	0.084	0.080
220	0.191	0.183	0.175	0.167	0.161	0.154	0.149	0.138	0.129	0.122	0.115	0.108	0.103	0.098	0.093	0.087	0.082	0.077	0.073
230	0.176	0.168	0.160	0.154	0.147	0.142	0.136	0.127	0.119	0.112	0.105	0.099	0.094	0.090	0.086	0.080	0.075	0.071	0.067
240	0.162	0.155	0.148	0.141	0.136	0.131	0.126	0.117	0.109	0.103	0.097	0.091	0.087	0.083	0.079	0.074	0.069	0.065	0.061
250	0.150	0.143	0.136	0.131	0.125	0.121	0.116	0.108	0.101	0.095	0.089	0.084	0.080	0.076	0.073	0.068	0.064	0.060	0.057

Table 8(B) Stress Reduction Factor, χ for Flexural Column Buckling Class a

(*Clauses* 14.1.2.1 *and* 14.1.2.3)

KL/*r* ↓	**Yield Stress, f_y** (MPa)																		
	200	210	220	230	240	250	260	280	300	320	340	360	380	400	420	450	480	510	540
10	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
20	1.000	0.999	0.998	0.997	0.995	0.994	0.993	0.993	0.990	0.988	0.986	0.984	0.983	0.981	0.979	0.977	0.975	0.972	0.970
30	0.977	0.975	0.974	0.972	0.970	0.969	0.967	0.965	0.961	0.957	0.954	0.951	0.948	0.946	0.943	0.938	0.934	0.930	0.925
40	0.952	0.949	0.947	0.944	0.942	0.939	0.937	0.934	0.926	0.921	0.916	0.911	0.906	0.901	0.896	0.888	0.881	0.873	0.865
50	0.923	0.919	0.915	0.911	0.908	0.904	0.900	0.896	0.884	0.876	0.867	0.859	0.851	0.842	0.834	0.820	0.807	0.794	0.780
60	0.888	0.883	0.877	0.871	0.865	0.859	0.853	0.847	0.828	0.816	0.803	0.790	0.777	0.763	0.750	0.730	0.710	0.690	0.671
70	0.846	0.837	0.829	0.820	0.811	0.803	0.794	0.785	0.758	0.740	0.722	0.703	0.686	0.668	0.651	0.626	0.602	0.579	0.557
80	0.793	0.781	0.769	0.757	0.746	0.734	0.722	0.710	0.675	0.653	0.631	0.610	0.589	0.570	0.551	0.525	0.501	0.478	0.458
90	0.730	0.715	0.700	0.685	0.671	0.657	0.643	0.628	0.590	0.565	0.542	0.520	0.500	0.481	0.463	0.439	0.416	0.396	0.377
100	0.661	0.644	0.627	0.610	0.594	0.579	0.564	0.549	0.510	0.486	0.463	0.443	0.424	0.407	0.390	0.368	0.348	0.331	0.314
110	0.591	0.573	0.555	0.538	0.522	0.507	0.492	0.478	0.440	0.418	0.397	0.379	0.362	0.346	0.332	0.312	0.295	0.279	0.265
120	0.525	0.507	0.489	0.473	0.458	0.443	0.429	0.416	0.381	0.361	0.343	0.326	0.311	0.297	0.284	0.267	0.252	0.238	0.226
130	0.466	0.448	0.432	0.416	0.402	0.388	0.376	0.364	0.332	0.314	0.298	0.283	0.269	0.257	0.246	0.231	0.217	0.206	0.195
140	0.413	0.397	0.382	0.368	0.355	0.342	0.331	0.320	0.291	0.275	0.260	0.247	0.235	0.224	0.214	0.201	0.189	0.179	0.170
150	0.368	0.353	0.339	0.326	0.314	0.303	0.293	0.283	0.257	0.243	0.229	0.218	0.207	0.197	0.189	0.177	0.166	0.157	0.149
160	0.329	0.316	0.303	0.291	0.280	0.270	0.261	0.252	0.229	0.215	0.204	0.193	0.184	0.175	0.167	0.157	0.147	0.139	0.132
170	0.296	0.283	0.272	0.261	0.251	0.242	0.233	0.225	0.204	0.192	0.182	0.172	0.164	0.156	0.149	0.140	0.131	0.124	0.117
180	0.267	0.255	0.245	0.235	0.226	0.218	0.210	0.203	0.184	0.173	0.163	0.155	0.147	0.140	0.134	0.125	0.118	0.111	0.105
190	0.242	0.231	0.222	0.213	0.205	0.197	0.190	0.183	0.166	0.156	0.147	0.140	0.133	0.126	0.121	0.113	0.106	0.100	0.095
200	0.220	0.210	0.202	0.193	0.186	0.179	0.172	0.166	0.151	0.142	0.134	0.127	0.120	0.115	0.109	0.102	0.096	0.091	0.086
210	0.201	0.192	0.184	0.177	0.170	0.163	0.157	0.152	0.137	0.129	0.122	0.115	0.110	0.104	0.099	0.093	0.087	0.083	0.078
220	0.184	0.176	0.169	0.162	0.155	0.149	0.144	0.139	0.126	0.118	0.111	0.106	0.100	0.095	0.091	0.085	0.080	0.075	0.071
230	0.170	0.162	0.155	0.149	0.143	0.137	0.132	0.128	0.115	0.108	0.102	0.097	0.092	0.088	0.083	0.078	0.073	0.069	0.065
240	0.157	0.149	0.143	0.137	0.132	0.127	0.122	0.118	0.106	0.100	0.094	0.089	0.085	0.081	0.077	0.072	0.068	0.064	0.060
250	0.145	0.138	0.132	0.127	0.122	0.117	0.113	0.109	0.098	0.092	0.087	0.082	0.078	0.074	0.071	0.066	0.062	0.059	0.056

Table 8(C) Stress Reduction Factor, χ for Flexural Column Buckling Class b

(*Clauses* 14.1.2.1 *and* 14.1.2.3)

***KL*/r** ↓	**Yield Stress, f_y (MPa)**																		
	200	210	220	230	240	250	260	280	300	320	340	360	380	400	420	450	480	510	540
10	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
20	1.000	0.998	0.996	0.994	0.993	0.991	0.990	0.986	0.983	0.981	0.978	0.975	0.972	0.970	0.967	0.963	0.960	0.956	0.953
30	0.963	0.961	0.958	0.955	0.953	0.950	0.948	0.943	0.938	0.933	0.929	0.924	0.920	0.915	0.911	0.904	0.898	0.892	0.886
40	0.925	0.921	0.917	0.913	0.909	0.906	0.902	0.895	0.887	0.880	0.873	0.866	0.859	0.852	0.845	0.835	0.825	0.815	0.805
50	0.883	0.877	0.872	0.866	0.861	0.855	0.850	0.839	0.829	0.818	0.808	0.798	0.787	0.777	0.767	0.752	0.737	0.722	0.708
60	0.835	0.827	0.820	0.812	0.805	0.798	0.790	0.775	0.761	0.746	0.732	0.718	0.704	0.691	0.677	0.657	0.638	0.620	0.602
70	0.781	0.771	0.761	0.751	0.742	0.732	0.722	0.703	0.685	0.667	0.649	0.632	0.615	0.599	0.584	0.561	0.540	0.520	0.502
80	0.721	0.709	0.697	0.685	0.673	0.661	0.650	0.627	0.606	0.585	0.566	0.547	0.529	0.512	0.496	0.474	0.453	0.434	0.416
90	0.657	0.643	0.629	0.615	0.602	0.589	0.576	0.552	0.530	0.508	0.488	0.470	0.452	0.436	0.421	0.400	0.380	0.363	0.346
100	0.593	0.577	0.562	0.548	0.534	0.520	0.507	0.483	0.461	0.440	0.421	0.403	0.387	0.372	0.358	0.339	0.321	0.306	0.291
110	0.531	0.515	0.500	0.485	0.471	0.458	0.445	0.422	0.401	0.381	0.364	0.348	0.333	0.319	0.306	0.289	0.274	0.260	0.247
120	0.474	0.458	0.443	0.429	0.416	0.403	0.391	0.370	0.350	0.332	0.316	0.301	0.288	0.276	0.265	0.249	0.236	0.223	0.212
130	0.423	0.408	0.394	0.380	0.368	0.356	0.345	0.325	0.307	0.291	0.276	0.263	0.251	0.240	0.230	0.217	0.204	0.194	0.184
140	0.378	0.364	0.350	0.338	0.327	0.316	0.306	0.287	0.271	0.256	0.243	0.231	0.221	0.211	0.202	0.190	0.179	0.169	0.161
150	0.339	0.325	0.313	0.302	0.291	0.281	0.272	0.255	0.241	0.227	0.215	0.205	0.195	0.186	0.178	0.167	0.158	0.149	0.142
160	0.305	0.292	0.281	0.271	0.261	0.252	0.243	0.228	0.215	0.203	0.192	0.182	0.174	0.166	0.158	0.149	0.140	0.133	0.126
170	0.275	0.264	0.253	0.244	0.235	0.227	0.219	0.205	0.193	0.182	0.172	0.163	0.155	0.148	0.142	0.133	0.125	0.118	0.112
180	0.249	0.239	0.229	0.220	0.212	0.205	0.198	0.185	0.174	0.164	0.155	0.147	0.140	0.133	0.128	0.120	0.113	0.106	0.101
190	0.227	0.217	0.208	0.200	0.193	0.186	0.179	0.168	0.157	0.148	0.140	0.133	0.127	0.121	0.115	0.108	0.102	0.096	0.091
200	0.207	0.198	0.190	0.183	0.176	0.169	0.163	0.153	0.143	0.135	0.128	0.121	0.115	0.110	0.105	0.098	0.092	0.087	0.083
210	0.190	0.182	0.174	0.167	0.161	0.155	0.149	0.140	0.131	0.123	0.117	0.110	0.105	0.100	0.096	0.090	0.084	0.080	0.075
220	0.174	0.167	0.160	0.154	0.148	0.142	0.137	0.128	0.120	0.113	0.107	0.101	0.096	0.092	0.088	0.082	0.077	0.073	0.069
230	0.161	0.154	0.147	0.141	0.136	0.131	0.126	0.118	0.111	0.104	0.098	0.093	0.088	0.084	0.080	0.075	0.071	0.067	0.063
240	0.149	0.142	0.136	0.131	0.126	0.121	0.117	0.109	0.102	0.096	0.091	0.086	0.082	0.078	0.074	0.070	0.065	0.062	0.058
250	0.138	0.132	0.126	0.121	0.117	0.112	0.108	0.101	0.095	0.089	0.084	0.080	0.076	0.072	0.069	0.064	0.060	0.057	0.054

Table 8(D) Stress Reduction Factor, χ for Column Flexural Buckling Class c

(*Clauses* 14.1.2.1 *and* 14.1.2.3)

***KL*/r** ↓	**Yield Stress, f_y** (MPa)																		
	200	210	220	230	240	250	260	280	300	320	340	360	380	400	420	450	480	510	540
10	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
20	0.999	0.997	0.994	0.992	0.990	0.987	0.985	0.981	0.976	0.972	0.968	0.964	0.961	0.957	0.953	0.948	0.943	0.938	0.933
30	0.948	0.944	0.941	0.937	0.933	0.930	0.926	0.920	0.913	0.907	0.901	0.895	0.889	0.883	0.877	0.869	0.861	0.853	0.845
40	0.896	0.891	0.885	0.880	0.875	0.870	0.866	0.856	0.847	0.838	0.829	0.820	0.812	0.803	0.795	0.783	0.771	0.760	0.748
50	0.841	0.834	0.827	0.821	0.814	0.807	0.801	0.788	0.776	0.763	0.752	0.740	0.729	0.717	0.706	0.690	0.675	0.660	0.645
60	0.783	0.774	0.765	0.757	0.748	0.740	0.732	0.716	0.700	0.685	0.670	0.656	0.642	0.628	0.615	0.596	0.578	0.561	0.544
70	0.722	0.711	0.700	0.690	0.680	0.670	0.660	0.641	0.623	0.605	0.588	0.572	0.557	0.542	0.528	0.508	0.489	0.471	0.454
80	0.659	0.646	0.634	0.622	0.611	0.600	0.589	0.568	0.548	0.529	0.512	0.495	0.479	0.464	0.450	0.430	0.412	0.395	0.379
90	0.596	0.583	0.569	0.557	0.544	0.533	0.521	0.499	0.479	0.460	0.443	0.426	0.411	0.397	0.383	0.365	0.348	0.332	0.318
100	0.536	0.522	0.508	0.495	0.483	0.471	0.459	0.438	0.418	0.400	0.384	0.368	0.354	0.341	0.328	0.311	0.296	0.282	0.269
110	0.480	0.466	0.453	0.440	0.428	0.416	0.405	0.385	0.366	0.349	0.333	0.319	0.306	0.294	0.283	0.268	0.254	0.242	0.230
120	0.430	0.416	0.403	0.391	0.379	0.368	0.358	0.339	0.321	0.306	0.291	0.278	0.267	0.256	0.246	0.232	0.220	0.209	0.199
130	0.385	0.372	0.360	0.348	0.337	0.327	0.317	0.299	0.283	0.269	0.256	0.244	0.234	0.224	0.215	0.203	0.192	0.182	0.173
140	0.346	0.333	0.322	0.311	0.301	0.291	0.282	0.266	0.251	0.238	0.227	0.216	0.206	0.197	0.189	0.178	0.168	0.160	0.152
150	0.311	0.300	0.289	0.279	0.269	0.261	0.252	0.237	0.224	0.212	0.202	0.192	0.183	0.175	0.168	0.158	0.149	0.141	0.134
160	0.281	0.270	0.260	0.251	0.242	0.234	0.227	0.213	0.201	0.190	0.180	0.172	0.164	0.156	0.150	0.141	0.133	0.126	0.120
170	0.255	0.245	0.236	0.227	0.219	0.212	0.205	0.192	0.181	0.171	0.162	0.154	0.147	0.140	0.134	0.126	0.119	0.113	0.107
180	0.232	0.223	0.214	0.206	0.199	0.192	0.186	0.174	0.164	0.155	0.147	0.139	0.133	0.127	0.121	0.114	0.107	0.102	0.096
190	0.212	0.203	0.195	0.188	0.181	0.175	0.169	0.158	0.149	0.140	0.133	0.126	0.120	0.115	0.110	0.103	0.097	0.092	0.087
200	0.194	0.186	0.179	0.172	0.166	0.160	0.154	0.144	0.136	0.128	0.121	0.115	0.110	0.105	0.100	0.094	0.089	0.084	0.079
210	0.178	0.171	0.164	0.158	0.152	0.146	0.141	0.132	0.124	0.117	0.111	0.105	0.100	0.096	0.092	0.086	0.081	0.076	0.072
220	0.164	0.157	0.151	0.145	0.140	0.135	0.130	0.122	0.114	0.108	0.102	0.097	0.092	0.088	0.084	0.079	0.074	0.070	0.066
230	0.152	0.145	0.140	0.134	0.129	0.124	0.120	0.112	0.105	0.099	0.094	0.089	0.085	0.081	0.077	0.073	0.068	0.065	0.061
240	0.141	0.135	0.129	0.124	0.120	0.115	0.111	0.104	0.098	0.092	0.087	0.082	0.078	0.075	0.071	0.067	0.063	0.060	0.056
250	0.131	0.125	0.120	0.115	0.111	0.107	0.103	0.096	0.090	0.085	0.081	0.076	0.073	0.069	0.066	0.062	0.058	0.055	0.052

Table 8(E) Stress Reduction Factor, χ for Flexural Column Buckling Class d

(*Clauses* 14.1.2.1 *and* 14.1.2.3)

KL/r ↓	**Yield Stress, fy** (MPa)																		
	200	210	220	230	240	250	260	280	300	320	340	360	380	400	420	450	480	510	540
10	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
20	0.999	0.995	0.991	0.988	0.984	0.980	0.977	0.970	0.964	0.958	0.952	0.946	0.940	0.935	0.930	0.922	0.915	0.908	0.901
30	0.922	0.916	0.911	0.906	0.901	0.896	0.891	0.881	0.872	0.863	0.855	0.847	0.839	0.831	0.823	0.813	0.802	0.792	0.782
40	0.848	0.841	0.834	0.828	0.821	0.815	0.808	0.796	0.784	0.773	0.762	0.751	0.741	0.731	0.721	0.707	0.694	0.681	0.668
50	0.777	0.768	0.760	0.752	0.744	0.736	0.728	0.713	0.699	0.685	0.672	0.659	0.647	0.635	0.624	0.608	0.592	0.577	0.563
60	0.707	0.697	0.687	0.678	0.668	0.659	0.651	0.634	0.617	0.602	0.587	0.573	0.560	0.547	0.535	0.517	0.501	0.486	0.471
70	0.640	0.629	0.618	0.607	0.597	0.587	0.578	0.559	0.542	0.526	0.510	0.496	0.482	0.469	0.456	0.439	0.423	0.408	0.394
80	0.576	0.564	0.553	0.542	0.531	0.521	0.511	0.492	0.474	0.458	0.442	0.428	0.414	0.402	0.390	0.373	0.358	0.344	0.330
90	0.517	0.505	0.493	0.482	0.471	0.461	0.451	0.432	0.415	0.399	0.384	0.370	0.357	0.345	0.334	0.319	0.304	0.292	0.280
100	0.464	0.451	0.440	0.428	0.418	0.408	0.398	0.380	0.363	0.348	0.334	0.321	0.309	0.298	0.288	0.274	0.261	0.249	0.239
110	0.416	0.404	0.392	0.381	0.371	0.361	0.352	0.335	0.319	0.305	0.292	0.281	0.270	0.259	0.250	0.237	0.226	0.215	0.206
120	0.373	0.361	0.350	0.340	0.330	0.321	0.313	0.297	0.282	0.269	0.257	0.246	0.236	0.227	0.219	0.207	0.197	0.187	0.179
130	0.336	0.325	0.314	0.305	0.295	0.287	0.279	0.264	0.251	0.239	0.228	0.218	0.209	0.200	0.193	0.182	0.173	0.164	0.157
140	0.303	0.292	0.283	0.274	0.265	0.257	0.250	0.236	0.224	0.213	0.203	0.194	0.185	0.178	0.171	0.161	0.153	0.145	0.138
150	0.274	0.264	0.255	0.247	0.239	0.231	0.224	0.212	0.201	0.190	0.181	0.173	0.165	0.159	0.152	0.144	0.136	0.129	0.123
160	0.249	0.240	0.231	0.223	0.216	0.209	0.203	0.191	0.181	0.171	0.163	0.155	0.149	0.142	0.137	0.129	0.122	0.116	0.110
170	0.227	0.218	0.210	0.203	0.196	0.190	0.184	0.173	0.164	0.155	0.147	0.140	0.134	0.128	0.123	0.116	0.110	0.104	0.099
180	0.207	0.199	0.192	0.185	0.179	0.173	0.167	0.157	0.149	0.141	0.134	0.127	0.122	0.116	0.111	0.105	0.099	0.094	0.089
190	0.190	0.183	0.176	0.169	0.164	0.158	0.153	0.144	0.136	0.128	0.122	0.116	0.111	0.106	0.101	0.095	0.090	0.085	0.081
200	0.175	0.168	0.162	0.156	0.150	0.145	0.140	0.132	0.124	0.118	0.112	0.106	0.101	0.097	0.093	0.087	0.082	0.078	0.074
210	0.161	0.155	0.149	0.143	0.138	0.134	0.129	0.121	0.114	0.108	0.102	0.097	0.093	0.089	0.085	0.080	0.075	0.071	0.068
220	0.149	0.143	0.138	0.133	0.128	0.123	0.119	0.112	0.105	0.100	0.094	0.090	0.086	0.082	0.078	0.074	0.069	0.066	0.062
230	0.138	0.133	0.128	0.123	0.118	0.114	0.110	0.104	0.097	0.092	0.087	0.083	0.079	0.075	0.072	0.068	0.064	0.061	0.058
240	0.129	0.123	0.119	0.114	0.110	0.106	0.103	0.096	0.090	0.085	0.081	0.077	0.073	0.070	0.067	0.063	0.059	0.056	0.053
250	0.120	0.115	0.110	0.106	0.102	0.099	0.095	0.089	0.084	0.079	0.075	0.071	0.068	0.065	0.062	0.058	0.055	0.052	0.049

Table 9(A) Design Compressive Stress, f_{cd} (MPa) For Column Flexural Buckling Class a_0

(*Clauses* 14.1.2 *and* 14.1.2.3)

***KL*/r** ↓	**Yield Stress, f_y** (MPa)																		
	200	210	220	230	240	250	260	280	300	320	340	360	380	400	420	450	480	510	540
10	182	191	200	209	218	227	236	255	273	291	309	327	345	364	382	409	436	464	491
20	182	191	200	209	218	226	235	253	271	289	306	324	342	359	377	403	429	456	482
30	179	188	197	205	214	223	231	249	266	283	300	317	334	351	368	393	418	443	467
40	176	185	193	202	210	218	227	243	260	276	292	308	324	340	356	379	402	424	446
50	173	181	189	197	205	213	221	236	252	267	282	296	310	324	338	358	377	395	412
60	168	176	184	191	198	206	213	227	240	253	266	278	289	300	310	324	337	349	359
70	163	170	176	183	189	195	201	213	223	233	242	251	258	265	271	279	286	292	297
80	155	160	166	171	176	181	185	194	201	207	212	217	221	225	228	232	236	239	241
90	144	148	152	156	160	163	166	171	175	178	182	184	186	188	190	192	194	196	197
100	131	134	137	139	141	143	145	148	150	152	154	155	157	158	159	160	161	162	163
110	117	119	120	122	123	124	125	127	129	130	131	132	133	133	134	135	135	136	136
120	103	104	105	106	107	108	109	110	111	111	112	113	113	114	114	115	115	115	116
130	91.0	91.7	92.4	93.0	93.5	94.0	94.4	95.2	95.8	96.3	96.8	97.2	97.6	97.9	98.2	98.6	98.9	99.2	99.4
140	80.3	80.8	81.2	81.6	82.0	82.3	82.6	83.2	83.6	84.0	84.3	84.6	84.9	85.1	85.3	85.6	85.9	86.1	86.3
150	71.1	71.5	71.8	72.1	72.3	72.6	72.8	73.2	73.5	73.8	74.0	74.3	74.5	74.6	74.8	75.0	75.2	75.4	75.5
160	63.3	63.6	63.8	64.0	64.2	64.4	64.6	64.8	65.1	65.3	65.5	65.7	65.8	66.0	66.1	66.3	66.4	66.5	66.7
170	56.6	56.8	57.0	57.2	57.3	57.5	57.6	57.8	58.0	58.2	58.3	58.5	58.6	58.7	58.8	58.9	59.1	59.2	59.3
180	50.9	51.1	51.2	51.3	51.5	51.6	51.7	51.9	52.0	52.1	52.3	52.4	52.5	52.6	52.6	52.7	52.8	52.9	53.0
190	46.0	46.1	46.2	46.3	46.4	46.5	46.6	46.8	46.9	47.0	47.1	47.2	47.3	47.3	47.4	47.5	47.6	47.6	47.7
200	41.7	41.9	41.9	42.0	42.1	42.2	42.2	42.4	42.5	42.6	42.6	42.7	42.8	42.8	42.9	43.0	43.0	43.1	43.2
210	38.0	38.1	38.2	38.3	38.3	38.4	38.5	38.6	38.6	38.7	38.8	38.8	38.9	39.0	39.0	39.1	39.1	39.2	39.2
220	34.8	34.9	34.9	35.0	35.1	35.1	35.2	35.2	35.3	35.4	35.4	35.5	35.5	35.6	35.6	35.7	35.7	35.8	35.8
230	32.0	32.0	32.1	32.1	32.2	32.2	32.3	32.3	32.4	32.4	32.5	32.5	32.6	32.6	32.7	32.7	32.7	32.8	32.8
240	29.4	29.5	29.5	29.6	29.6	29.7	29.7	29.8	29.8	29.9	29.9	29.9	30.0	30.0	30.0	30.1	30.1	30.2	30.2
250	27.2	27.3	27.3	27.3	27.4	27.4	27.4	27.5	27.5	27.6	27.6	27.6	27.7	27.7	27.7	27.8	27.8	27.8	27.9

Table 9(B) Design Compressive Stress, f_{cd} (MPa) For Column Flexural Buckling Class a

(*Clauses* 14.1.2 *and* 14.1.2.3)

KL/r ↓	Yield Stress, f_y (MPa)																		
	200	210	220	230	240	250	260	280	300	320	340	360	380	400	420	450	480	510	540
10	182	191	200	213	218	227	236	255	273	291	309	327	345	364	382	409	436	464	491
20	182	191	200	208	217	226	235	252	270	287	305	322	339	357	374	400	425	451	476
30	178	186	195	203	212	220	229	245	262	279	295	311	328	344	360	384	408	431	454
40	173	181	189	197	205	213	221	237	253	268	283	298	313	328	342	363	384	405	425
50	168	176	183	191	198	205	213	227	241	255	268	281	294	306	318	336	352	368	383
60	162	169	175	182	189	195	202	214	226	237	248	258	268	278	286	299	310	320	329
70	154	160	166	171	177	182	188	197	207	215	223	230	237	243	249	256	263	268	274
80	144	149	154	158	163	167	171	178	184	190	195	199	204	207	210	215	219	222	225
90	133	137	140	143	146	149	152	157	161	164	168	170	173	175	177	179	182	184	185
100	120	123	125	128	130	132	133	136	139	141	143	145	146	148	149	151	152	153	154
110	107	109	111	112	114	115	116	118	120	121	123	124	125	126	127	128	129	129	130
120	95.5	96.7	97.9	98.9	100	101	101	103	104	105	106	107	107	108	109	109	110	110	111
130	84.6	85.5	86.3	87	87.7	88.3	88.8	89.8	90.6	91.3	92.0	92.5	93.0	93.5	93.9	94.4	94.9	95.3	95.7
140	75.2	75.8	76.4	76.9	77.4	77.8	78.2	78.9	79.5	80.0	80.5	80.9	81.3	81.6	81.9	82.3	82.6	83.0	83.2
150	67.0	67.4	67.9	68.2	68.6	68.9	69.2	69.7	70.2	70.6	70.9	71.2	71.5	71.8	72.0	72.3	72.6	72.9	73.1
160	59.9	60.3	60.6	60.9	61.1	61.4	61.6	62.0	62.4	62.7	62.9	63.2	63.4	63.6	63.8	64.0	64.3	64.5	64.6
170	53.8	54.1	54.3	54.6	54.8	55.0	55.1	55.5	55.7	56.0	56.2	56.4	56.6	56.7	56.9	57.1	57.3	57.4	57.6
180	48.6	48.8	49.0	49.2	49.3	49.5	49.6	49.9	50.1	50.3	50.5	50.6	50.8	50.9	51.0	51.2	51.3	51.5	51.6
190	44.0	44.2	44.3	44.5	44.6	44.7	44.9	45.1	45.3	45.4	45.6	45.7	45.8	45.9	46.0	46.2	46.3	46.4	46.5
200	40.0	40.2	40.3	40.4	40.5	40.7	40.7	40.9	41.1	41.2	41.3	41.4	41.5	41.6	41.7	41.8	41.9	42.0	42.1
210	36.6	36.7	36.8	36.9	37.0	37.1	37.2	37.3	37.4	37.6	37.7	37.8	37.8	37.9	38.0	38.1	38.2	38.3	38.3
220	33.5	33.6	33.7	33.8	33.9	34.0	34.0	34.2	34.3	34.4	34.5	34.5	34.6	34.7	34.7	34.8	34.9	35.0	35.0
230	30.8	30.9	31.0	31.1	31.2	31.2	31.3	31.4	31.5	31.6	31.6	31.7	31.8	31.8	31.9	31.9	32.0	32.1	32.1
240	28.5	28.5	28.6	28.7	28.7	28.8	28.8	28.9	29.0	29.1	29.1	29.2	29.3	29.3	29.4	29.4	29.5	29.5	29.6
250	26.3	26.4	26.5	26.5	26.6	26.6	26.7	26.7	26.8	26.9	26.9	27.0	27.0	27.1	27.1	27.2	27.2	27.3	27.3

Table 9(C) Design Compressive Stress, f_{cd} (MPa) for Column Flexural Buckling Class b

(*Clauses* 14.1.2 *and* 14.1.2.3)

KL/r ↓	Yield Stress, f_y (MPa)																		
	200	210	220	230	240	250	260	280	300	320	340	360	380	400	420	450	480	510	540
10	182	191	200	209	218	227	236	255	273	291	309	327	345	364	382	409	436	464	491
20	182	190	199	208	217	225	234	251	268	285	302	319	336	353	369	394	419	443	468
30	175	183	192	200	208	216	224	240	256	271	287	302	318	333	348	370	392	414	435
40	168	176	183	191	198	206	213	228	242	256	270	283	297	310	323	342	360	378	395
50	161	167	174	181	188	194	201	214	226	238	250	261	272	283	293	308	322	335	347
60	152	158	164	170	176	181	187	197	207	217	226	235	243	251	259	269	279	287	295
70	142	147	152	157	162	166	171	179	187	194	201	207	213	218	223	230	236	241	246
80	131	135	139	143	147	150	154	160	165	170	175	179	183	186	190	194	198	201	204
90	120	123	126	129	131	134	136	141	144	148	151	154	156	159	161	163	166	168	170
100	108	110	112	114	116	118	120	123	126	128	130	132	134	135	137	139	140	142	143
110	96.5	98.3	100	101	103	104	105	107	109	111	112	114	115	116	117	118	119	121	121
120	86.2	87.5	88.6	89.7	90.7	91.7	92.5	94.1	95.4	96.6	97.7	98.6	100	100	101	102	103	104	104
130	76.9	77.8	78.7	79.5	80.3	81.0	81.6	82.7	83.7	84.6	85.4	86.1	86.8	87.3	87.9	88.6	89.2	89.8	90.3
140	68.7	69.4	70.1	70.7	71.3	71.8	72.3	73.1	73.9	74.6	75.2	75.7	76.2	76.6	77.1	77.6	78.1	78.5	78.9
150	61.6	62.1	62.6	63.1	63.6	64.0	64.3	65.0	65.6	66.1	66.6	67.0	67.4	67.7	68.1	68.5	68.9	69.2	69.5
160	55.4	55.8	56.2	56.6	56.9	57.3	57.5	58.1	58.5	59.0	59.3	59.7	60.0	60.3	60.5	60.9	61.2	61.5	61.7
170	50.0	50.3	50.7	51.0	51.2	51.5	51.7	52.2	52.5	52.9	53.2	53.5	53.7	53.9	54.1	54.4	54.7	54.9	55.1
180	45.3	45.6	45.9	46.1	46.3	46.5	46.7	47.1	47.4	47.7	47.9	48.1	48.3	48.5	48.7	48.9	49.2	49.3	49.5
190	41.2	41.5	41.7	41.9	42.1	42.2	42.4	42.7	42.9	43.2	43.4	43.6	43.7	43.9	44.0	44.2	44.4	44.6	44.7
200	37.6	37.8	38.0	38.2	38.3	38.5	38.6	38.9	39.1	39.3	39.5	39.6	39.8	39.9	40.0	40.2	40.3	40.5	40.6
210	34.5	34.7	34.8	35.0	35.1	35.2	35.3	35.5	35.7	35.9	36.0	36.2	36.3	36.4	36.5	36.6	36.8	36.9	37.0
220	31.7	31.9	32.0	32.1	32.2	32.3	32.4	32.6	32.8	32.9	33.0	33.1	33.2	33.3	33.4	33.6	33.7	33.8	33.9
230	29.2	29.4	29.5	29.6	29.7	29.8	29.9	30.0	30.1	30.3	30.4	30.5	30.6	30.7	30.7	30.8	30.9	31.0	31.1
240	27.1	27.2	27.3	27.3	27.4	27.5	27.6	27.7	27.8	27.9	28.0	28.1	28.2	28.3	28.3	28.4	28.5	28.6	28.7
250	25.1	25.2	25.3	25.3	25.4	25.5	25.6	25.7	25.8	25.9	26.0	26.0	26.1	26.2	26.2	26.3	26.4	26.5	26.5

Table 9(D) Design Compressive Stress, f_{cd} (MPa) for Column Flexural Buckling Class c

(*Clauses* 14.1.2 *and* 14.1.2.3)

***KL*/r** ↓	**Yield Stress, f_y, (MPa)**																		
	200	210	220	230	240	250	260	280	300	320	340	360	380	400	420	450	480	510	540
10	182	191	200	209	218	227	236	255	273	291	309	327	345	364	382	409	436	464	491
20	182	190	199	207	216	224	233	250	266	283	299	316	332	348	364	388	412	435	458
30	172	180	188	196	204	211	219	234	249	264	278	293	307	321	335	355	376	395	415
40	163	170	177	184	191	198	205	218	231	244	256	268	280	292	304	320	337	352	367
50	153	159	165	172	178	183	189	201	212	222	232	242	252	261	270	282	295	306	317
60	142	148	153	158	163	168	173	182	191	199	207	215	222	228	235	244	252	260	267
70	131	136	140	144	148	152	156	163	170	176	182	187	192	197	202	208	213	218	223
80	120	123	127	130	133	136	139	145	149	154	158	162	165	169	172	176	180	183	186
90	108	111	114	116	119	121	123	127	131	134	137	140	142	144	146	149	152	154	156
100	97.5	100	102	104	105	107	109	112	114	116	119	120	122	124	125	127	129	131	132
110	87.3	89.0	90.5	92.0	93.3	94.6	95.7	97.9	100	102	103	104	106	107	108	110	111	112	113
120	78.2	79.4	80.6	81.7	82.7	83.7	84.6	86.2	87.6	88.9	90.1	91.1	92.1	93.0	93.8	94.9	95.9	96.8	97.6
130	70.0	71.0	71.9	72.8	73.5	74.3	75.0	76.2	77.3	78.3	79.2	80.0	80.7	81.4	82.0	82.9	83.6	84.3	84.9
140	62.9	63.6	64.4	65.0	65.6	66.2	66.7	67.7	68.6	69.3	70.0	70.7	71.2	71.8	72.3	72.9	73.5	74.1	74.6
150	56.6	57.2	57.8	58.3	58.8	59.2	59.7	60.4	61.1	61.7	62.3	62.8	63.3	63.7	64.1	64.6	65.1	65.5	65.9
160	51.1	51.6	52.1	52.5	52.9	53.3	53.6	54.2	54.8	55.3	55.7	56.1	56.5	56.9	57.2	57.6	58.0	58.4	58.7
170	46.4	46.8	47.1	47.5	47.8	48.1	48.4	48.9	49.3	49.8	50.1	50.5	50.8	51.1	51.3	51.7	52.0	52.3	52.6
180	42.2	42.5	42.8	43.1	43.4	43.6	43.9	44.3	44.7	45.0	45.3	45.6	45.8	46.1	46.3	46.6	46.9	47.1	47.3
190	38.5	38.8	39.0	39.3	39.5	39.7	39.9	40.3	40.6	40.9	41.1	41.4	41.6	41.8	42.0	42.2	42.5	42.7	42.9
200	35.3	35.5	35.7	35.9	36.1	36.3	36.5	36.8	37.0	37.3	37.5	37.7	37.9	38.1	38.2	38.4	38.6	38.8	39.0
210	32.4	32.6	32.8	33.0	33.1	33.3	33.4	33.7	33.9	34.1	34.3	34.5	34.7	34.8	34.9	35.1	35.3	35.4	35.6
220	29.9	30.1	30.2	30.4	30.5	30.6	30.8	31.0	31.2	31.4	31.5	31.7	31.8	31.9	32.1	32.2	32.4	32.5	32.6
230	27.6	27.8	27.9	28.0	28.2	28.3	28.4	28.6	28.8	28.9	29.1	29.2	29.3	29.4	29.5	29.7	29.8	29.9	30.0
240	25.6	25.7	25.9	26.0	26.1	26.2	26.3	26.4	26.6	26.7	26.9	27.0	27.1	27.2	27.3	27.4	27.5	27.6	27.7
250	23.8	23.9	24.0	24.1	24.2	24.3	24.4	24.5	24.7	24.8	24.9	25.0	25.1	25.2	25.3	25.4	25.5	25.6	25.7

Table 9(E) Design Compressive Stress, f_{cd} (MPa) for Column Buckling Class d

(*Clauses* 14.1.2 *and* 14.1.2.3)

***KL*/r** ↓	**Yield Stress, f_y (MPa)**																		
	200	210	220	230	240	250	260	280	300	320	340	360	380	400	420	450	480	510	540
10	182	191	200	209	218	227	236	255	273	291	309	327	345	364	382	409	436	464	491
20	182	190	198	206	215	223	231	247	263	279	294	310	325	340	355	377	399	421	442
30	168	175	182	189	197	204	211	224	238	251	264	277	290	302	314	332	350	367	384
40	154	161	167	173	179	185	191	203	214	225	235	246	256	266	275	289	303	316	328
50	141	147	152	157	162	167	172	182	191	199	208	216	224	231	238	249	258	268	277
60	129	133	137	142	146	150	154	161	168	175	182	188	193	199	204	212	219	225	231
70	116	120	124	127	130	133	137	142	148	153	158	162	167	171	174	180	184	189	193
80	105	108	111	113	116	118	121	125	129	133	137	140	143	146	149	153	156	159	162
90	94.1	96.4	98.6	101	103	105	107	110	113	116	119	121	123	126	128	130	133	135	137
100	84.3	86.2	87.9	89.6	91.1	92.6	94.0	96.7	99.1	101	103	105	107	108	110	112	114	116	117
110	75.6	77.0	78.4	79.7	81.0	82.1	83.2	85.3	87.1	88.8	90.4	91.8	93.1	94.4	95.5	97.1	98.5	100	101
120	67.8	69.0	70.1	71.1	72.1	73.0	73.9	75.5	77.0	78.3	79.5	80.6	81.7	82.6	83.5	84.7	85.8	86.9	87.8
130	61.0	62.0	62.8	63.7	64.5	65.2	65.9	67.2	68.3	69.4	70.4	71.2	72.1	72.8	73.5	74.5	75.4	76.2	76.9
140	55.0	55.8	56.5	57.2	57.8	58.4	59.0	60.0	61.0	61.8	62.6	63.3	64.0	64.6	65.2	66.0	66.7	67.3	67.9
150	49.8	50.4	51.0	51.6	52.1	52.6	53.1	53.9	54.7	55.4	56.0	56.6	57.2	57.7	58.1	58.8	59.3	59.9	60.4
160	45.2	45.7	46.2	46.7	47.1	47.5	47.9	48.6	49.3	49.9	50.4	50.9	51.3	51.7	52.1	52.7	53.1	53.6	54.0
170	41.2	41.6	42.1	42.4	42.8	43.1	43.5	44.1	44.6	45.1	45.5	45.9	46.3	46.7	47.0	47.4	47.8	48.2	48.6
180	37.7	38.0	38.4	38.7	39.0	39.3	39.6	40.1	40.5	41.0	41.3	41.7	42.0	42.3	42.6	43.0	43.3	43.6	43.9
190	34.5	34.9	35.2	35.4	35.7	35.9	36.2	36.6	37.0	37.4	37.7	38.0	38.2	38.5	38.7	39.1	39.4	39.6	39.9
200	31.8	32.0	32.3	32.5	32.8	33.0	33.2	33.6	33.9	34.2	34.5	34.7	35.0	35.2	35.4	35.7	35.9	36.2	36.4
210	29.3	29.6	29.8	30.0	30.2	30.4	30.5	30.9	31.2	31.4	31.7	31.9	32.1	32.3	32.5	32.7	32.9	33.1	33.3
220	27.1	27.3	27.5	27.7	27.9	28.0	28.2	28.5	28.7	29.0	29.2	29.4	29.6	29.7	29.9	30.1	30.3	30.5	30.6
230	25.2	25.3	25.5	25.7	25.8	26.0	26.1	26.4	26.6	26.8	27.0	27.1	27.3	27.5	27.6	27.8	27.9	28.1	28.2
240	23.4	23.6	23.7	23.9	24.0	24.1	24.2	24.5	24.7	24.8	25.0	25.2	25.3	25.4	25.5	25.7	25.9	26.0	26.1
250	21.8	22.0	22.1	22.2	22.3	22.5	22.6	22.8	22.9	23.1	23.2	23.4	23.5	23.6	23.7	23.9	24.0	24.1	24.2

Table 10 Buckling Class of Cross Sections

(*Clause* 14.1.2.3)

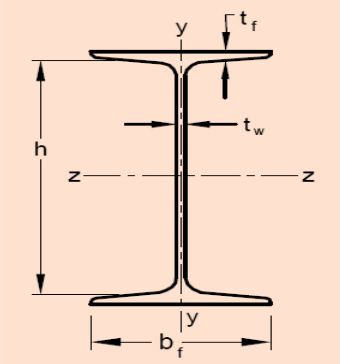
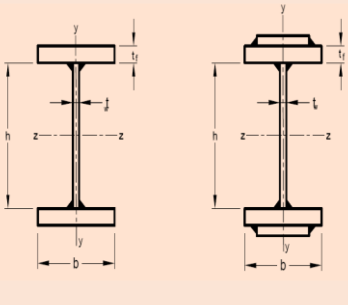
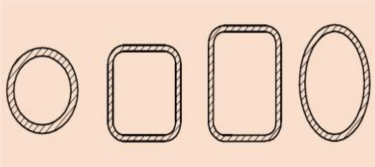
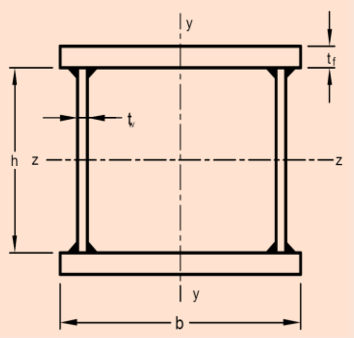
Cross Section	Limits		Buckling About Axis	Buckling Class	
				$f_y \le 420$ MPa	$f_y > 420$ MPa
(1)	(2)		(3)	(4)	(5)
Rolled I-Sections 	$h/b_f > 1.2$	$t_f \le 40$ mm	*z-z* *y-y*	a b	a_0 a
		$t_f > 40$mm	*z-z* *y-y*	b c	a b
	$h/b_f \le 1.2$	$t_f \le 100$ mm	*z-z* *y-y*	b c	a b
		$t_f > 100$ mm	*z-z* *y-y*	d d	c c
Welded I-Section  y t_f t h z z y b y t_f t h z z y b	$t_f \le 40$ mm		*z-z* *y-y*	b c	b c
	$t_f > 40$ mm		*z-z* *y-y*	c d	c d
Hollow Section 	Hot rolled		any	a	a_0
	Cold formed		any	c	c
Welded Box Section, Cruciform column 	Generally (except as below)		any	b	b
	Thick welds $s_w > 0.5t_t$ and $b/t_f < 30$ and $h/t_w < 30$		any	c	c

Table 10 (*Concluded*)

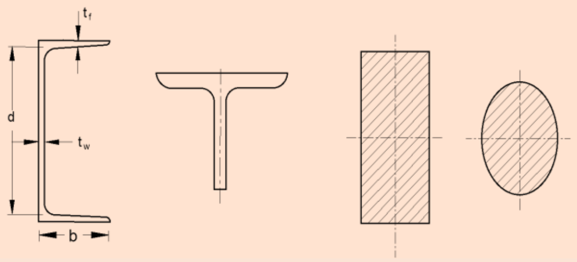
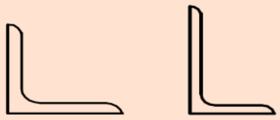
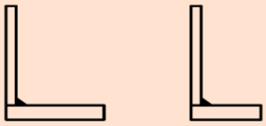
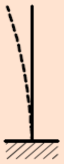
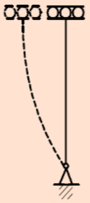
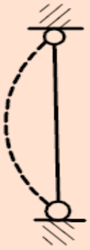
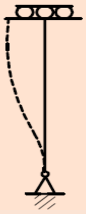
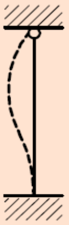
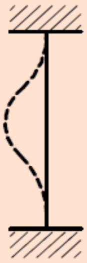
Cross Section	Limits	Buckling About Axis	Buckling Class	
			$f_y \leq 420$ MPa	$f_y > 420$ MPa
(1)	(2)	(3)	(4)	(5)
Channel, T, and Solid Sections 		any	c	c
Rolled angle or L sections 		any	b	a
Welded angle or L sections t ≤ 40 mm 		any	c	c

Table 11 Effective Length of Prismatic Compression Members

(*Clause* 14.2.2)

Boundary Conditions				**Schematic Representation**	**Effective Length**
At One End		At the Other End			
Translation	Rotation	Translation	Rotation		
(1)	(2)	(3)	(4)	(5)	(6)
Restrained	Restrained	Free	Free		2.0L
Restrained	Free	Free	Restrained		
Restrained	Free	Restrained	Free		1.0L
Restrained	Restrained	Free	Restrained		1.2L
Restrained	Restrained	Restrained	Free		0.8L
Restrained	Restrained	Restrained	Restrained		0.65L

NOTE — L is the unsupported length of the compression member (*see* **13.2.1**).

14.3.3.2 In continuous columns, the bending moments due to eccentricities of loading on the columns at any floor may be divided equally between the columns above and below that floor level, provided that the moment of inertia of one column section, divided by its effective length does not exceed 1.5 times the corresponding value of the other column. Where this ratio is exceeded, the bending moment shall be divided in proportion to the moment of inertia of the column sections divided by their respective effective lengths.

14.3.4 *Splices*

14.3.4.1 Where the ends of compression members are prepared for bearing over the whole area, they shall be spliced to hold the connected members accurately in position, and to resist bending or tension, if present. Such splices should maintain the intended member stiffness about each axis. Splices should be located as close to the point of inflection as possible. Otherwise their capacity should be adequate to carry magnified moment (*see* **16.3.2.2**). The ends of compression members faced for bearing shall invariably be machined to ensure perfect contact of surfaces in bearing.

14.3.4.2 Where such members are not faced for complete bearing, the splices shall be designed to transmit all the forces to which the members are subjected.

14.3.4.3 Wherever possible, splices shall be proportioned and arranged so that the centroidal axis of the splice coincides as nearly as possible with the centroidal axes of the members being jointed, in order to avoid eccentricity; but where eccentricity is present in the joint, the resulting stress shall be accounted for.

14.4 Column Bases

14.4.1 *General*

Column bases should have sufficient stiffness and strength to transmit axial force, bending moments and shear forces at the base of the columns to their foundation without exceeding the load carrying capacity of the supports. Anchor bolts and shear keys should be provided wherever necessary. Shear resistance at the proper contact surface between steel base and concrete/grout may be calculated using a friction coefficient of 0.45. Design recommendations of anchor bolts in concrete foundations may be referred as per good practice [C-6A(38)].

The nominal bearing pressure between the base plate and the support below may be determined on the basis of linearly varying distribution of pressure. The maximum bearing pressure on concrete under the limit states design load should not exceed the bearing strength equal to $0.3f_{ck}\,[\sqrt{(A_1/A_2)}]$ and $0.9f_{ck}$, whichever is smaller, where f_{ck} is the smaller of characteristic cube strength of concrete or bedding material, A_1 is the area of concrete pedestal on which the base plate is sitting, and A_2 is the surface area of the steel base plate transferring the load to the concrete pedestal.

If the size of the base plate is larger than that required to limit the bearing pressure on the base support, an equal projection, *c* of the base plate beyond the face of the column and gusset may be taken as effective in transferring the column load as given in Fig. 9, such that bearing pressure on the effective area does not exceed bearing capacity of concrete base.

14.4.2 *Gusseted Bases*

For stanchion with gusseted bases, the gusset plates, angle cleats, stiffeners, fastenings, etc, in combination with the bearing area of the shaft, shall be sufficient to take the loads, bending moments and reactions to the base plate without exceeding specified strength. All the bearing surfaces shall be machined to ensure perfect contact.

14.4.2.1 Where the ends of the column shaft and the gusset plates are not faced for complete bearing, the welds, fastenings connecting them to the base plate shall be sufficient to transmit all the forces to which the base is subjected.

14.4.2.2 *Column and base plate connections*

Where the end of the column is connected directly to the base plate by means of full penetration butt welds, the connection shall be deemed to transmit to the base all the forces and moments to which the column is subjected.

14.4.3 *Slab Bases*

Columns with slab bases need not be provided with gussets, but sufficient fastenings shall be provided to retain the parts securely in place and to resist all moments and forces, other than direct compression, including those arising during transit, unloading and erection. Minimum of four number of anchor bolts shall be used to anchor column bases to foundation and minimum of six numbers in the case of slab bases transferring earthquake forces.

14.4.3.1 The minimum thickness, t_s, of rectangular slab bases, supporting columns under axial compression shall be

$$t_s = \sqrt{2.5\,w(a^2 - 0.3b^2)\gamma_{m0} / f_y} \quad > t_f$$

where

a, b = larger and smaller projection, respectively of the slab base beyond the rectangle circumscribing the column;

t_f = flange thickness of compression member; and

w = uniform pressure from below on the slab base under the factored load axial compression.

When only the effective area of the base plate is used as in **14.4.1**, c^2 may be used in the above equation (*see* Fig. 9) instead of ($a^2 - 0.3b^2$).

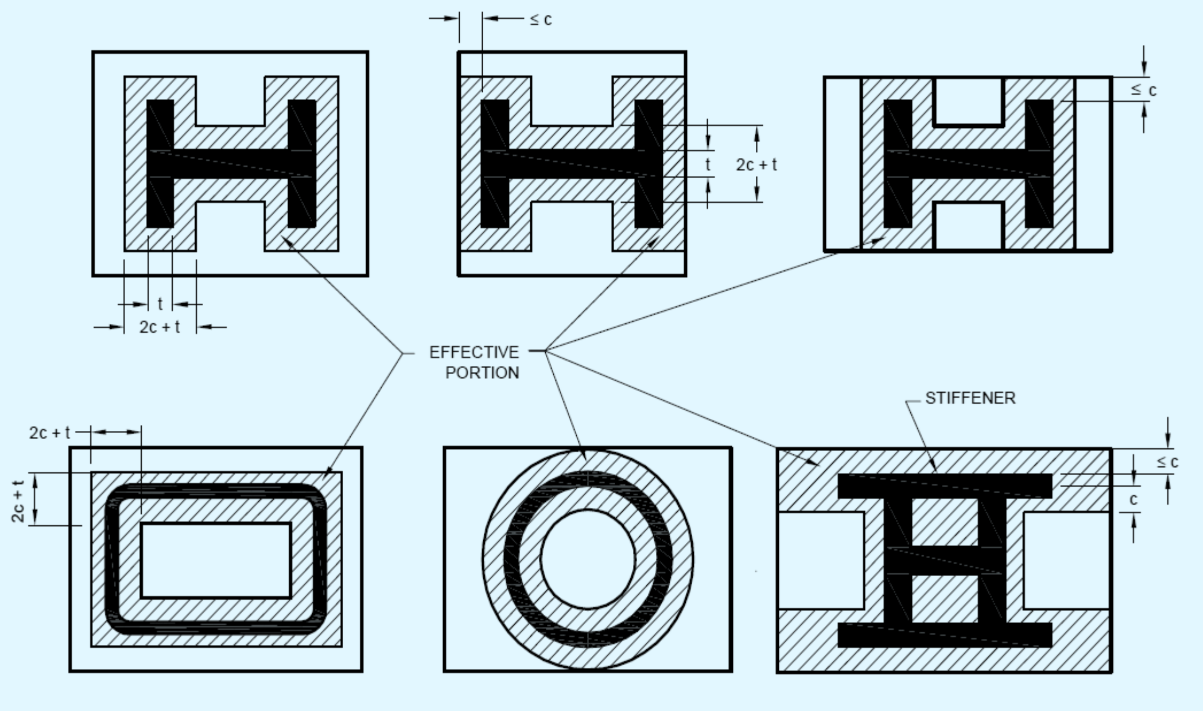


FIG. 9 EFFECTIVE AREA OF A BASE PLATE

14.4.3.2 When the slab does not distribute the column load uniformly, due to eccentricity of the load etc, special calculation shall be made to show that the base is adequate to resist the moment due to the non-uniform pressure from below.

14.4.3.3 Bases for bearing upon concrete or masonry need not be machined on the underside.

14.4.3.4 In cases where the cap or base is fillet welded directly to the end of the column without boring and shouldering, the contact surfaces shall be machined to give a perfect bearing and the welding shall be sufficient to transmit the forces as required in **14.4.3**. Where full strength butt welds are provided, machining of contact surfaces is not required.

14.5 Angle Struts

14.5.1 *Single Angle Struts*

The compression in single angles may be transferred either concentrically to its centroid through the end connections or eccentrically by connecting one of its legs to a gusset or adjacent member.

14.5.1.1 *Concentric loading*

When a single angle is concentrically loaded in compression, the design strength may be evaluated using **14.1.2**, by calculating the non-dimensional slenderness ratio, λ_{vv}, for buckling about the minor axis, *v-v*, as given by:

$$\lambda_{vv} = \frac{\left(\dfrac{l_{vv}}{r_{vv}}\right)}{\varepsilon\sqrt{\dfrac{\pi^2 E}{250}}}$$

r_{vv} = radius of gyration of the angle section about the minor axis; and

l_{vv} = laterally unsupported length preventing translation normal to the minor axis

14.5.1.2 *Loaded through one leg*

The design strength of single angle members loaded in compression through one of its legs, f_{cde}, is affected by flexural torsional buckling and bending. The design compressive strength of such eccentrically loaded angle members, *in lieu of* a more exact second order design under combined bending axial compression, may be evaluated approximately as given below.

The design compressive strength, of single angles loaded through gusset connection to one leg parallel to the *a-a* axis (*a-a* axis being either the *z-z* or the *y-y* axis, depending on which leg is connected to the gusset) of the member may be calculated as:

$$f_{cde} = K_f \chi_{aa} f_y / \gamma_{m0} \quad \leq f_{cd} \text{ (given in 14.1.2)}$$

where

f_{cde} = Design compressive stress of single angle.

K_f = $k_1 + k_2\lambda_{aa} + k_3\lambda_{\phi}$;

χ_{aa} = Stress reduction factor (*see* Table 8) for buckling class ‘b’, calculated as per **14.1.2.1**, using the non-dimensional slenderness ratio, λ_{aa}.

where

k_1, k_2, k_3 = constants depending upon the end condition, as given in Table 12; and

K_f = modification factor to account for eccentric end connection.

$$\lambda_{aa} = \frac{\left(\dfrac{l_{aa}}{r_{aa}}\right)}{\varepsilon\sqrt{\dfrac{\pi^2 E}{250}}}$$

$$\lambda_{\varphi} = \frac{(b_1 + b_2)/2t}{\varepsilon\sqrt{\frac{\pi^2 E}{250}}}$$

b_1, b_2 = width of the connected and outstanding legs of the angle, respectively;

l_{aa} = centre to centre length of the lateral support preventing translation of the member perpendicular to a-a axis (a-a axis being either the z-z or the y-y axis, depending on which leg is connected to the gusset);

r_{aa} = radius of gyration of the angle member about the *a-a* axis (*a-a* axis being either the *z-z* or the *y-y* axis, depending on which leg is connected to the gusset), parallel to the plane of the end gusset plates;

t = thickness of the leg; and

ε = is the yield stress ratio, $\sqrt{\frac{250}{f_y}}$, f_y being in MPa

Table 12 Constants k_1, k_2, and k_3

(*Clause* 14.5.1.2)

Sl No.	End Connection	Gusset/Connecting Member Fixity [1]	k_1	k_2	k_3
(1)	(2)	(3)	(4)	(5)	(6)
i)	Fully welded or connected with two or more bolts	Fixed	0.798	0.563	-2.072
		Hinged	0.401	0.420	-1.040
ii)	Single bolt	Fixed	0.418	0.547	-1.400
		Hinged	0.374	0.415	-2.072

---

[1] In-plane rotational restraint provided to the gusset by the supporting member. For partial restraint, k_f can be interpolated between the results for fixed and hinged cases.

14.5.2 *Double Angle Struts*

14.5.2.1 For double angle discontinuous struts, connected back to back, on opposite sides of the gusset or a section, by not less than two bolts or rivets in line along the angles at each end, or by the equivalent in welding, the load may be regarded as applied axially. The effective length, *KL*, in the plane of end gusset shall be taken as between 0.7 times and 0.85 times the distance between intersections, depending on the degree of the restraint provided. The effective length, *KL*, in the plane perpendicular to that of the end gusset, shall be taken as equal to the distance between centres of intersections. The calculated average compressive stress shall not exceed the values based on **14.1.2**. The angles shall be connected together over their lengths so as to satisfy the requirements of **14.8** and **17.2.5**.

14.5.2.2 Double angle discontinuous struts connected back-to-back, to one side of a gusset or section by one or more bolts or rivets in each angle, or by the equivalent in welding, shall be designed in accordance with **14.5.1** and the angles shall be connected together over their lengths so as to satisfy the requirements of **14.8** and **17.2.5**.

14.5.3 *Continuous Members*

Double angle continuous struts such as those forming the flanges, chords or ties of trusses or trussed girders, or the legs of towers shall be designed as axially loaded compression members, and the effective length shall be taken in accordance with **14.2.4**.

14.5.4 *Combined Stresses*

In addition to axial loads, if the struts carry loads which cause transverse bending, the combined bending and axial stresses shall be checked in accordance with **16.3**. For determining the permissible axial and bending stresses, the effective length shall be taken in accordance with the **14.2** and **15.3**.

14.6 Laced Columns

14.6.1 *General*

14.6.1.1 Members comprising two main components laced and tied, should where practicable, have a radius of gyration about the axis perpendicular to the plane of lacing not less than the radius of gyration about the axis parallel to the plane of lacing [*see* Fig.10(A) and Fig. 10(B)].

14.6.1.2 As far as practicable, the lacing system shall be uniform throughout the length of the column.

14.6.1.3 Except for tie plates as specified in **14.7**, double laced systems [*see* Fig. 10(B)] and single laced systems [*see* Fig. 10(A)] on opposite sides of the main components shall not be combined with cross members (ties) perpendicular to the longitudinal axis of the strut [*see* Fig. 10(C)], unless all forces resulting from deformation of the strut members are calculated and provided for in the design of lacing and its fastenings.

14.6.1.4 Single laced systems, on opposite faces of the components being laced together shall preferably be in the same direction so that one is the shadow of the other, instead of being mutually opposed in direction.

14.6.1.5 The effective slenderness ratio, $(KL/r)_e$, of laced columns shall be taken as 1.05 times the $(KL/r)_0$, the actual maximum slenderness ratio, in order to account for shear deformation effects.

14.6.2 *Width of Lacing Bars*

In bolted/riveted construction, the minimum width of lacing bars shall be three times the nominal diameter of the end bolt/rivet.

14.6.3 *Thickness of Lacing Bars*

The thickness of flat lacing bars shall not be less than one-fortieth of its effective length for single lacings and one-sixtieth of the effective length for double lacings.

Rolled sections or tubes of equivalent strength may be permitted instead of flats, for lacings.

14.6.4 *Angle of Inclination*

Lacing bars, whether in double or single systems, shall be inclined at an angle not less than 40º nor more than 70º to the axis of the built-up member.

14.6.5 *Spacing*

14.6.5.1 The maximum spacing of lacing bars, whether connected by bolting, riveting or welding, shall also be such that the maximum slenderness ratio of the components of the main member (a_1/r_1), between consecutive lacing connections is not greater than 50 or 0.7 times the most unfavourable slenderness ratio of the member as a whole, whichever is less, where a_1 is the unsupported length of the individual member between lacing points, and r_1 is the minimum radius of gyration of the individual member being laced together.

14.6.5.2 Where lacing bars are not lapped to form the connection to the components of the members, they shall be so connected that there is no appreciable interruption in the triangulation of the system.

14.6.6 *Design of Lacings*

14.6.6.1 The lacing shall be proportioned to resist a total transverse shear, V_t, at any point in the member, equal to at least 2.5 percent of the axial force in the member and shall be divided equally among all transverse-lacing systems in parallel planes.

14.6.6.2 For members carrying calculated bending stress due to eccentricity of loading, applied end moments and/or lateral loading, the lacing shall be proportioned to resist the actual shear due to bending, in addition to that specified in **14.6.6.1**.

14.6.6.3 The slenderness ratio, *KL/r*, of the lacing bars shall not exceed 145. In bolted/riveted construction, the effective length of lacing bars for the determination of the design strength shall be taken as the length between the inner end fastener of the bars for single lacing, and as 0.7 of this length for double lacings effectively connected at intersections. In welded construction, the effective lengths shall be taken as 0.7 times the distance between the inner ends of welds connecting the single lacing bars to the members.

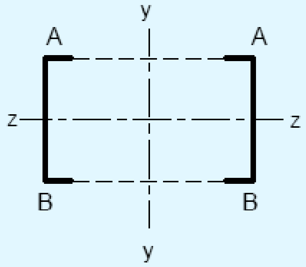
NOTE — The required section for lacing bars as compression/tension members shall be determined by using the appropriate design stresses, f_{cd} subject to the requirements in **14.6.3** to **14.6.6** and T_d in **13.1**.

14.6.7 *Attachment to Main Members*

The bolting, riveting or welding of lacing bars to the main members shall be sufficient to transmit the force calculated in the bars. Where welded lacing bars overlap the main members, the amount of lap measured along either edge of the lacing bar shall be not less than four times the thickness of the bar or the thickness of the element of the members to which it is connected, whichever is less. The welding should be sufficient to transmit the load in the bar and shall, in any case, be provided along each side of the bar for the full length of lap.

14.6.8 *End Tie Plates*

Laced compression members shall be provided with tie plates as per **14.7** at the ends of lacing systems and at intersection with other members/stays and at points where the lacing systems are interrupted.



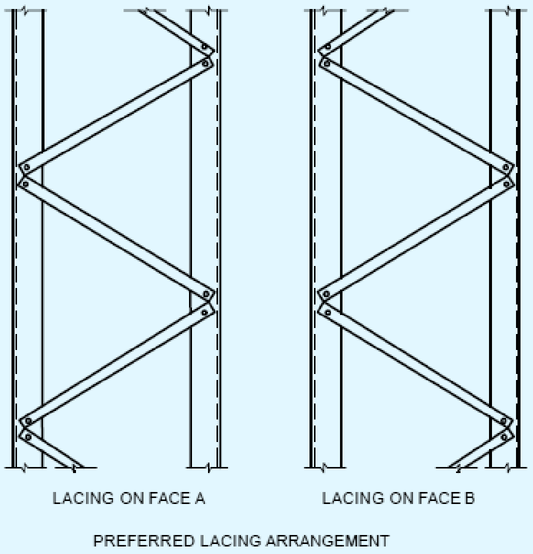


Fig. 10(A) Single Laced Syste

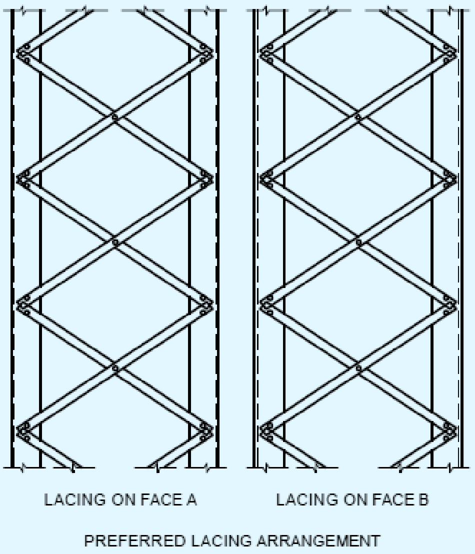


Fig. 10(B) Double Laced System

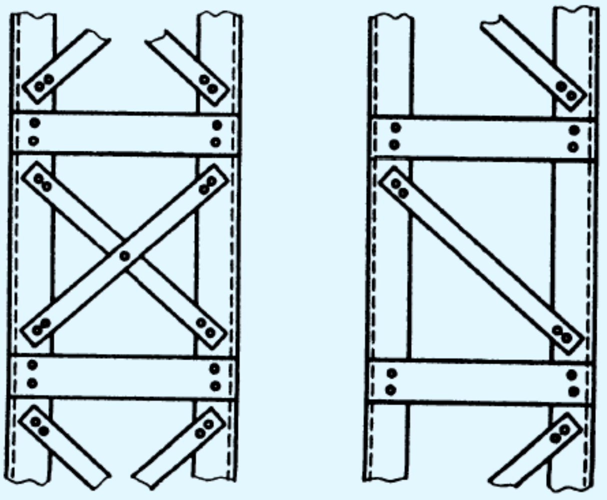


FIG. 10(C) DOUBLE LACED AND SINGLE LACED SYSTEM COMBINED WITH CROSS MEMBERS

FIG. 10 LACED COLUMNS

14.7 Battened Columns

14.7.1 *General*

14.7.1.1 Compression members composed of two main components battened should preferably have the individual members of the same cross section and symmetrically disposed about their major axis. Where practicable, the compression members should have a radius of gyration about the axis perpendicular to the plane of the batten not less than the radius of gyration about the axis parallel to the plane of the batten (*see* Fig. 11).

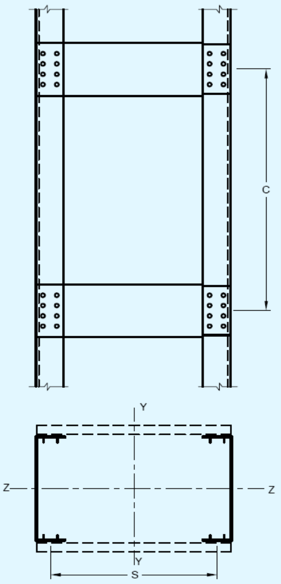


FIG. 11 BATTEN COLUMN SECTION

14.7.1.2 Battened compression members, not complying with the requirements specified in this Section or those subjected to eccentricity of loading, applied moments or lateral forces in the plane of the battens (*see* Fig. 11), shall be designed according to the exact theory of elastic stability or empirically, based on verification by tests.

NOTE — If the column section is subjected to eccentricity or other moments about an axis perpendicular to battens, the battens and the column section should be specially designed for such moments and shears.

14.7.1.3 The battens shall be placed opposite to each other at each end of the member and at points where the member is stayed in its length and as far as practicable, be spaced and proportioned uniformly throughout. The number of battens shall be such that the member is divided into not less than three bays within its actual length from centre to centre of end connections.

14.7.1.4 The effective slenderness ratio $(KL/r)_e$ of battened columns, shall be taken as 1.1 times the $(KL/r)_0$, the maximum actual slenderness ratio of the column, to account for shear deformation effects.

14.7.2 *Design of Battens*

14.7.2.1 *Battens*

Battens shall be designed to carry the bending moments and shear forces arising from transverse shear force V_t equal to 2.5 percent of the total axial force on the whole compression member, at any point in the length of the member, divided equally between parallel planes of battens. Battened member carrying calculated bending moment due to eccentricity of axial loading, calculated end moments or lateral loads parallel to the plane of battens, shall be designed to carry actual shear in addition to the above shear. The main members shall also be checked for the same shear force and bending moments as for the battens.

Battens shall be of plates, angles, channels, or I-sections and at their ends shall be riveted, bolted or welded to the main components so as to resist simultaneously a shear $V_b = V_t\ C/NS$ along the column axis and a moment $M = V_t C/2N$ at each connection,

where

C = distance between centre-to-centre of battens, longitudinally;

N = number of parallel planes of battens;

S = minimum transverse distance between the centroid of the rivet/bolt group/welding connecting the batten to the main member; and

V_t = transverse shear force as defined above.

14.7.2.2 *Tie plates*

Tie plates are members provided at the ends of battened and laced members, and shall be designed by the same method as battens. In no case shall a tie plate and its fastenings be incapable of carrying the forces for which the lacing or batten has been designed.

14.7.2.3 *Size*

When plates are used for battens, the end battens and those at points where the member is stayed in its length shall have an effective depth, longitudinally, not less than the perpendicular distance between the centroids of the main members. The intermediate battens shall have an effective depth of not less than three quarters of this distance, but in no case shall the effective depth of any batten be less than twice the width of one member, in the plane of the battens. The effective depth of a batten shall be taken as the longitudinal distance between outermost bolts, rivets or welds at the ends. The thickness of batten or the tie plates shall be not less than one fiftieth of the distance between the innermost connecting lines of rivets, bolts or welds, perpendicular to the main member.

14.7.2.4 The requirement of bolt size and thickness of batten specified above does not apply when angles, channels or I-sections are used for battens with their legs or flanges perpendicular to the main member. However, it should be ensured that the ends of the compression members are tied to achieve adequate rigidity.

14.7.3 *Spacing of Battens*

In battened compression members where the individual members are not specifically checked for shear stress and bending moments, the spacing of battens, centre-to-centre of its end fastenings, shall be such that the slenderness ratio (KL/r) of any component over that distance shall be not greater than 50 nor greater than 0.7 times the slenderness ratio of the member as a whole about its z-z axis (parallel to the battens).

14.7.4 *Attachment to Main Members*

14.7.4.1 *Welded connections*

Where tie or batten plates overlap the main members, the amount of lap shall be not less than four times the thickness of the plate. The length of weld connecting each edge of the batten plate to the member shall, in aggregate, be not less than half the depth of the batten plate. At least one-third of the weld shall be placed at each end of this edge. The length of weld and depth of batten plate shall be measured along the longitudinal axis of the main member.

In addition, the welding shall be returned along the other two edges of the plates transversely to the axis of the main member for a length not less than the minimum lap specified above.

14.8 Compression Members Composed of Two Components Back-to-Back

14.8.1 Compression members composed of two angles, channels, or tees back-to-back in contact or separated by a small distance, shall be connected together by riveting, bolting or welding so that the ratio of most unfavorable slenderness of each member between the intermediate connections is not greater than 40 or 0.6 times the most unfavorable ratio of slenderness of the strut as a whole, whichever is less [*see* **17**].

14.8.2 In no case shall the ends of the strut be connected together with less than two rivets or bolts or their equivalent in welding, and there shall be not less than two additional connections in between, spaced equidistant along the length of the strut. Where the members are separated back-to-back, the rivets or bolts through these connections shall pass through solid washers or packing in between. Where the legs of the connected angles or the connected tees are 125 mm wide or more, or where webs of channels are 150 mm wide or over, not less than two rivets or bolts shall be used in each connection, one on line of each gauge mark.

14.8.3 Where these connections are made by welding, solid packing shall be used to effect the jointing unless the members are sufficiently close together to permit direct welding, and the members shall be connected by welding along both pairs of edges of the main components.

14.8.4 The rivets, bolts or welds in these connections shall be sufficient to carry the shear force and moments, if any, specified for battened struts (*see* **14.7.3**), and in no case shall the rivets or bolts be less than 16 mm diameter for members up to and including 10 mm thick; 20 mm diameter for members up to and including 16 mm thick; and 22 mm diameter for members over 16 mm thick.

Compression members connected by such riveting, bolting or welding shall not be subjected to transverse loading in a plane perpendicular to the riveted, bolted or welded surfaces.

14.8.5 Where the components are in contact back-to-back, the spacing of the rivets, bolts or intermittent welds shall not exceed the maximum spacing for compression members as given under **17**.

15 DESIGN OF MEMBERS SUBJECTED TO BENDING

15.1 General

Members subjected to predominant bending shall have adequate design strength to resist bending moment, shear force, and concentrated forces imposed upon and their combinations. Further, the members shall satisfy the deflection limitation presented under **12**, as serviceability criteria. Member subjected to other forces in addition to bending or biaxial bending shall be designed in accordance with the provisions under **16**.

15.1.1 *Effective Span of Beams*

The effective span of a beam shall be taken as the distance between the centres of the supports, except where the point of application of the reaction is taken as eccentric at the support, when it shall be permissible to take the effective span as the length between the assumed lines of the reactions.

15.2 Design Strength in Bending (Flexure)

The design bending strength of beam, adequately supported against lateral torsional buckling (laterally supported beam) is governed by the yield stress (*see* 15.2.1). When a beam is not adequately supported against lateral buckling (laterally un-supported beams) the design bending strength may be governed by lateral torsional buckling strength (*see* 15.2.2).

The factored design moment, M at any section, in a beam due to external actions, shall satisfy:

$$M \leq M_{\mathrm{d}}$$

where

M_{d} = design bending strength of the section, calculated as given in 15.2.1.2.

15.2.1 *Laterally Supported Beam*

A beam may be assumed to be adequately supported at the supports, provided the compression flange has full lateral restraint and nominal torsional restraint at supports supplied by web cleats, partial depth end plates, fin plates or continuity with the adjacent span. Full lateral restraint to compression flange may be assumed to exist if the frictional or other positive restraint of a floor connection to the compression flange of the member is capable of resisting a lateral force not less than 2.5 percent of the maximum force in the compression flange of the member. This may be considered to be uniformly distributed along the flange, provided gravity loads constitute the dominant loading on the member and the floor construction is capable of resisting this lateral force.

The design bending strength of a section which are not susceptible to web buckling under shear before yielding (where $d/t_{\mathrm{w}} \leq 67\varepsilon$) shall be determined according to 15.2.1.2.

15.2.1.1 *Section with webs susceptible to shear buckling before yielding*

When the flanges are plastic, compact or semi-compact but the web is susceptible to shear buckling before yielding (*see* 15.4.2.1), the design bending strength shall be calculated using one of the following methods:

a) the bending moment and axial force acting on the section may be assumed to be resisted by flanges only and the web is designed only to resist shear (*see* 15.4); and

b) the bending moment and axial force acting on the section may be assumed to be resisted by the whole section. In such a case, the web shall be designed for combined shear and normal stresses using simple elastic theory in case of semi-compact webs and simple plastic theory in the case of compact and plastic webs.

15.2.1.2 When the factored design shear force does not exceed 0.6 V_{d}, where V_{d} is the design shear strength of the cross section (*see* 15.4), the design bending strength, M_{d} shall be taken as:

$$M_{\mathrm{d}} = \beta_{\mathrm{b}} Z_{\mathrm{p}} f_{\mathrm{y}} / \gamma_{\mathrm{m0}}$$

To avoid irreversible deformation under serviceability loads, M_{d} shall be less than 1.2 $Z_{\mathrm{e}} f_{\mathrm{y}} / \gamma_{\mathrm{m0}}$ in case of simply supported and cantilever beams and 1.5 $Z_{\mathrm{e}} f_{\mathrm{y}} / \gamma_{\mathrm{m0}}$ in all other cases. of;

where

β_{b} = 1.0 for plastic and compact sections;

β_{b} = $Z_{\mathrm{e}} / Z_{\mathrm{p}}$ for semi-compact sections;

f_y = yield stress of the material;

γ_{m0} = partial safety factor (*see* **12.4.1**); and

Z_p, Z_e = plastic and elastic section moduli of the cross section, respectively

15.2.1.3 When the design shear force (factored), V exceeds $0.6V_d$, where V_d is the design shear strength of the cross section (*see* **15.4**) the design bending strength, M_d shall be taken as:

$$M_d = M_{dv}$$

where

M_{dv} = design bending strength under high shear as defined in **16.2**.

15.2.1.4 *Holes in the tension zone*

a) The effect of holes in the tension flange, on the design bending strength need not be considered if:

$$(A_{nf}/A_{gf}) \geq (f_y/f_u)\,(\gamma_{m1}/\gamma_{m0})\,/\,0.9$$

where

A_{nf}/A_{gf} = ratio of net to gross area of the flange in tension;

f_y/f_u = ratio of yield and ultimate stress of the material; and

γ_{m1}/γ_{m0} = ratio of partial safety factors against ultimate to yield stress (*see* **12.4.1**).

When the A_{nf}/A_{gf} does not satisfy the above requirement, the reduced effective flange area, A_{ef} satisfying the above equation may be taken as the effective flange area in tension, instead of A_{gf}.

b) The effect of holes in the tension region of the web on the design flexural strength need not be considered, if the limit given in **15.2.1.4**(a) above is satisfied for the complete tension zone of the cross section, comprising the tension flange and tension region of the web; and

c) Fastener holes in the compression zone of the cross section need not be considered in design bending strength calculation, except for oversize and slotted holes or holes without any fastener.

15.2.1.5 *Shear lag effects*

The shear lag effects in flanges may be disregarded provided:

a) For outstand elements (supported along one edge), $b_o \leq L_o / 20$; and

b) For internal elements (supported along two edges), $b_i \leq L_o / 10$.

where

b_o = width of the flange with outstand;

b_i = width of the flange as an internal element; and

L_o = length between points of zero moment (inflection) in the span.

Where these limits are exceeded, the effective width of flange for design strength may be calculated using specialist literature, or conservatively taken as the value satisfying the limit given above.

15.2.2 *Laterally Unsupported Beams*

Resistance to lateral torsional buckling need not be checked separately (member may be treated as laterally supported, *see* **15.2.1**) in the following cases:

a) bending is about the minor axis of the section;

b) section is hollow (rectangular/ tubular) or solid bars; and

c) in case of major axis bending, λ_{LT} (as defined herein) is less than 0.4.

The design bending strength of laterally unsupported beam as governed by lateral torsional buckling is given by:

$$M_d = \beta_b Z_p f_{bd}$$

where

β_b = 1.0 for plastic and compact sections;

= Z_e/Z_p for semi-compact sections (Class 3);

= Z_{eff}/Z_p for slender sections (Class 4);

f_{bd} = $\chi_{LT} f_y / \gamma_{m0}$;

= design bending compressive stress;

f_m = the moment gradient effect parameter given in the Table 14;

χ_{LT} = bending stress reduction factor to account for lateral torsional buckling, in doubly symmetrical sections with lateral support at the ends given by;

$$= \frac{f_m}{\left\{\varphi_{LT} + \left[\varphi_{LT}^2 - f_m \lambda_{LT}^2\right]^{0.5}\right\}} \leq 1.0 \;;$$

Z_p, Z_e, Z_{eff} = plastic section modulus and elastic section modulus (Class 3) and effective section modulus (class 4) with respect to extreme compression fibre;

α_{LT} = the imperfection parameter is given in Table 13; and

$$\varphi_{LT} = 0.5\left[1 + f_m\left(\left(\frac{\lambda_{LT}}{\lambda_y}\right)^2 \alpha_{LT}\left(\lambda_y - 0.2\right) + \lambda_{LT}^2\right)\right];$$

The non-dimensional slenderness ratio, λ_{LT}, is given by:

$$\lambda_{LT} = \sqrt{\beta_b Z_p f_y / M_{crLT}} \leq \sqrt{1.2 Z_e f_y / M_{crLT}} = \sqrt{f_y / f_{crLT}} \qquad \lambda_y = \sqrt{f_y / f_{cry}}$$

where

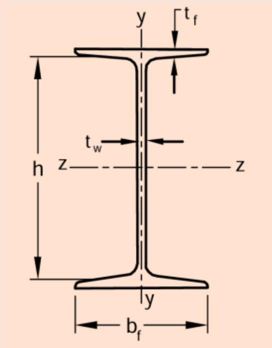
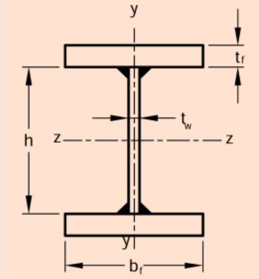
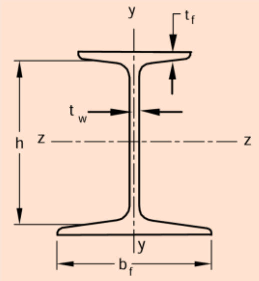
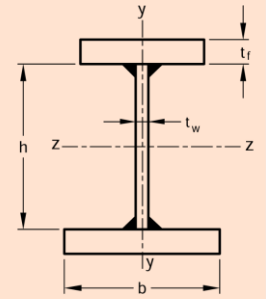
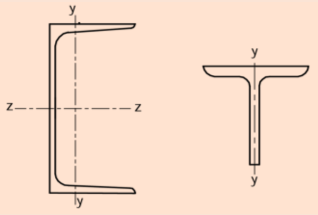
f_{cry} = the non-dimensional weak axis slenderness ratio for laterally supported length equal to distance between lateral supports to the compression flange;

f_{crLT} = extreme fibre bending compressive stress corresponding to elastic lateral torsional buckling moment (*see* **15.2.2.1**); and

M_{crLT} = elastic lateral torsional buckling moment calculated in accordance with **15.2.2.1**.

Table 13 Imperfection Parameter, α_{LT} for Lateral Torsional Buckling of Beams

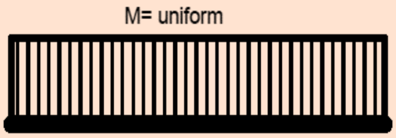
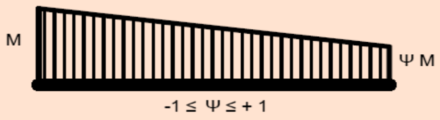
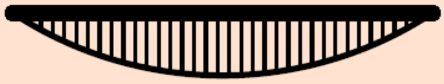
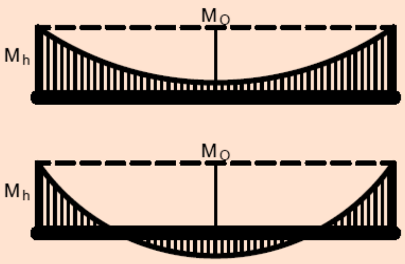
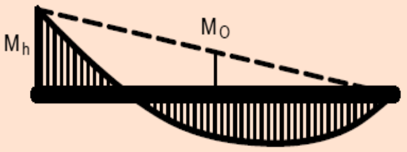
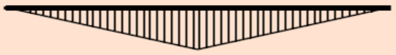
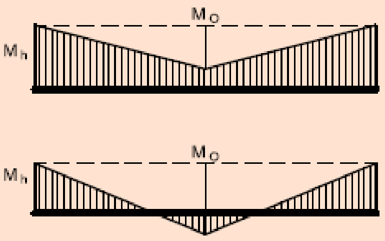
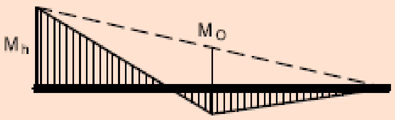
(*Clause* 15.2.2)

Cross Section	Limits		α_{LT}
Rolled I or H Sections 	$h/b>1.2$	$t_f \leq 40$ mm	$0.12\sqrt{\frac{Z_{ez}}{Z_{ey}}} \leq 0.34$
		$t_f > 40$ mm	$0.16\sqrt{\frac{Z_{ez}}{Z_{ey}}} \leq 0.49$
	$h/b \leq 1.2$	—	$0.16\sqrt{\frac{Z_{ez}}{Z_{ey}}} \leq 0.49$
Welded I Sections 	$t_f \leq 40$ mm		$0.21\sqrt{\frac{Z_{ez}}{Z_{ey}}} \leq 0.64$
	$t_f > 40$ mm		$0.25\sqrt{\frac{Z_{ez}}{Z_{ey}}} \leq 0.76$
Rolled unequal I or H Sections 	$h/b_{min} \leq 2.0$		0.21
	$h/b_{min} > 2.0$		0.34
Welded unequal I section 	$h/b_{min} \leq 2.0$		0.64
	$h/b_{min} > 2.0$		0.76
Other rolled Sections 	-------		0.76

NOTE — The selection of lateral torsional buckling imperfection factor is based on b_{min} irrespective of it being tension or compression flange.

Table 14 Moment Gradient Effect Parameter

(*Clauses* 15.2.2 *and* 15.2.2.2)

Load Case	**Factor f_M (*Clause* 15.2.2)**	**Factor k_c (Clause 15.2)**
(1)	(2)	(3)
	1.0	1.0
	$1.25 - 0.1\psi - 0.15\ \psi^2$	$\dfrac{1}{1.33 - 0.33\ \psi}$
	1.05	0.94
	For $0 \le \frac{M_0}{M_h} < 2.0$: $1.0 + 1.35\ \frac{M_0}{M_h} - 0.33\ \left[\frac{M_0}{M_h}\right]^3$ For $\frac{M_0}{M_h} \ge 2.0$: 1.05	$\frac{M_0}{M_h} < 1.0 : 1.0$ $\frac{M_0}{M_h} \ge 1.0 : 0.9$
	For $0 \le \frac{M_0}{M_h} < 1.47$: $1.25 + 0.5\ \left[\frac{M_0}{M_h}\right]^2 - 0..275\ \left[\frac{M_0}{M_h}\right]^4$ For $\frac{M_0}{M_h} \ge 1.47$: 1.05	$\frac{M_0}{M_h} < 0.5 : 0.75$ $\frac{M_0}{M_h} \ge 0.5 : 0.91$
	1.10	0.86
	For $0 \le \frac{M_0}{M_h} < 2.0$: $1.0 + 1.25\ \frac{M_0}{M_h} - 0.30\ \left[\frac{M_0}{M_h}\right]^3$ For $\frac{M_0}{M_h} \ge 2.0$: 1.10	$\frac{M_0}{M_h} < 1.0 : 1.0$ $\frac{M_0}{M_h} \ge 1.0 : 0.77$
	For $0 \le \frac{M_0}{M_h} < 1.5$: $1.25 + 0.325\ \left[\frac{M_0}{M_h}\right]^2 - 0.175\ \left[\frac{M_0}{M_h}\right]^4$ For $\frac{M_0}{M_h} \ge 1.50$: 1.10	$\frac{M_0}{M_h} < 0.5 : 0.75$ $\frac{M_0}{M_h} \ge 0.5 : 0.82$

Where

M_0 is the bending moment at midspan, and may be determined by subtracting the average of the tow hogging end moments, form the midspan sagging moment for simply supported boundary condition.

For $\frac{M_0}{M_h} < 0.0$, f_m and k_c may be conservatively taken as 1.0.

15.2.2.1 *Elastic lateral torsional buckling moment*

In case of simply supported, prismatic members with doubly symmetric cross section subjected to uniform moment, the elastic lateral torsional buckling moment, M_{crLT}, can be determined from:

$$M_{\mathrm{crLT}} = \sqrt{\left\{\left(\frac{\pi^2 E I_y}{(L_{\mathrm{LT}})^2}\right)\left(G\, I_t + \frac{\pi^2 E\, I_w}{(L_{\mathrm{LT}})^2}\right)\right\}}$$

where

L_{LT} = effective lateral unbraced length for lateral torsional buckling (*see* **15.3**);

I_t = torsional constant $= \sum b_i t_i^3 / 3$ for open section;

I_w = warping constant; and

I_y = moment of inertia about the weaker, (y), axis.

M_{cr} for different beam sections, considering loading, support condition, and asymmetric section, shall be more accurately calculated using the method given in Annex E. The above equations for calculating M_{cr} may be conservatively used for channel sections.

15.2.2.2 *Simplified method for lateral torsional buckling*

A simplified method based on effective compression flange lateral buckling as given below may be used for monosymmetric and doubly symmetric I and H sections with and without lateral restraints, to determine the equivalent compression flange lateral buckling stress reduction factor, χ_{LTc},, that is substituted in equation given in **15.2.2** for calculating the design bending strength, M_d,

The stress reduction factor for lateral buckling of equivalent compression flange, χ_{LTc}, is evaluated using equations given in **14.1.2.1** for compression members, by treating the equivalent compression flange as a strut and substituting equivalent non-dimensional slenderness , λ_{LTc},, in the place of λ.

where

$$\lambda_{\mathrm{LTc}} = k_c \beta_c \lambda_{c,z}$$

k_c is a slenderness correction factor for moment gradient between restraints, as given in Table 14.

$$\beta_c = \sqrt{\frac{0.06\,\frac{h}{t_{f,\max}}}{\lambda_{c,z} + \frac{t_{f,\max}}{t_{f,\min}}}}$$

$t_{f,\max}$ is the maximum thickness of the top and bottom flange of the section

$t_{f,\min}$ is the minimum thickness of the top and bottom flange of the section

$$\lambda_{c,z} = \sqrt{\frac{f_y}{f_{cr,cz}}}$$

where

A_c = is the area of equivalent compression flange, given by;

A_c = $A_{cf}+A_w/2$ for load applied at compression flange;

A_c = $A_{cf}+A_w/6$ for load applied at shear centre of the beam section;

A_c = A_{cf} for load applied at tension flange;

A_{cf} = is the area of compression flange (= b_c t_{fc});

A_w = is the area of the web (=h t_w); and

$f_{cr,cz}$ = is the elastic critical axial stress of the equivalent compression flange of area of the baeam, A_c, as given below, buckling about the centre line axis of the web as a strut.

15.3 Effective Length for Lateral Torsional Buckling

15.3.1 For simply supported beams and girders of span length, L, where no lateral restraint to the compression flanges is provided, but where each end of the beam is restrained against torsion, the effective length L_{LT} of the lateral buckling to be used in **15.2.2.1** shall be taken as in Table 15.

In simply supported beams with intermediate lateral restraints against lateral torsional buckling, the effective length for lateral torsional buckling, L_{LT} to be used in **15.2.2.1**, may be conservatively taken as the length of the relevant segment in between the lateral restraints, or can be calculated using other known methods or rigorous analysis**.** In the case of intermediate partial lateral restraints, the effective length, L_{LT} shall be taken as equal to 1.2 times the length of the relevant segment in between the partial lateral restraints.

Restraint against torsional rotation at supports in these beams may be provided by:

a) web or flange cleats; or

b) bearing stiffeners acting in conjunction with the bearing of the beam; or

c) lateral end frames or external supports providing lateral restraint to the compression flanges at the ends; or

d) their being built into walls.

Table 15 Effective Length for Simply Supported Beams, L_{LT}

(*Clause* 15.3.1)

Sl No.	Conditions of Restraint at Supports		Loading Condition	
	Torsional Restraint	Warping Restraint	Normal	Destabilizing
(1)	(2)	(3)	(4)	(5)
i)	Fully restrained	Both flanges fully restrained	0.70 L	0.85 L
ii)	Fully restrained	Only compression flange fully restrained	0.75 L	0.90 L
iii)	Fully restrained	Both flanges partially restrained	0.80 L	0.95 L
iv)	Fully restrained	Only compression flange partially restrained	0.85 L	1.00 L
v)	Fully restrained	No restraint in both flanges	1.00 L	1.20 L
vi)	Partially restrained by bottom flange support connection	No restraint in both flanges	1.0 L+ 2D	1.2 L+2D
vii)	Partially restrained by bottom flange bearing support	No restraint in both flanges	1.2 L+2D	1.4 L+2D

NOTES

1 Torsional restraint prevents rotation about the longitudinal axis.

2 Warping restraint prevents rotation of the flange in its plane.

3 D is the overall depth of the beam.

4 In case of continuous beams, L shall be taken as the distance between points of inflection, and the restraint conditions at the point of inflections should be considered.

15.3.2 For beams, which are provided with members giving effective lateral restraint to the compression flange at intervals along the span, in addition to the end torsional restraint required in **15.3.1**, the effective length for lateral torsional buckling shall be taken as the distance, centre-to-centre of the restraint members in the critical segment under normal loading condition and 1.2 times this distance, where the load is acting on the beam above the shear centre and towards the shear centre, so as to have greater destabilizing effect during lateral torsional buckling deformation.

15.3.3 For cantilever beams of projecting length L, the effective length L_{LT} to be used in **15.2.2.1** shall be taken as in Table 16 for different support conditions.

15.3.4 Where a member is provided intermediate lateral supports to improve the lateral buckling strength, these restraints should have sufficient strength and stiffness to prevent lateral movement of the compression flange at that point, relative to the end supports. The intermediate lateral restraints should be either connected to an appropriate bracing system capable of transferring the restraint force to the effective lateral support at the ends of the member, or should be connected to an independent robust part of the structure capable of transferring the restraint force. Two or more parallel member requiring such lateral restraint shall not be simply connected together assuming mutual dependence for the lateral restraint.

The intermediate lateral restraints should be connected to the member as close to the compression flange as practicable. Such restraints should be closer to the shear centre of the compression flange than to the shear centre of the section. However, if torsional restraint preventing relative rotation between the two flanges is provided, the intermediate lateral restraint may be connected at any appropriate level. The point of contraflexure in beams with double curvature should be additionally effectively restrained against torsion in order to be considered it as a brace location.

For beams which are provided with members giving effective lateral restraint at intervals along the span, the effective lateral restraint shall be capable of resisting a force of 2.5 percent of the maximum force in the compression flange taken as divided equally between the points at which the restraint members are provided. Further, each restraint point should be capable of resisting 1 percent of the maximum force in the compression flange.

15.3.4.1 In a series of such beams, with solid webs, which are connected together by the same system of restraint members, the sum of the restraining forces required shall be taken as 2.5 percent of the maximum flange force in one beam only.

15.3.4.2 In the case of a series of latticed beams, girders or roof trusses which are connected together by the same system of restraint members, the sum of the restraining forces required shall be taken as 2.5 percent of the maximum force in the compression flange plus 1.25 percent of this force for every member of the series other than the first, up to a maximum total of 7.5 percent.

15.3.5 Purlins adequately restrained by sheeting need not be normally checked for the restraining forces required by rafters, roof trusses or portal frames that carry predominately roof loads provided there is bracing of adequate stiffness in the plane of rafters or roof sheeting which is capable of acting as a stressed skin diaphragm.

15.3.6 In case of beams with double curvature bending, adequate direct lateral support to the compression flange in the hogging moment region may be provided as given above for simply supported beam. The effect of support to the tension (top) flange in the hogging moment region on lateral restraint to the compression flange may be considered as per specialist literature.

15.3.7 In case of cantilever beams with tip loading, at the free end the tension flange also shall be effectively braced against lateral movement.

15.4 Shear

The design of plated webs with and without stiffeners are treated in this section. The design recommendations of Corrugated plate girders are presented in Annex G.

The factored design shear force, V, in a beam due to external actions shall satisfy:

$$V \leq V_{\mathrm{d}}$$

where

V_d = design strength

= V_n / γ_{m0}

where

γ_{m0} = partial safety factor against shear failure (*see* **12.4.1**)

The nominal shear strength of a cross section, V_n, may be governed by plastic shear resistance (*see* **15.4.1**) or strength of the web as governed by shear buckling (*see* **15.4.2**).

15.4.1 The nominal plastic shear resistance under pure shear is given by:

$$V_n = V_p$$

where

$$V_p = \frac{A_v f_{yw}}{\sqrt{3}}$$

A_v = shear area; and

f_{yw} = yield strength of the web.

15.4.1.1 The shear area may be calculated as given below:

a) I-and channel sections:

1) *Major Axis Bending*:

Hot-rolled : $h\, t_w$

Welded : $d\, t_w$

2) *Minor Axis Bending*:

Hot-rolled or welded : $2b\, t_f$

b) Rectangular hollow sections of uniform thickness:

Loaded parallel to depth (h) : $A\, h / (b+h)$

Loaded parallel to width (b) : $A\, b / (b+h)$

c) Circular hollow tubes of uniform thickness : $2A / \pi$

d) Plates and solid bars : A

where

A = cross section area;

b = overall breadth of tubular section, breadth of I-section flanges;

d = clear depth of the web between flanges;

h = overall depth of the section;

t_f = thickness of the flange; and

t_w = thickness of the web.

NOTE — Fastener holes need not be accounted for in plastic design shear strength calculation provided that:

$$A_{vn} \geq (f_y / f_u)(\gamma_{m1} / \gamma_{m0})\, A_v / 0.9$$

If A_{vn} does not satisfy the above condition, the effective shear area may be taken as that satisfying the above limit. Block shear failure criteria may be verified at the end connections. Provisions given under **16** may be referred to for design strength under combined high shear and bending.

15.4.2 *Resistance to Shear Buckling*

15.4.2.1 Resistance to shear buckling shall be verified as specified, when

$d/t_w > 67\varepsilon_w$ for a web without stiffeners, and

$> 67\varepsilon_w \sqrt{\frac{K_v}{5.35}}$ for a web with stiffeners

where

K_v = shear buckling coefficient (*see* **15.4.2.2**); and

$\varepsilon_w = \sqrt{250 / f_{yw}}$

15.4.2.2 *Shear buckling design methods*

The nominal shear strength, V_n, of webs with or without intermediate stiffeners as governed by buckling may be evaluated using one of the following methods:

a) *Simple post-critical method* — The simple post critical method, based on the shear buckling strength can be used for webs of I-section girders, with or without intermediate transverse stiffener, provided that the web has transverse stiffeners at the supports. The nominal shear strength is given by:

$$V_n = V_{cr}$$

where

V_{cr} = shear force corresponding to web buckling; and

= $A_v\tau_b$

where

τ_b = shear stress corresponding to web buckling, determined as follows:

1) when $\lambda_w \leq 0.8$, $\tau_b = f_{yw}/\sqrt{3}$
2) when $0.8 < \lambda_w < 1.2$, $\tau_b = [1-0.8(\lambda_w - 0.8)](f_{yw}/\sqrt{3})$
3) when $\lambda_w \geq 1.2$, $\tau_b = f_{yw}/\left(\sqrt{3}\,\lambda_w^{\;2}\right)$

where

λ_w = Non -dimensional web slenderness ratio for shear buckling stress, given by:

$$\lambda_w = \sqrt{f_{yw}/(\sqrt{3}\,\tau_{cr,e})}$$

$\tau_{cr,e}$ = the elastic critical shear stress of the web = $\dfrac{K_v \pi^2 E}{12\left(1-\mu^2\right)\left[d/t_w\right]^2}$

where

μ = Poisson’s ratio; and

K_v = 5.35 when transverse stiffeners are provided only at supports

= $4.0 + 5.35/(c/d)^2$ for $c/d < 1.0$

= $5.35 + 4.0/(c/d)^2$ for $c/d \geq 1.0$

where c, d are the spacing of transverse stiffeners and depth of the web, respectively.

b) *Tension field method* — The tension field method, based on the post-shear buckling strength, may be used for webs with intermediate transverse stiffeners, in addition to the transverse stiffeners at supports, provided the panels adjacent to the panel under tension field action, or the end posts provide anchorage for the tension fields and if $c/d \geq 1.0$, where c, d are the spacing of transverse stiffeners and depth of the web, respectively.

In the tension field method, the nominal shear resistance, V_n, is given by:

$$V_n = V_{tf}$$

where

$$V_{tf} = [A_v \tau_b + 0.9\, w_{tf} t_w f_v \sin\phi] \leq V_p$$

where

τ_b = shear stress corresponding to buckling of web **15.4.2.2**(a);

f_v = yield strength of the tension field obtained from $\left[f_{yw}^2 - 3\tau_b^2 + \psi^2\right]^{0.5} - \psi$;

ψ = $1.5\,\tau_b \sin 2\phi$;

ϕ = inclination of the tension field nearly $= \tan^{-1}\dfrac{\left(\dfrac{d}{c}\right)}{1.5}$;

w_{tf} = width of the tension field, given by:

= $d\cos\phi - (c - s_c - s_t)\sin\phi$;

f_{yw} = yield stress of the web;

d = depth of the web;

c = spacing of transverse stiffeners in the web; and

s_c, s_t = anchorage lengths of tension field along the compression and tension flange respectively, obtained from:

$$s = \frac{2}{\sin\phi}\left[\frac{M_{fr}}{f_{yw} t_w}\right]^{0.5} \leq c$$

M_{fr} = reduced plastic moment capacity of the respective flange plate (disregarding any edge stiffener) after accounting for the axial force, N_f in the flange, due to overall bending and any external axial force in the cross section, and is calculated as :

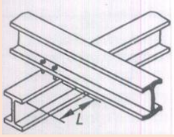
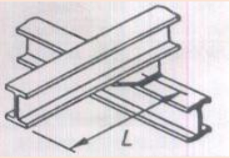
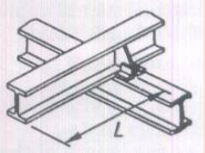
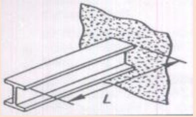
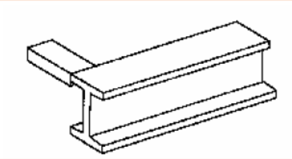
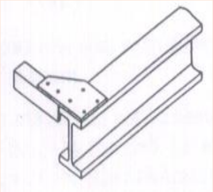
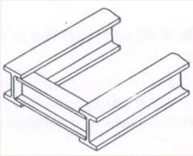
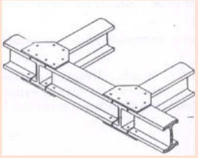
$$M_{fr} = 0.25 b_f t_f^2 f_{yf}\left[1 - \left\{N_f / \left(b_f t_f f_{yf}/\gamma_{m0}\right)\right\}^2\right]$$

b_f, t_f = width and thickness of the relevant flange respectively; and

f_{yf} = yield stress of the flange.

Table 16 Effective Length, L_{LT} for Cantilever of Length, *L*

(*Clause* 15.3.3)

Restraint Condition		**Loading Conditions**	
At Support	At tip	Normal	Destabilizing
(2)	(3)	(4)	(5)
a) Continuous, with lateral restraint to top flange 	1) Free 2) Lateral restraint to top flange 3) Torsional restraint 4) Lateral and torsional restraint	3.0*L* 2.7*L* 2.4*L* 2.1*L*	7.5*L* 7.5*L* 4.5*L* 3.6*L*
b) Continuous, with partial torsional restraint 	1) Free 2) Lateral restraint to top flange 3) Torsional restraint 4) Lateral and torsional restraint	2.0*L* 1.8*L* 1.6*L* 1.4*L*	5.0*L* 5.0*L* 3.0*L* 2.4*L*
c) Continuous, with lateral and torsional restraint 	1) Free 2) Lateral restraint to top flange 3) Torsional restraint 4) Lateral and torsional restraint	1.0*L* 0.9*L* 0.8*L* 0.7*L*	2.5*L* 2.5*L* 1.5*L* 1.2*L*
d) Restrained laterally, torsionally and against rotation on plan 	1) Free 2) Lateral restraint to top flange 3) Torsional restraint 4) Lateral and torsional restraint	0.8*L* 0.7*L* 0.6*L* 0.5*L*	1.4*L* 1.4*L* 0.6*L* 0.5*L*
Tip Restraint Conditions			
a) Free 	b) Lateral restraint to top flange 	c) Torsional restraint 	d) Lateral and torsional restraint 

15.5 Stiffened Web Panels

15.5.1 *End Panels Design* (*see* Fig.12)

The girders in which the interior panel (panel A) is designed using tension field action, the end panels shall be designed using only simple post critical method, according to **15.4.2.2**(a).

Additionally, the end panel along with the stiffeners should be checked as a beam spanning between the flanges to resist a shear force, $R_{tf,}$ and a moment, $M_{tf,}$ due to tension field forces as given in **15.5.3**. Further, end stiffener should be capable of resisting the reaction plus a compressive force due to the moment, equal to M_{tf} [*see* Fig. (12)].

15.5.2 *End Panels Designed Using Tension Field Action* (*see* Fig. 13 and Fig. 14)

The end panel (Panel A) shall be designed according to **15.4.2.2**(b).

Additionally, it should be provided with an end post consisting of a single or double stiffener, (*see* Fig. 13 and Fig. 14), satisfying the following.

a) *Single stiffener* (*see* Fig. 13) — The top of the end post should be rigidly connected to the flange using full strength welds.

The end post should be capable of resisting the reaction plus a moment from the anchor forces equal to 2/3 M_{tf} due to tension field forces, where M_{tf} is obtained from **15.5.3**. The width and thickness of the end post are not to exceed the width and thickness of the flange.

b) *Double stiffener* (*see* Fig. 14) —The end post should be checked as a beam spanning between the flanges of the girder and capable of resisting a shear force R_{tf} and a moment, M_{tf} due to the tension field forces as given in **15.5.3**.

15.5.3 *Anchor Forces*

The resultant longitudinal shear, R_{tf}, and a moment M_{tf} from the anchor of tension field forces are evaluated as given below:

$$R_{tf} = \frac{H_q}{2} \text{ and } M_{tf} = \frac{H_q d}{10}$$

where

$$H_q = 1.25V_p\left(1 - \frac{V_{cr}}{V_p}\right)^{1/2}$$

$$V_p = \frac{dtf_y}{\sqrt{3}}$$

d = web depth,

If the actual factored shear force, V in the panel designed using tension field approach is less than the shear strength, V_{tf} as given in **15.4.2.2**(b), then the values of H_q may be reduced by the ratio $\frac{V - V_{cr}}{V_{tf} - V_{cr}}$

where

V_{cr} = critical shear strength for the panel designed utilizing tension field action as given in **15.4.2.2**(a); and

V_{tf} = basic shear strength for the panel utilizing tension field action as given in **15.4.2.2**(b).

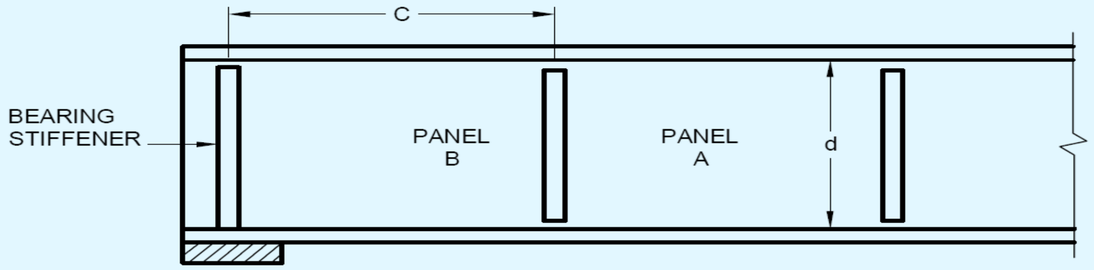

C
BEARING STIFFENER
PANEL B
PANEL A
d

FIG. 12 END PANEL DESIGNED NOT USING TENSION FIELD ACTION

NOTES

1 Panel A is designed utilizing tension field action as given in 15.4.2.2(b).

2 Panel B is designed using simple post critical method as given in 15.4.2.2(a).

3 Bearing stiffener is designed for the compressive force due to bearing plus compressive force due to the moment M_{tf} as given in 15.5.3.

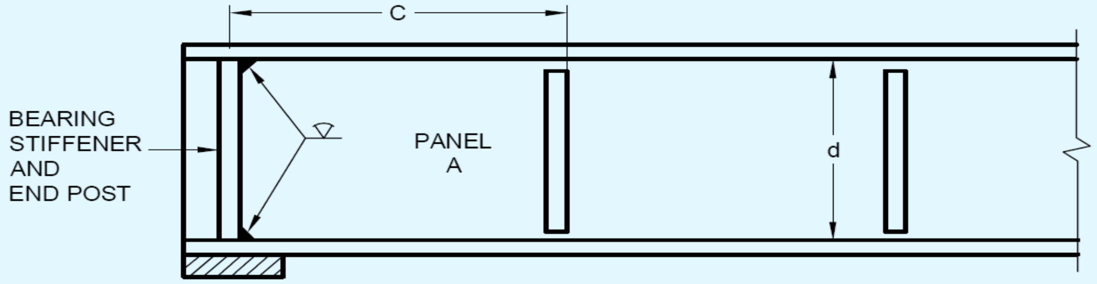

C
BEARING STIFFENER AND END POST
PANEL A
d

FIG. 13 END PANEL DESIGNED USING TENSION FIELD ACTION (SINGLE STIFFENER)

NOTES

1 Panel A is designed utilizing tension field action as given in 15.4.2.2(b).

2 Bearing stiffener and end post is designed for combination of compressive loads due to bearing and a moment equal to 2/3 M_{tf} as given in 15.5.3.

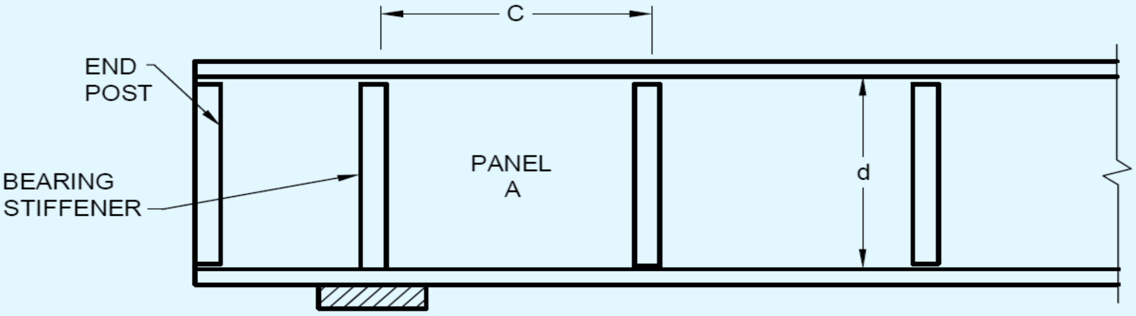

C
END POST
BEARING STIFFENER
PANEL A
d

FIG. 14 END PANEL DESIGNED USING TENSION FIELD ACTION (DOUBLE STIFFENER)

NOTES

1 Panel A is designed utilizing tension field action as given in 15.4.2.2(b).

2 Bearing stiffener is designed for compressive force due to bearing as given in 15.4.2.2(a).

3 End post is designed for horizontal shear R_{tf} and moment M_{tf} as given in 15.5.3.

15.5.4 *Panels with Openings* — Panels with opening of dimension greater than 10 percent of the minimum panel dimension should be designed without using tension field action as given in 15.4.2.2(b). The adjacent panels should be designed as an end panel as given in 15.5.1 or 15.5.2, as appropriate.

15.6 Design of Beams and Plate Girders with Solid Webs

15.6.1 *Minimum Web Thickness*

The thickness of the web in a section shall satisfy the requirements given in 15.6.1.1 and 15.6.1.2.

15.6.1.1 *Serviceability requirement*

a) when transverse stiffeners are not provided:

   1) $\frac{d}{t_w} \leq 200\varepsilon_w$ (web connected to flanges along both longitudinal edges); and

   2) $\frac{d}{t_w} \leq 90\varepsilon_w$ (web connected to flanges along one longitudinal edge only).

b) when only transverse stiffeners are provided (in webs connected to flanges along both longitudinal edges):

   1) when $3d \geq c \geq d$

   $\frac{d}{t_w} \leq 200\varepsilon_w$;

   2) when $0.74\,d \leq c < d$

   $\frac{c}{t_w} \leq 200\varepsilon_w$;

   3) when $c < 0.74d$

   $\frac{d}{t_w} \leq 270\varepsilon_w$; and

   4) when $c > 3d$, the web shall be considered as unstiffened.

c) when transverse stiffeners and longitudinal stiffeners at one level only are provided (distance from the compression flange equal to 2/5 of the distance from the compression flange angle, plate or tongue plate to the neutral axis) according to 15.7.13(a):

   1) when $2.4d \geq c \geq d$

   $\frac{d}{t_w} \leq 250\varepsilon_w$

   2) when $0.74\,d \leq c \leq d$

   $\frac{c}{t_w} \leq 250\varepsilon_w$

   3) when $c < 0.74\,d$

   $\frac{d}{t_w} \leq 340\varepsilon_w$

d) when a second longitudinal stiffener (located at neutral axis is provided) $\frac{d}{t_w} \leq 400\varepsilon_w$

where

c = spacing of transverse stiffener (*see* Fig. 12 and Fig. 13);

d = depth of the web;

f_{yw} = yield stress of the web;

t_w = thickness of the web; and

ε_w = yield stress ratio of web = $\sqrt{250/f_{yw}}$.

15.6.1.2 *Compression flange buckling requirement*

In order to avoid buckling of the compression flange into the web, the web thickness shall satisfy the following:

a) When transverse stiffeners are not provided;

$$\frac{d}{t_w} \leq 345\varepsilon_f^2$$

b) When transverse stiffeners are provided, and

1) when $c \geq 1.5\ d$

$$\frac{d}{t_w} \leq 345\varepsilon_f^2$$

2) when $c < 1.5d$

$$\frac{d}{t_w} \leq 345\varepsilon_f$$

where

c = spacing of transverse stiffener (*see* Fig. 12 and Fig. 13);

d = depth of the web;

f_{yf} = yield stress of compression flange;

t_w = thickness of the web; and

ε_f = yield stress ratio of flange = $\sqrt{250/f_{yf}}$.

15.6.2 *Sectional Properties*

The effective sectional area of compression flanges shall be the gross area with deductions for excessive width of plates as specified for compression members [*see* **14**] and for open holes occurring in a plane perpendicular to the direction of stress at the section being considered (*see* **15.2.1.4**).

The effective sectional area of tension flanges shall be the gross sectional area with deductions for holes as specified in **15.2.1.4**.

The effective sectional area for parts in shear shall be taken as specified in **15.4.1.1**.

15.6.3 *Flanges*

15.6.3.1 In riveted or bolted construction, flange angles shall form as large a part of the area of the flange as practicable (preferably not less than one-third) and the number of flange plates shall be kept to a minimum.

In exposed situations, where flange angles are used, at least one plate of the top flange shall extend over the full length of the girder, unless the top edge of the web is machined flush with the flange angles. Where two or more flange plates are used, tacking rivets shall be provided, if necessary to comply with the requirements of **17**.

Each flange plate shall extend beyond its theoretical cut-off point, and the extension shall contain sufficient rivets, bolts or welds to develop in the plate, the load calculated for the bending moment on the girder section (taken to include the curtailed plate) at the theoretical cut-off point.

The outstand of flange plates, that is the projection beyond the outer line of connections to flange angles, channel or joist flanges or in the case of welded constructions their projection beyond the face of the web or tongue plate, shall not exceed the values given in **10.8.2** (*see* Table 2).

In the case of box girders, the thickness of any plate, or the aggregate thickness of two or more plates, when these plates are tacked together to form the flange, shall satisfy the requirements given in **10.8.2** (*see* Table 2).

15.6.3.2 *Flange splices*

Flange splices should preferably, not be located at points of maximum stress. Where splice plates are used, their area shall be not less than 5 percent in excess of the area of the flange element spliced; their centre of gravity shall coincide, as nearly as possible, with that of the element spliced. There shall be enough bolts, rivets or welds on each side of the splice to develop the load in the element spliced plus 5 percent but in no case should the strength developed be less than 50 percent of the effective strength of the material spliced. In welded construction, flange plates shall be joined by complete penetration butt welds, wherever possible. These butt welds shall develop the full strength of the plates.

15.6.3.3 *Connection of flanges to web*

The flanges of plate girders shall be connected to the web by sufficient rivets, bolts or welds to transmit the maximum horizontal shear force resulting from the bending moment gradient in the girder, combined with any vertical loads which are directly applied to the flange. If the web is designed using tension field method as given in **15.4.2.2** (b), the weld should be able to transfer the tension field stress, f_{yw} acting on the web.

15.6.3.4 *Bolted/Riveted construction*

For girders in exposed situations and which do not have flange plates for their entire length, the top edge of the web plate shall be flush with or above the angles, and the bottom edge of the web plate shall be flush with or set back from the angles.

15.6.3.5 *Welded construction*

The gap between the web plates and flange plates shall be kept to a minimum and for fillet welds shall not exceed 1 mm at any point before welding.

15.6.4 *Webs*

15.6.4.1 *Effective sectional area of web of plate girder*

The effective cross sectional area shall be taken as the full depth of the web plate multiplied by the thickness.

NOTE — Where webs are varied in thickness in the depth of the section by the use of tongue plates or the like, or where the proportion of the web included in the flange area is 25 percent or more of the overall depth, the above approximation is not permissible and the maximum shear stress shall be computed on theory.

15.6.4.2 *Splices in webs*

Splices and cutouts for service ducts in the webs should preferably not be located at points of maximum shear force and heavy concentrated loads.

Splices in the webs of the plate girders and rolled sections shall be designed to resist the shears and moments at the spliced section (*see* Annex F).

In riveted or bolted construction, splice plates shall be provided on each side of the web. In welded construction, web splices shall preferably be made with complete penetration butt welds.

15.6.4.3 Where additional plates are required to augment the strength of the web, they shall be placed on each side of the web and shall be equal in thickness. The proportion of shear force assumed to be resisted by these plates shall be limited by the amount of horizontal shear which they can transmit to the flanges through their fastenings, and such reinforcing plates and their fastenings shall be carried up to the points at which the flange without the additional plates is adequate.

15.7 Stiffener Design

15.7.1 *General*

15.7.1.1 When the web of a member acting alone (that is, without stiffeners) proves inadequate, stiffeners for meeting the following requirements should be provided:

a) *Intermediate transverse web stiffener* — To improve the buckling strength of a slender web due to shear (*see* **15.7.2**).

b) *Load carrying stiffener* — To prevent local buckling of the web due to concentrated loading (*see* **15.7.3** and **15.7.5**).

c) *Bearing stiffener* — To prevent local crushing of the web due to concentrated loading (*see* **15.7.4** and **15.7.6**).

d) *Torsion stiffener* — To provide torsional restraint to beams and girders at supports (*see* **15.7.9**).

e) *Diagonal stiffener* — To provide local reinforcement to a web under shear and bearing (*see* **15.7.7**).

f) *Tension stiffener* — To transmit tensile forces applied to a web through a flange (*see* **15.7.8**).

The same stiffeners may perform more than one function and their design should comply with the requirements of all the functions for which designed.

15.7.1.2 *Outstand of web stiffeners*

Unless the outer edge is continuously stiffened, the outstand from the face of the web should not exceed $20t_q\varepsilon$.

When the outstand of web stiffener is between $14t_q\varepsilon$ and $20t_q\varepsilon$, then the stiffener design should be on the basis of a core section with an outstand of only $14t_q\varepsilon$, where t_q is the thickness of the stiffener.

15.7.1.3 *Stiff bearing length*

The stiff bearing length of any element, b_1, is that length which cannot deform appreciably in bending. To determine b_1, the dispersion of load through a steel bearing element should be taken as 45° through solid material, such as bearing plates, flange plates, etc (*see* Fig.15).

15.7.1.4 *Eccentricity*

Where a load or reaction is applied eccentric to the centreline of the web or where the centroid of the stiffener does not lie on the centreline of the web, the resulting eccentricity of loading should be accounted for in the design of the stiffener.

15.7.1.5 *Buckling resistance of stiffeners*

The buckling resistance F_{qd} should be based on the design compressive stress f_{cd} (*see* **14.1.2**) of a strut (curve c), the radius of gyration being taken about the axis parallel to the web. The effective section is the full area or core area of the stiffener (*see* **15.7.1.2**) together with an effective length of web on each side of the centreline of the stiffeners, limited to 20 times the web thickness. The design strength used should be the minimum value obtained for buckling about the web or the stiffener.

The effective length for intermediate transverse stiffeners used in calculating the buckling resistance, F_{qd}, should be taken as 0.7 times the length, L of the stiffener.

The effective length for load carrying web stiffeners used in calculating the buckling resistance, F_{xd}, assumes that the flange through which the load or reaction is applied is effectively restrained against lateral movement relative to the other flange, the effective length should be taken as:

a) $KL = 0.7L$, when flange is restrained against rotation in the plane of the stiffener (by other structural elements); and

b) $KL = L$, when flange is not so restrained.

where

L = length of the stiffener.

If the load or reaction is applied to the flange by a compression member, then unless effective lateral restraint is provided at that point, the stiffener should be designed as part of the compression member applying the load, and the connection between the column and beam flange shall be checked for the effects of the strut action.

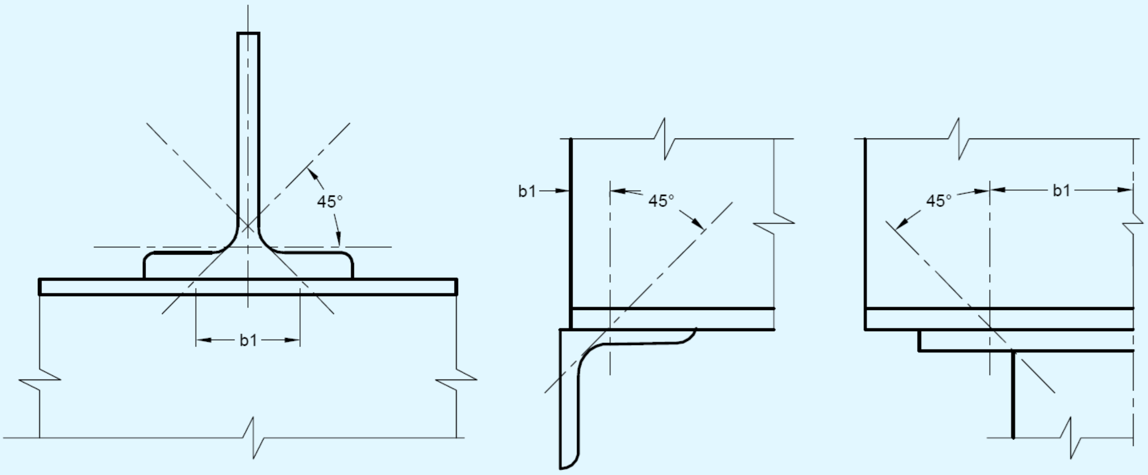


FIG. 15 STIFF BEARING LENGTH, B1

15.7.2 *Design of Intermediate Transverse Web Stiffeners*

15.7.2.1 *General*

Intermediate transverse stiffeners may be provided on one or both sides of the web.

15.7.2.2 *Spacing*

Spacing of intermediate stiffeners, where provided, shall comply with 15.6.1 depending on the thickness of the web.

15.7.2.3 *Outstand of stiffeners*

The outstand of the stiffeners should comply with 15.7.1.2.

15.7.2.4 *Minimum stiffeners*

Transverse web stiffeners not subject to external loads or moments should have a second moment of area, I_s about the centreline of the web, if stiffeners are on both sides of the web and about the face of the web, if single stiffener on only one side of the web is used such that:

if $c/d \geq \sqrt{2}$, $I_s \geq 0.75\, d\, t_w^3$, and

if $c/d < \sqrt{2}$, $I_s \geq \dfrac{1.5\, d^3 t_w^3}{c^2}$

where

c = actual stiffener spacing;

d = depth of the web; and

t_w = minimum required web thickness for spacing using tension field action, as given in **15.4.2.1**.

15.7.2.5 *Buckling check on intermediate transverse web stiffeners*

Stiffeners not subjected to external loads or moments should be checked for a stiffener force:

$$F_q = V - V_{cr} / \gamma_{m0} \leq F_{qd}$$

where

F_{qd} = design resistance of the intermediate stiffeners;

V_{cr} = shear buckling resistance of the web panel designed without using tension field action as given in **15.4.2.2 (a)**; and

V = factored shear force adjacent to the stiffener.

Stiffeners subject to external loads and moments should meet the conditions for load carrying web stiffeners in **15.7.3**. In addition they should satisfy the following interaction expression:

$$\frac{F_q - F_x}{F_{qd}} + \frac{F_x}{F_{xd}} + \frac{M_q}{M_{yq}} \leq 1$$

where

F_q = stiffener force given above;

F_{qd} = design resistance of an intermediate web stiffener corresponding to buckling about an axis parallel to the web (*see* **15.7.1.5**);

F_x = external load or reaction at the stiffener;

F_{xd} = design resistance of a load carrying stiffener corresponding to buckling about axis parallel to the web (*see* **15.7.1.5**);

M_q = moment on the stiffener due to eccentrically applied load and transverse load, if any; and

M_{yq} = yield moment capacity of the stiffener based on its elastic modulus about its centroidal axis parallel to the web.

If $F_q < F_x$, then $(F_q - F_x)$ should be taken as zero;

15.7.2.6 *Connection of intermediate stiffeners to web*

Intermediate transverse stiffeners not subject to external loading should be connected to the web so as to withstand a shear between each component of the stiffener and the web (in kN/mm) of not less than:

$$t_w^2 / (5 b_s)$$

where

t_w = web thickness, in mm; and

b_s = outstand width of the stiffener, in mm.

For stiffeners subject to external loading, the shear between the web and the stiffener due to such loading has to be added to the above value.

Stiffeners not subject to external loads or moments may terminate clear of the tension flange and in such a situation the distance cut short from the line of the weld should not be more than $4t_w$.

15.7.3 *Load Carrying Stiffeners*

15.7.3.1 *Web check*

Load carrying web stiffeners should be provided where compressive forces applied through a flange by loads or reactions exceed the buckling strength, F_{cdw}, of the unstiffened web, calculated using the following:

The effective length of the web for evaluating the slenderness ratio is calculated as in 15.7.1.5. The area of cross section is taken as $(b_1+n_1)\ t_w$.

where

b_1 = width of stiff bearing on the flange (*see* 15.7.1.3); and

n_1 = dispersion of the load through the web at 45°, to the level of half the depth of the cross-section.

The buckling strength of this web about axis parallel to the web is calculated as given in 14.1.2.1, using curve 'c'.

15.7.4 *Bearing Stiffeners*

Bearing stiffeners should be provided for webs where forces applied through a flange by loads or reactions exceeding the local capacity of the web at its connection to the flange, F_w, given by:

$$F_w = (b_1 + n_2) t_w f_{yw} / \gamma_{m0}$$

where

b_1 = Stiff bearing length (*see* 15.7.1.3);

n_2 = Length obtained by dispersion through the flange to the web junction at a slope of 1 : 2.5 to the plane of the flange;

t_w = Thickness of the web; and

f_{yw} = Yield stress of the web.

15.7.5 *Design of Load Carrying Stiffeners*

15.7.5.1 *Buckling check*

The external load or reaction, F_x on a stiffener should not exceed the buckling resistance, F_{xd} of the stiffener as given in 15.7.1.5.

Where the stiffener also acts as an intermediate stiffener it should be checked for the effect of combined loads in accordance with 15.7.2.5.

15.7.5.2 *Bearing check*

Load carrying web stiffeners should also be of sufficient size that the bearing strength of the stiffener, $F_{psd,}$ given below is not less than the load transferred, F_x

$$F_{psd} = A_q f_{yq} / (0.8\gamma_{m0}) \geq F_x$$

where

F_x = external load or reaction,

A_q = area of the stiffener in contact with the flange, and

f_{yq} = yield stress of the stiffener.

15.7.6 *Design of Bearing Stiffeners*

Bearing stiffeners should be designed for the applied load or reaction less the local capacity of the web as given in **15.7.4**. Where the web and the stiffener material are of different strengths the lesser value should be assumed to calculate the capacity of the web and the stiffener. Bearing stiffeners should project nearly as much as the overhang of the flange through which load is transferred.

15.7.7 *Design of Diagonal Stiffeners*

Diagonal stiffeners should be designed to carry the portion of the applied shear and bearing that exceeds the capacity of the web.

Where the web and the stiffener are of different strengths, the value for design should be taken as given in **15.7.6**.

15.7.8 *Design of Tension Stiffeners*

Tension stiffeners should be designed to carry the portion of the applied load or reaction less the capacity of the web as given in **15.7.4** for bearing stiffeners.

Where the web and the stiffener are of different strengths, the value for design should be taken as given in **15.7.6**.

15.7.9 *Torsional Stiffeners*

Where bearing stiffeners are required to provide torsional restraint at the supports of the beam, they should meet the following criteria:

a) Conditions of **15.7.4**; and

b) Second moment of area of the stiffener section about the centreline of the web, I_s should be such that:

$$I_s \geq 0.34\, \alpha_s\, D^3\, T_{cf}$$

where

α_s = 0.006 for $L_{LT} / r_y \leq 50$;

= $0.3/(L_{LT}/r_y)$ for $50 < L_{LT}/r_y \leq 100$;

= $30/(L_{LT}/r_y)^2$ for $L_{LT}/r_y > 100$;

D = Overall depth of beam at support;

T_{cf} = Maximum thickness of compression flange in the span under consideration;

L_{LT} = Laterally unsupported effective length of the compression flange of the beam; and

r_y = Radius of gyration of the beam about the minor axis.

15.7.10 *Connection to Web of Load Carrying and Bearing Stiffeners* — Stiffeners, which resist loads or reactions applied through a flange, should be connected to the web by sufficient welds or fasteners to transmit a design force equal to the lesser of:

a) tension capacity of the stiffener; and

b) sum of the forces applied at the two ends of the stiffener when they act in the same direction or the larger of the forces when they act in opposite directions.

Stiffeners, which do not extend right across the web, should be of such length that the shear stress in the web due to the design force transmitted by the stiffener does not exceed the shear strength of the web. In addition, the capacity of the web beyond the end of the stiffener should be sufficient to resist the applied force.

15.7.11 *Connection to Flanges*

15.7.11.1 *In tension*

Stiffeners required to resist tension should be connected to the flange transmitting the load by continuous welds or non-slip fasteners.

15.7.11.2 *In compression*

Stiffeners required to resist compression should either be fitted against the loaded flange or connected by continuous welds or non-slip fasteners.

The stiffener should be fitted against or connected to both flanges when:

a) a load is applied directly over a support; or

b) it forms the end stiffener of a stiffened web; or

c) it acts as a torsion stiffener.

15.7.12 *Hollow Sections*

Where concentrated loads are applied to hollow sections consideration should be given to local stresses and deformations and the section reinforced as necessary.

15.7.13 *Horizontal Stiffeners*

Where horizontal stiffeners are used in addition to vertical stiffeners, they shall be as follows:

a) One horizontal stiffener shall be placed on the web at a distance from the compression flange equal to 2/5 of web depth, d when the thickness of the web is less than the limits specified in **15.6.1**. The stiffener shall be designed so that I_s is not less than $4ct_w^3$ where I_s and t_w are as defined in **15.7.2.4** and c is the actual distance between the vertical stiffeners;

b) A second horizontal stiffener (single or double) shall be placed at the neutral axis of the girder when the thickness of the web is less than the limit specified in **15.6.1**. This stiffener shall be designed so that I_s is not less than $d_2\,t_w^3$ where I_s and t_w are as defined in **15.7.2.4** and d_2 is twice the clear distance from the compression flange angles, plates or tongue plates to the neutral axis;

c) Horizontal web stiffeners shall extend between vertical stiffeners, but need not be continuous over them; and

d) Horizontal stiffeners may be in pairs arranged on each side of the web, or single located on one side of the web.

15.8 Box Girders

The design and detailing of box girders shall be such as to give full advantage of its higher load carrying capacity. Box girder shall be designed in accordance with specialist literature. The diaphragms and horizontal stiffeners should conform to **15.7.12** and **15.7.13**.

15.8.1 All diaphragms shall be connected so as to transfer the resultant shears to the web and flanges.

15.8.2 Where the concentrated or moving load does not act directly on top of the web, the local effect shall be considered in the design of flanges and the diaphragms.

15.9 Purlins and Sheeting Rails (Girts)

All purlins shall be designed in accordance with the requirements for beams as specified in **15.2.1** and **15.2.2**. The limitations of bending stress based on lateral instability of the compression flange shall be considered if the purlin does not receive adequate support from bracings and sheathings in the plane of compression flange. In any case the maximum bending moment shall not exceed the values specified in **15.2.1**. The calculated deflections should not exceed those permitted for the type of roof cladding used, as specified in **12.6.1**. In calculating the bending moment, advantage may be taken of the continuity of the purlin over supports. The bending about the two axes shall be determined separately and checked according to the biaxial bending requirements specified under **16**.

15.10 Bending in a Non-Principal Plane

15.10.1 When the flexural deflection of a member is constrained to a non-principal plane by lateral restraints preventing lateral deflection, then the force exerted by the restraints shall be determined, and the principal axes bending moments acting on the member shall be calculated from these forces and applied forces, by a rational analysis. The combined effect of bending about the principal axes shall satisfy the requirements given under **16**.

15.10.2 When the deflections of a member loaded in a non-principal plane are unconstrained; the principal axes bending moments shall be calculated by a rational analysis. The combined effect of bending about the principal axes shall satisfy the requirements given under **16**.

16 MEMBER SUBJECTED TO COMBINED FORCES

16.1 General

This Section governs the design of members subjected to combined forces, such as shear force and bending, axial force and bending, or shear force, axial force and bending.

16.2 Combined Shear and Bending

16.2.1 No reduction in moment capacity of the section is necessary as long as the cross section is not subjected to high shear force (factored value of applied shear force is less than or equal to 60 percent of the shear strength of the section as given in **15.4**). The moment capacity may be taken as, M_d (*see* **15.2**) without any reduction.

16.2.2 When the factored value of the applied shear force is high (exceeds the limit specified in **16.2.1**), the factored moment of the section should be less than the moment capacity of the section under higher shear force, M_{dv}, calculated as given below:

a) Plastic or compact section:

$$M_{dv} = M_d - \beta(M_d - M_{fd}) \leq 1.2\, Z_e f_y / \gamma_{m0}$$

where

$\beta = (2\,V/V_d - 1)^2$;

M_d = plastic design moment of the whole section disregarding high shear force effect (*see* **15.2.1.2**); considering web buckling effects (*see* **15.2.1.1**);

V = factored applied shear force as governed by web yielding or web buckling;

V_d = design shear strength as governed by web yielding or web buckling (*see* **15.4.1** or **15.4.2**);

M_{fd} = plastic design strength of the area of the cross section excluding the shear area, considering partial safety factor γ_{m0}; and

Z_e = elastic section modulus of the whole section.

b) Semi-compact section:

$$M_{dv} = Z_e f_y / \gamma_{m0}$$

16.3 Combined Axial Force and Bending Moment

Under combined axial force and bending moment, section strength as governed by material failure and member strength as governed by buckling failure shall be checked in accordance with **16.3.1** and **16.3.2** respectively.

16.3.1 *Section Strength*

16.3.1.1 *Plastic and compact sections*

In the design of members subjected to combined axial force (tension or compression) and bending moment, the following should be satisfied:

$$\left(\frac{M_{\mathrm{y}}}{M_{\mathrm{ndy}}}\right)^{\alpha_1} + \left(\frac{M_{\mathrm{z}}}{M_{\mathrm{ndz}}}\right)^{\alpha_2} \leq 1.0$$

Conservatively, the following equation may also be used under combined axial force and bending moment:

$$\frac{N}{N_{\mathrm{d}}} + \frac{M_{\mathrm{y}}}{M_{\mathrm{dy}}} + \frac{M_{\mathrm{z}}}{M_{\mathrm{dz}}} \leq 1.0$$

where

α_1, α_2 = constants as given in Table 17;

A_{g} = gross area of the cross section;

M_{dy}, M_{dz} = design strength under corresponding moment acting alone (*see* **15.2**);

M_{ndy}, M_{ndz} = design reduced flexural strength under combined axial force and the respective uniaxial moment acting alone (*see* **16.3.1.2**);

M_{y}, M_{z} = factored applied moments about the minor and major axis of the cross section, respectively;

N = factored applied axial force (Tension, T or Compression, P);

N_{d} = design strength in tension, T_{d} as obtained from **12** or in compression due to yielding given by $N_{\mathrm{d}} = A_{\mathrm{g}} f_{\mathrm{y}}/\gamma_{\mathrm{m0}}$; and

γ_{m0} = partial factor of safety in yielding.

16.3.1.2 For plastic and compact sections without bolts holes, the following approximations may be used for evaluating M_{ndy} and M_{ndz}:

a) Plates:

$$M_{\mathrm{nd}} = M_{\mathrm{d}}\,(1 - n^2)$$

b) Welded I or H-sections:

$$M_{ndy} = M_{dy}\left[1 - \left(\frac{n-a}{1-a}\right)^2\right] \leq M_{dy} \qquad (n \geq a)$$

$$M_{\mathrm{ndz}} = M_{\mathrm{dz}}\,(1 - n)\,/\,(1 - 0.5a) \leq M_{\mathrm{dz}}$$

where

$n = N/N_{\mathrm{d}}$ and $a = (A - 2\,b\,t_{\mathrm{f}})\,/A \leq 0.5$

c) For standard I or H sections:

$M_{\mathrm{ndz}} = 1.11\,M_{\mathrm{dz}}\,(1 - n) \leq M_{\mathrm{dz}}$

for $n \leq 0.2$, $M_{\mathrm{ndy}} = M_{\mathrm{dy}}$

for $n > 0.2$, $M_{\mathrm{ndy}} = 1.56\,M_{\mathrm{dy}}\,(1 - n)\,(n + 0.6)$

d) For rectangular hollow sections and welded box sections:

When the section is symmetric about both axes and without bolt holes:

$$M_{\mathrm{ndy}} = M_{\mathrm{dy}}\,(1 - n)/(1 - 0.5a_{\mathrm{f}}) \leq M_{\mathrm{dy}}$$

$$M_{\mathrm{ndz}} = M_{\mathrm{dz}}\,(1 - n)/(1 - 0.5a_{\mathrm{w}}) \leq M_{\mathrm{dz}}$$

where

$a_{\mathrm{f}} = (A - 2\,h\,t_{\mathrm{w}})/A \leq 0.5$

$a_{\mathrm{w}} = (A - 2\,b\,t_{\mathrm{f}})/A \leq 0.5$

e) Circular hollow tubes without bolt holes:

$$M_{\mathrm{nd}} = 1.04\,M_{\mathrm{d}}\,(1 - n^{1.7}) \leq M_{\mathrm{d}}$$

Table 17 Constants α_1 and α_2

(*Clause* 16.3.1.1)

Sl No. (1)	Section (2)	α_1 (3)	α_2 (4)
i)	I and Channel	$5n \geq 1$	2
ii)	Circular tubes	2	2
iii)	Rectangular tubes	$1.66/(1 - 1.13n^2) \leq 6$	$1.66/(1 - 1.13n^2) \leq 6$
iv)	Solid rectangles	$1.73 + 1.8n^3$	$1.73 + 1.8\,n^3$

NOTE — $n = N/N_{\mathrm{d}}$

16.3.1.3 *Semi-compact section*

In the absence of high shear force (*see* **16.2.1**), semi-compact section design is satisfactory under combined axial force and bending, if the maximum longitudinal stress under combined axial force and bending, f_{x} satisfies the following criteria:

$$f_{\mathrm{x}} \leq f_{\mathrm{y}}/\gamma_{\mathrm{m0}}$$

For cross section without holes, the above criterion reduces to,

$$\frac{N}{N_{\mathrm{d}}} + \frac{M_{\mathrm{y}}}{M_{\mathrm{dy}}} + \frac{M_{\mathrm{z}}}{M_{\mathrm{dz}}} \leq 1.0$$

where

N_{d}, M_{dy}, M_{dz} are as defined in **16.3.1.1**.

16.3.2 *Overall Member Strength*

Members subjected to combined axial force and bending moment shall be checked for overall buckling failure as given in this section.

16.3.2.1 *Bending and axial tension*

The reduced effective moment, M_{eff}, under tension and bending calculated as given below, should not exceed the bending strength due to lateral torsional buckling, M_{d} (*see* **15.2.2**),

$$M_{\mathrm{eff}} = \left[M - \psi\,T\,Z_{\mathrm{ec}}/A\right] \leq M_{\mathrm{d}}$$

where

A = area of cross section;

M, T = factored applied moment and tension, respectively;

Z_{ec} = elastic section modulus of the section with respect to extreme compression fibre;

ψ = 0.8, if T and M can vary independently, or otherwise; and

= 1.0.

16.3.2.2 *Bending and axial compression*

Members subjected to combined axial compression and biaxial bending shall satisfy the following interaction relationships:

$$\frac{P}{P_{dy}} + K_{yy}\frac{M_y}{M_{dy}} + K_{yz}\frac{M_z}{M_{dz}} \leq 1.0$$

$$\frac{P}{P_{dz}} + K_{zy}\frac{M_y}{M_{dy}} + K_{zz}\frac{M_z}{M_{dz}} \leq 1.0$$

where

K_{yy}, k_{yz}, K_{zy}, K_{zz} = interaction factors as given in Table 18;

M_{dy}, M_{dz} = design bending strength about y (minor) or z (major) axis, considering laterally unsupported length of the cross section [*see* 15];

M_y, M_z = maximum factored applied bending moments about y and z-axis of the member, respectively;

P = applied axial compression under factored load; and

P_{dy}, P_{dz} = design strength under axial compression as governed by buckling about minor (y) and major (z) axis respectively.

Table 18 Interaction Factors (Section 10.3.2.2)

(*Clause* 16.3.2.2)

Sl No.	Type of Section	Slenderness Ratio	Plastic Sections (Class 1, Class 2)	Elastic Sections (Class 3, Class 4)
(1)	(2)	(3)	(4)	(5)
i)	All	$\lambda_z < 1.0$	$K_{zz} = C_{mz}\,[1+(\lambda_z\text{-}0.2)\,n_z]$	$K_{zz} = C_{mz}\,[1+ 0.6\,\lambda_z\,n_z]$
		$\lambda_z \geq 1.0$	$K_{zz} = C_{mz}\,[1+0.8\,n_z]$	$K_{zz} = C_{mz}\,[1+0.6\,n_z]$
ii)	I sections	$\lambda_y < 1.0$	$K_{yy} = C_{my}\,[1+(2\lambda_y\text{-}0.6)\,n_y]$	$K_{yy} = C_{my}\,[1+0.6\,\lambda_y\,n_y]$
		$\lambda_y \geq 1.0$	$K_{yy} = C_{my}\,[1+1.4\,n_y]$	$K_{yy} = C_{my}\,[1+0.6\,n_y]$
iii)	Hollow sections	$\lambda_y < 1.0$	$K_{yy} = C_{my}\,[1+(\lambda_y\text{-}0.2)\,n_y]$	$K_{yy} = C_{my}\,[1+0.6\,\lambda_y\,n_y]$
		$\lambda_y \geq 1.0$	$K_{yy} = C_{my}\,[1+0.8\,n_y]$	$K_{yy} = C_{my}\,[1+0.6\,n_y]$
iv)	All	All	$K_{zy} = 0.66\,K_{yy}$	$K_{zy} = K_{yy}$

Table 18 (*Concluded*)

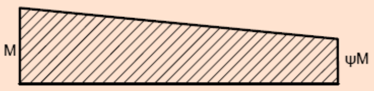
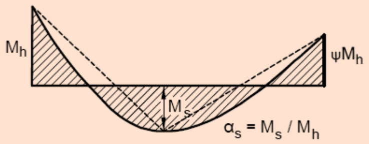
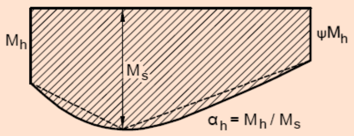
Sl No.	Type of Section	Slenderness Ratio	Plastic Sections (Class 1, Class 2)	Elastic Sections (Class 3, Class 4)
(1)	(2)	(3)	(4)	(5)
v)	Not susceptible to lateral torsional buckling	All	$K_{yz} = 0.6\ K_{zz}$	$K_{yz} = 0.8\ K_{zz}$
vi)	Susceptible to lateral torsional buckling	$\lambda_y < 0.4$	$K_{yz} = 1 - \frac{0.1\ \lambda_y n_y}{C_{mLT} - 0.25}$ $\leq 0.6\ \lambda_y$	$K_{yz} = 1 - \frac{0.05\ \lambda_y n_y}{C_{mLT} - 0.25}$
		$0.4 \leq \lambda_y < 1.0$	$K_{yz} = 1 - \frac{0.1\ \lambda_y n_y}{C_{mLT} - 0.25}$	$K_{yz} = 1 - \frac{0.05\ \lambda_y n_y}{C_{mLT} - 0.25}$
		$\lambda_y \geq 1.0$	$K_{yz} = 1 - \frac{0.1 n_y}{C_{mLT} - 0.25}$	$K_{yz} = 1 - \frac{0.05\ n_y}{C_{mLT} - 0.25}$

Where

n_y, n_z = ratio of actual applied axial force to the design axial strength for buckling about the y and z-axis, respectively C_{my}, C_{mz}, C_{mLT} = Equivalent uniform moment factor for lateral torsional buckling as per Table 19.

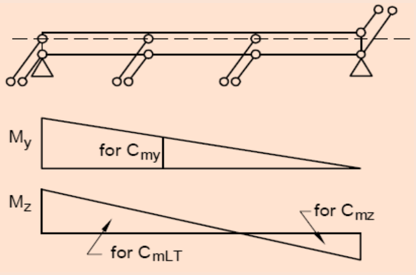
Table 19 Equivalent Uniform Moment Factor

(*Table 18*)

Bending Moment Diagram	Range		C_{my}, C_{mz}, C_{mLT}	
			Uniform Loading	Concentrated Load
(1)	(2)		(3)	(4)
	$-1 \leq \psi \leq 1$		$0.6 + 0.4\ \psi \geq 0.4$	
 M_h ψM_h M_s α_s = M_s / M_h	$0 \leq \alpha_s \leq 1$	$-1 \leq \psi \leq 1$	$0.2 + 0.8\ \alpha_s \geq 0.4$	$0.2 + 0.8\ \alpha_s \geq 0.4$
	$-1 \leq \alpha_s \leq 0$	$0 \leq \psi \leq 1$	$0.1\ - 0.8\ \alpha_s \geq 0.4$	$- 0.8\ \alpha_s \geq 0.4$
		$-1 \leq \psi \leq 0$	$0.1(1-\psi) - 0.8\ \alpha_s \geq 0.4$	$-0.2\psi - 0.8\ \alpha_s \geq 0.4$
 M_h ψM_h M_s α_h = M_h / M_s	$0 \leq \alpha_h \leq 1$	$-1 \leq \psi \leq 1$	$0.95 - 0.05\ \alpha_h$	$0.90 + 0.10\ \alpha_h$
	$-1 \leq \alpha_h \leq 0$	$0 \leq \psi \leq 1$	$0.95 + 0.05\ \alpha_h$	$0.90 + 0.10\ \alpha_h$
		$-1 \leq \psi \leq 0$	$0.95 + 0.05\ \alpha_h\ (1+2\ \psi)$	$0.90 + 0.1\alpha_h\ (1+2\ \psi)$

For members with sway buckling mode, the equivalent uniform moment factor $C_{my} = C_{mz} = 0.9$.

Table 19 (*Concluded*)

<table>
<tr><th rowspan="2">Bending Moment Diagram</th><th rowspan="2">Range</th><th colspan="2">C_{my}, C_{mz}, C_{mLT}</th></tr>
<tr><th>Uniform Loading</th><th>Concentrated Load</th></tr>
<tr><td>(1)</td><td>(2)</td><td>(3)</td><td>(4)</td></tr>
<tr><td colspan="4">C_{my}, C_{mz}, C_{mLT} shall be obtained according to the bending moment diagram between the relevant braced points</td></tr>
<tr><td colspan="2">Moment factor direction &#124; Bending axis | Points braced in
C_{my} &#124; z-z &#124; y-y
C_{mz} &#124; y-y &#124; z-z
C_{mLT} &#124; z-z &#124; z-z</td><td colspan="2">
</td></tr>
</table>

17 CONNECTIONS

17.1 General

17.1.1 This Section deals with the design and detailing requirements for joints between members. Connection elements consist of components such as cleats, gusset plates, brackets, connecting plates and connectors such as rivets, bolts, pins, and welds. The connections in a structure shall be designed so as to be consistent with the assumptions made in the analysis of the structure and comply with the requirements specified in this section. Connections shall be capable of transmitting the calculated design actions.

17.1.2 Where members are connected to the surface of a web or the flange of a section, the ability of the web or the flange to transfer the applied forces locally should be checked and where necessary, local stiffening provided.

17.1.3 Ease of fabrication and erection should be considered in the design of connections. Attention should be paid to clearances necessary for field erection, tolerances, tightening of fasteners, welding procedures, subsequent inspection, surface treatment and maintenance.

17.1.4 The ductility of steel assists the distribution of forces generated within a joint. Effects of residual stresses and stresses due to tightening of fasteners and normal tolerances of fit-up need not therefore be considered in connection design, provided ductile behaviour is ensured.

17.1.5 In general, use of different forms of fasteners to transfer the same force shall be avoided. However, when different forms of fasteners are used to carry a shear load or when welding and fasteners are combined, then one form of fastener shall be normally designed to carry the total load. Nevertheless, fully tensioned friction grip bolts may be designed to share the load with welding, provided the bolts are fully tightened to develop necessary pretension after welding.

17.1.6 The partial safety factor in the evaluation of design strength of connections shall be taken as given in Table 5.

17.2 Location Details of Fasteners

17.2.1 *Clearances for Holes for Fasteners*

Bolts may be located in standard size, over size, short slotted or long slotted hole, as follows:

a) *Standard clearance hole* — Except where fitted bolts, bolts in low-clearance or oversize holes are specified, the diameter of standard clearance holes for fasteners shall be as given in Table 20;

b) *Oversize hole* — Holes of size larger than the standard clearance holes, as given in Table 20 may be used in slip resistant connections and hold down bolted connections, only where specified, provided the oversize;

c) Holes in the outer ply is covered by a cover plate of sufficiently large size and thickness and having a hole not larger than the standard clearance hole (and hardened washer in slip resistant connections); and

d) *Short and long slots* — Slotted holes of size larger than the standard clearance hole, as given in Table 20 may be used in slip resistant connections and hold down bolted connections, only where specified, provided the oversize holes in the outer ply is covered by a cover plate of sufficiently large size and thickness and having a hole of size not larger than the standard clearance hole (and hardened washer in slip resistant connection).

Table 20 Clearances for Fastener Holes

(*Clauses* 17.2.1 *and* 24.2.2.1)

Sl No.	**Nominal Size of Fastener, *d*** mm	**Size of the Hole = Nominal Diameter of the Fastener + Clearances** mm			
		Standard clearance in diameter and width of slot	Over size clearance in diameter	Clearance in the length of the slot	
				Short Slot	Long Slot
(1)	(2)	(3)	(4)	(5)	(6)
i)	12 to 14	1.0	3.0	4.0	2.5 *d*
ii)	16 to 22	2.0	4.0	6.0	2.5 *d*
iii)	24	2.0	6.0	8.0	2.5 *d*
iv)	Larger than 24	3.0	8.0	10.0	2.5 *d*

17.2.2 *Minimum Spacing*

The distance between centres of fasteners shall not be less than 2.5 times the nominal diameter of the fastener.

17.2.3 *Maximum Spacing*

17.2.3.1 The distance between the centres of any two adjacent fasteners shall not exceed 32*t* or 300 mm, whichever is less, where *t* is the thickness of the thinner plate.

17.2.3.2 The distance between the centres of two adjacent fasteners (pitch) in a line lying in the direction of stress, shall not exceed 16*t* or 200 mm, whichever is less, in tension members and 12*t* or 200 mm, whichever is less, in compression members; where *t* is the thickness of the thinner plate. In the case of compression members wherein forces are transferred through butting faces, this distance shall not exceed 4.5 times the diameter of the fasteners for a distance equal to 1.5 times the width of the member from the butting faces.

17.2.3.3 The distance between the centres of any two consecutive fasteners in a line adjacent and parallel to an edge of an outside plate shall not exceed 100 mm plus 4*t* or 200 mm, whichever is less, in compression and tension members; where *t* is the thickness of the thinner outside plate.

17.2.3.4 When fasteners are staggered at equal intervals and the gauge does not exceed 75 mm, the spacing specified in **17.2.3.2** and **17.2.3.3** between centres of fasteners may be increased by 50 percent, subject to the maximum spacing specified in **17.2.3.1**.

17.2.4 *Edge and End Distances*

17.2.4.1 The edge distance is the distance at right angles to the direction of stress from the centre of a hole to the adjacent edge. The end distance is the distance in the direction of stress from the centre of a hole to the end of the element.

In slotted holes, the edge and end distances should be measured from the edge or end of the material to the centre of its end radius or the centre line of the slot, whichever is smaller. In oversize holes, the edge and end distances should be taken as the distance from the relevant edge/end plus half the diameter of the standard clearance hole corresponding to the fastener, less the nominal diameter of the oversize hole.

17.2.4.2 The minimum edge and end distances from the centre of any hole to the nearest edge of a plate shall not be less than 1.7 times the hole diameter in case of sheared or hand-flame cut edges; and 1.5 times the hole diameter in case of rolled, machine-flame cut, sawn and planed edges.

17.2.4.3 The maximum edge distance to the nearest line of fasteners from an edge of any un-stiffened part should not exceed 12 $t\varepsilon$, where $\varepsilon = (250/f_y)^{1/2}$ and t is the thickness of the thinner outer plate. This would not apply to fasteners interconnecting the components of back to back tension members. Where the members are exposed to corrosive influences, the maximum edge distance shall not exceed 40 mm plus $4t$, where t is the thickness of thinner connected plate.

17.2.5 *Tacking Fasteners*

17.2.5.1 In case of members covered under **17.2.4.3**, when the maximum distance between centres of two adjacent fasteners as specified in **17.2.4.3** is exceeded, tacking fasteners not subjected to calculated stress shall be used.

17.2.5.2 Tacking fasteners shall have spacing in a line not exceeding 32 times the thickness of the thinner outside plate or 300 mm, whichever is less. Where the plates are exposed to the weather, the spacing in line shall not exceed 16 times the thickness of the thinner outside plate or 200 mm, whichever is less. In both cases, the distance between the lines of fasteners shall not be greater than the respective pitches.

17.2.5.3 All the requirements specified in **17.2.5.2** shall generally apply to compression members, subject to the stipulations given under **14** affecting the design and construction of compression members.

17.2.5.4 In tension members [*see* **13**] composed of two flats, angles, channels or tees in contact back to back or separated back to back by a distance not exceeding the aggregate thickness of the connected parts, tacking fasteners with solid distance pieces shall be provided at a spacing in line not exceeding 1 000 mm.

17.2.5.5 For compression members covered under **14**, tacking fasteners in a line shall be spaced at a distance not exceeding 600 mm.

17.2.6 *Countersunk Heads*

For countersunk heads, one-half of the depth of the countersinking shall be neglected in calculating the length of the fastener in bearing in accordance with **17.3.3**. For fasteners in tension having countersunk heads, the tensile strength shall be reduced by 33.3 percent. No reduction is required to be made in shear strength calculations.

17.3 Bearing Type Bolts

17.3.1 *Effective Areas of Bolts*

17.3.1.1 Since threads can occur in the shear plane, the area A_e for resisting shear should normally be taken as the net tensile stress area, A_n of the bolts. For bolts where the net tensile stress area is not defined, A_n shall be taken as the area at the root of the threads.

17.3.1.2 Where it can be shown that the threads do not occur in the shear plane, A_e may be taken as the cross section area, A_s at the shank.

17.3.1.3 In the calculation of thread length, allowance should be made for tolerance and thread run off.

17.3.2 A bolt subjected to a factored shear force (V_{sb}) shall satisfy the condition

$$V_{sb} \leq V_{db}$$

where V_{db} is the design strength of the bolt, taken as the smaller of the value as governed by shear, V_{dsb} (*see* **17.3.3**) and bearing, V_{dpb} (*see* **17.3.4**).

17.3.3 *Shear Capacity of Bolt*

The design strength of the bolt, V_{dsb} as governed by shear strength is given by:

$$V_{dsb} = V_{nsb} / \gamma_{mb}$$

where

V_{nsb} = nominal shear capacity of a bolt, calculated as follows.

$$V_{nsb} = \frac{f_u}{\sqrt{3}} \left(n_n A_{nb} + n_s A_{sb} \right)$$

where

A_{nb} = net shear area of the bolt at threads, may be taken as the area corresponding to root diameter at the thread;

A_{sb} = nominal plain shank area of the bolt;

f_u = ultimate tensile strength of a bolt;

n_n = number of shear planes with threads intercepting the shear plane; and

n_s = number of shear planes without threads intercepting the shear plane.

17.3.3.1 *Long joints*

When the length of the joint, l_j of a splice or end connection in a compression or tension element containing more than two bolts (that is, the distance between the first and last rows of bolts in the joint, measured in the direction of the load transfer) exceeds 15d in the direction of load, the nominal shear capacity (*see* **17.3.2**), V_{db} shall be reduced by the factor β_{lj}, given by:

$$\beta_{lj} = 1.075 - l_j / (200\, d) \text{ but } 0.75 \leq \beta_{lj} \leq 1.0 = 1.075 - 0.005(l_j / d)$$

where

d = Nominal diameter of the fastener.

NOTE — This provision does not apply when the distribution of shear over the length of joint is uniform, as in the connection of web of a section to the flanges.

17.3.3.2 *Large grip lengths*

When the grip length, l_g (equal to the total thickness of the connected plates) exceeds 5 times the diameter, d of the bolts, the design shear capacity shall be reduced by a factor β_{lg}, given by:

$$\beta_{lg} = 8d / (3d + l_g) = 8 / (3 + l_g/d)$$

β_{lg} shall not be more than β_{lj} given in **17.3.3.1**. The grip length, l_g shall in no case be greater than 8d.

17.3.3.3 *Packing plates*

The design shear capacity of bolts carrying shear through a packing plate in excess of 6 mm shall be decreased by a factor, β_{pk} given by:

$$\beta_{pk} = (1 - 0.0125 t_{pk})$$

where

t_{pk} = thickness of the thicker packing, in mm.

17.3.4 *Bearing Capacity of the Bolt*

The design bearing strength of a bolt on any plate, V_{dpb} as governed by bearing is given by:

$$V_{dpb} = V_{npb} / \gamma_{mb}$$

where

V_{npb} = Nominal bearing strength of a bolt; and

= $2.5\, k_b\, d\, t\, f_u$.

where

d_0 = diameter of the hole;

d = nominal diameter of the bolt;

f_{ub}, f_u = Ultimate tensile stress of the bolt and the ultimate tensile stress of the plate, respectively;

e, p = end and pitch distances of the fastener along bearing direction;

k_b = is smaller of $\frac{e}{3d_0}$, $\frac{p}{3d_0} - 0.25$, $\frac{f_{ub}}{f_u}$, 1.0; and

t = summation of the thicknesses of the connected plates experiencing bearing stress in the same direction, or if the bolts are countersunk, the thickness of the plate minus one half of the depth of countersinking.

The bearing resistance (in the direction normal to the slots in slotted holes) of bolts in holes other than standard clearance holes may be reduced by multiplying the bearing resistance obtained as above, V_{npb}, by the factors given below:

a) Over size and short slotted holes – 0.7; and

b) Long slotted holes – 0.5.

NOTE — The block shear of the edge distance due to bearing force may be checked as given in 12.4.

17.3.5 *Tension Capacity*

A bolt subjected to a factored tensile force, T_b shall satisfy,

$$T_b \leq T_{db}$$

where

T_{db} = T_{nb} / γ_{mb}; and

T_{nb} = nominal tensile capacity of the bolt, calculated as.

$$T_{nb} = 0.90\, f_{ub} A_n < f_{yb} A_{sb} (\gamma_{mb} / \gamma_{m0})$$

where

A_{sb} = shank area of the bolt;

A_n = net tensile stress area as specified in the appropriate Indian Standard (for bolts where the tensile stress area is not defined, An shall be taken as the area at the bottom of the threads);

f_{ub} = ultimate tensile stress of the bolt; and

f_{yb} = yield stress of the bolt.

17.3.6 *Bolt Subjected to Combined Shear and Tension*

A bolt required to resist both design shear force (V_{sd}) and design tensile force (T_b) at the same time shall satisfy,

$$\left(\frac{V_{sb}}{V_{db}}\right)^2 + \left(\frac{T_b}{T_{db}}\right)^2 \leq 1.0$$

where

V_{db} = design shear capacity (*see* **17.3.2**);

V_{sb} = factored shear force acting on the bolt;

T_b = factored tensile force acting on the bolt, and

T_{db} = design tension capacity (*see* **17.3.5**).

17.4 Friction Grip Type Bolting

17.4.1 In friction grip type bolting, initial pretension in bolt (usually high strength) develops clamping force at the interfaces of elements being joined. The frictional resistance to slip between the plate surfaces subjected to clamping force opposes slip due to externally applied shear. Friction grip type bolts and nuts shall conform to the accepted standard [C-6A(39)]. Their installation procedures shall conform to good practice [C-6A(15)].

17.4.2 Where slip between bolted plates cannot be tolerated at working loads/ strength limit states loads (slip critical connections), the requirements of **17.4.3** shall be satisfied at service and strength limit states loads, respectively. However, the requirements of **17.4.4** shall be satisfied by all connections at the strength limit states.

17.4.3 *Slip Resistance*

Design for friction type bolting, where slip resistance is required at factored design force V_{sf}, shall satisfy the following:

$$V_{sf} \leq V_{dsf}$$

where

V_{dsf} = V_{nsf} / γ_{mf}; and

V_{nsf} = nominal shear capacity of a bolt as governed by slip for friction type connection, calculated as follows.

$$V_{nsf} = \mu_f n_e K_h F_o$$

where

A_{nb} = net area of the bolt at threads;

f_o = proof stress (= 0.70 f_{ub});

F_o = minimum bolt tension (proof load) at installation and may be taken as $A_{nb} f_o$;

K_h = 1.0 for fasteners in clearance holes;

= 0.85 for fasteners in oversized and short slotted holes and for fasteners in long slotted holes loaded perpendicular to the slot;

n_e = number of effective interfaces offering frictional resistance to slip;

μ_f = coefficient of friction (slip factor) as specified in Table 21 ($\mu_f \leq 0.55$);

= 0.7 for fasteners in long slotted holes loaded parallel to the slot;

γ_{mf} = 1.10 (if slip resistance is designed at service load); and

= 1.25 (if slip resistance is designed at ultimate load).

NOTE — V_{nsf} may be evaluated at a service load or ultimate load using appropriate partial safety factors, depending upon whether slip resistance is required at service load or ultimate load.

Table 21 Typical Average Values for Coefficient of Friction (μ_f)

(*Clause* 17.4.3)

Sl No. (1)	Treatment of Surface (2)	Coefficient of Friction, μ_f (3)
i)	Surfaces not treated	0.20
ii)	Surfaces blasted with short or grit with any loose rust removed, no pitting	0.50
iii)	Surfaces blasted with shot or grit and hot-dip galvanized	0.10
iv)	Surfaces blasted with shot or grit and spray-metallized with zinc (thickness 50 µm to 70 µm)	0.25
v)	Surfaces blasted with shot or grit and painted with ethyl zinc silicate coat (thickness 30 µm to 60 µm)	0.30
vi)	Sand blasted surface, after light rusting	0.52
vii)	Surfaces blasted with shot or grit and painted with ethyl zinc silicate coat (thickness 60 µm to 80 µm)	0.30
viii)	Surfaces blasted with shot or grit and painted with alkali zinc silicate coat (thickness 60 µm to 80 µm)	0.30
ix)	Surface blasted with shot or grit and spray metallized with aluminium (thickness > 50 µm)	0.50
x)	Clean mill scale	0.33
xi)	Sand blasted surface	0.48
xii)	Red lead painted surface	0.1

17.4.3.1 *Long Joints*

The provision for the long joints in **17.3.3.1** shall apply to friction grip connections also.

17.4.4 *Capacity after Slipping*

When friction type bolts are designed not to slip only under service loads, the design capacity at ultimate load may be calculated as per bearing type connection (*see* **17.3.2** and **17.3.3**).

NOTE — The block shear resistance of the edge distance due to bearing force may be checked as given in **13.4**.

17.4.5 *Tension Resistance*

A friction bolt subjected to a factored tension force (T_f) shall satisfy:

$$T_f \leq T_{df}$$

where

$T_{df} = T_{nf} / \gamma_{mf}$

T_{nf} = nominal tensile strength of the friction bolt, calculated as:

$$T_{nf} = 0.9\, f_{ub}\, A_n \leq f_{yb}\, A_{sb} (\gamma_{m1} / \gamma_{m0})$$

where

A_n = net tensile stress area as specified in various parts of the accepted standard [C-6A(40)] (for bolts where the tensile stress area is not defined, An shall be taken as the area at the root of the threads);

A_{sb} = shank area of the bolt;

f_{ub} = ultimate tensile stress of the bolt; and

γ_{mf} = partial factor of safety.

17.4.6 *Combined Shear and Tension*

Bolts in a connection for which slip in the serviceability limit state shall be limited, which are subjected to a tension force, *T*, and shear force, *V*, shall satisfy:

$$\left(\frac{V_{sf}}{V_{df}}\right)^2 + \left(\frac{T_f}{T_{df}}\right)^2 \le 1.0$$

where

V_{df} = design shear strength;

V_{sf} = applied factored shear at design load;

T_{df} = design tension strength; and

17.4.7 Where prying force, *Q* as illustrated in Fig. 16 shall be calculated as given below and added to the tension in the bolt:

$$Q = \frac{l_v}{2\,l_e}\left[T_e - \frac{\beta \eta\, f_o b_e t^4}{27 l_e l_v^2}\right]$$

where

l_e = distance between prying force and bolt centreline and is the minimum of either the end distance or the value given by; and

l_v = distance from the bolt centreline to the toe of the fillet weld or to half the root radius for a rolled section.

$$l_e = 1.1\,t\sqrt{\frac{\beta f_o}{f_y}}$$

where

β = 2 for non pre-tensioned bolt and 1 for pre-tensioned bolt;

b_e = effective width of flange per pair of bolts;

f_o = proof stress in consistent units;

η = 1.5; and

t = thickness of the end plate.

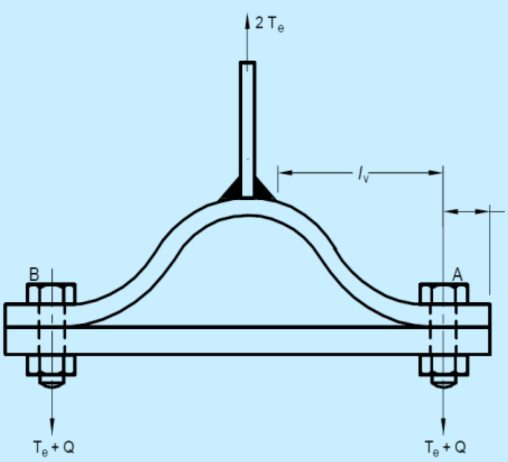


FIG. 16 COMBINED PRYING FORCE AND TENSION

17.5 Welds and Welding

17.5.1 *General*

Requirements of welds and welding shall conform to the accepted standards [C-6A(41)], as appropriate.

17.5.1.1 *End returns*

Fillet welds terminating at the ends or sides of parts should be returned continuously around the corners for a distance of not less than twice the size of the weld, unless it is impractical to do so. This is particularly important on the tension end of parts carrying bending loads.

17.5.1.2 *Lap joint*

In the case of lap joints, the minimum lap should not be less than four times the thickness of the thinner part joined or 40 mm, whichever is more. Single end fillet should be used only when lapped parts are restrained from openings. When end of an element is connected only by parallel longitudinal fillet welds, the length of the weld along either edge should not be less than the transverse spacing between longitudinal welds.

17.5.1.3 A single fillet weld should not be subjected to moment about the longitudinal axis of the weld.

17.5.2 *Size of Weld*

17.5.2.1 The size of normal fillets shall be taken as the minimum weld leg size. For deep penetration welds, where the depth of penetration beyond the root run is a minimum of 2.4 mm, the size of the fillet should be taken as the minimum leg size plus 2.4 mm.

17.5.2.2 For fillet welds made by semi-automatic or automatic processes, where the depth of penetration is considerably in excess of 2.4 mm, the size shall be taken considering actual depth of penetration subject to agreement between the purchaser and the contractor.

17.5.2.3 The size of fillet welds shall not be less than 3 mm. The minimum size of the first run or of a single run fillet weld shall be as given in Table 22, to avoid the risk of cracking in the absence of preheating.

17.5.2.4 The size of butt weld shall be specified by the effective throat thickness.

17.5.3 *Effective Throat Thickness*

17.5.3.1 The effective size of a fillet weld shall not be less than 3 mm and shall generally not exceed $0.7t$, or $1.0t$ under special circumstances, where t is the thickness of the thinner plate of elements being welded.

17.5.3.2 For the purpose of stress calculation in fillet welds joining faces inclined to each other, the effective throat thickness shall be taken as K times the fillet size, where K is a constant, depending upon the angle between fusion faces, as given in Table 23.

Table 22 Minimum Size of First Run or of a Single Run Fillet Weld

(*Clause* 17.5.2.3)

Sl No.	Thickness of Thicker Part mm		Minimum Size of First run mm
	Over	Up to and Including	
(1)	(2)	(3)	(4)
i)	—	10	3
ii)	10	20	5
iii)	20	32	6

Table 22 (*Concluded*)

Sl No.	**Thickness of Thicker Part** mm		**Minimum Size of First run** mm
	Over	Up to and Including	
(1)	(2)	(3)	(4)
iv)	32	50	8 of first run 10 for minimum size of weld

NOTES

1 When the minimum size of the fillet weld given in the table is greater than the thickness of the thinner part, the minimum size of the weld should be equal to the thickness of the thinner part. The thicker part shall be adequately preheated to prevent cracking of the weld.

2 Where the thicker part is more than 50 mm thick, special precautions like preheating should be taken.

Table 23 Values of *K* for Different Angles Between Fusion Faces

(*Clause* 17.5.3.2)

Sl No. (1)	**Angle Between Fusion Faces** (2)	**Constant, *K*** (3)
i)	60° to 90°	0.70
ii)	91° to 100°	0.65
iii)	101° to 106°	0.60
iv)	107° to 113°	0.55
v)	114° to 120°	0.50

17.5.3.3 The effective throat thickness of a complete penetration butt weld shall be taken as the thickness of the thinner part joined, and that of an incomplete penetration butt weld shall be taken as the minimum thickness of the weld metal common to the parts joined, excluding reinforcements.

17.5.4 *Effective Length or Area of Weld*

17.5.4.1 The effective length of fillet weld shall be taken as only that length which is of the specified size and required throat thickness. In practice the actual length of weld is made of the effective length shown in drawing plus two times the weld size, but not less than four times the size of the weld.

17.5.4.2 The effective length of butt weld shall be taken as the length of the continuous full size weld, but not less than four times the size of the weld.

17.5.4.3 The effective area of a plug weld shall be considered as the nominal area of the hole in the plane of the faying surface. These welds shall not be designed to carry stresses.

17.5.4.4 If the maximum length l_j of the side welds transferring shear along its length exceeds 150 times the throat size of the weld, t_t, the reduction in weld strength as per the long joint (*see* **17.5.7.3**) should be considered. For flange to web connection, where the welds are loaded for the full length, the above limitation would not apply.

17.5.5 *Intermittent Welds*

17.5.5.1 Unless otherwise specified, the intermittent fillet welding shall have an effective length of not less than four times the weld size, with a minimum of 40 mm.

17.5.5.2 The clear spacing between the effective lengths of intermittent fillet weld shall not exceed 12 and 16 times the thickness of thinner plate joined, for compression and tension joint, respectively, and in no case be more than 200 mm.

17.5.5.3 Unless otherwise specified, the intermittent butt weld shall have an effective length of not less than four times the weld size and the longitudinal space between the effective length of welds shall not be more than 16 times the thickness of the thinner part joined. The intermittent welds shall not be used in positions subject to dynamic, repetitive and alternating stresses.

17.5.6 *Weld Types and Quality*

For the purpose of this NBCS, weld shall be fillet, butt, slot or plug or compound welds. Welding electrodes shall conform to IS 814.

17.5.7 *Design Stresses in Welds*

17.5.7.1 *Shop welds*

17.5.7.1.1 *Fillet welds*

Design strength of a fillet weld, f_{wd} shall be based on its throat area and shall be given by:

$$f_{\mathrm{wd}} = f_{\mathrm{wn}} / \gamma_{\mathrm{mw}}$$

where

f_{u} = smaller of the ultimate stress of the weld or of the parent metal;

f_{wn} = $f_{\mathrm{u}} / \sqrt{3}$; and

γ_{mw} = partial safety factor (*see* Table 5).

17.5.7.1.2 *Butt welds*

Butt welds shall be treated as parent metal with a thickness equal to the throat thickness, and the stresses shall not exceed those permitted in the parent metal.

17.5.7.1.3 *Slot or plug welds*

The design shear stress on slot or plug welds shall be as per **17.5.7.1.1**.

17.5.7.2 *Site welds*

The design strength in shear and tension for site welds made during erection of structural members shall be calculated according to **17.5.7.1** but using a partial safety factor γ_{mw} of 1.5.

17.5.7.3 *Long joints*

When the length of the welded joint, l_{j} of a splice or end connection in a compression or tension element is greater than 150 t_{t}, the design capacity of weld (*see* **17.5.7.1.1**), f_{wd} shall be reduced by the factor:

$$\beta_{\mathrm{lw}} = 1.2 - \frac{0.2 l_{\mathrm{j}}}{150 t_{\mathrm{t}}} \leq 1.0$$

where

l_{j} = length of the joint in the direction of the force transfer; and

t_{t} = throat size of the weld.

17.5.8 *Fillet Weld Applied to the Edge of a Plate or Section*

17.5.8.1 Where a fillet weld is applied to the square edge of a part, the specified size of the weld should generally be at least 1.5 mm less than the edge thickness in order to avoid washing down of the exposed corner [*see* Fig. 17(A)].

17.5.8.2 Where the fillet weld is applied to the rounded toe of a rolled section, the specified size of the weld should generally not exceed 3/4 of the thickness of the section at the toe [*see* Fig. 17(B)].

17.5.8.3 Where the size specified for a fillet weld is such that the parent metal will not project beyond the weld, no melting of the outer cover or covers shall be allowed to occur to such an extent as to reduce the throat thickness (*see* Fig. 18).

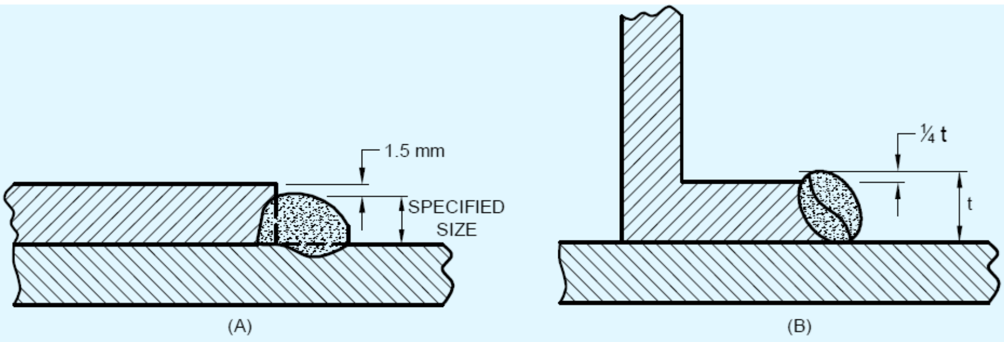
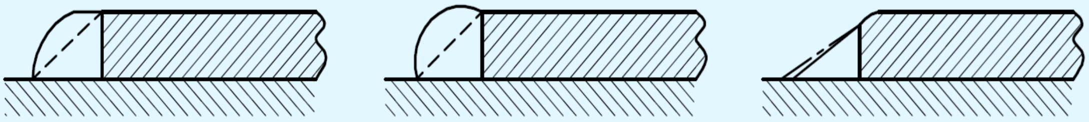


FIG. 17 FILLET WELDS ON SQUARE EDGE OF PLATE OR ROUND TOE OF ROLLED SECTION



18 A DESIRABLE

18 B ACCEPTABLE BECAUSE OF FULL THROAT THICKNESS

18 C NOT ACCEPTABLE BECAUSE OF REDUCED THROAT THICKNESS

FIG. 18 FULL SIZE FILLET WELD APPLIED TO THE EDGE OF A PLATE OR SECTION

17.5.8.4 When fillet welds are applied to the edges of a plate or section in members subject to dynamic loading, the fillet weld shall be of full size with its leg length equal to the thickness of the plate or section, with the limitations specified in **17.5.8.3**.

17.5.8.5 End fillet weld, normal to the direction of force shall be of unequal size with a throat thickness not less than $0.5t$, where t is the thickness of the part, as shown in Fig. 19. The difference in thickness of the welds shall be negotiated at a uniform slope.

17.5.9 *Stresses Due to Individual Forces*

When subjected to either compressive or tensile or shear force alone, the stress in the weld is given by and shall be less than or equal to design strength of the weld, f_{ws}, given in **17.5.7.1.1**:

$$f_a \text{ or } q = \frac{P}{t_t\, l_w}$$

where

f_a = Calculated, in N/mm^2, normal stress due to axial force;

l_w = Effective, in mm, length of weld;

P = force transmitted (axial force N or the shear force Q);

q = shear, in N/mm^2, stress; and

t_t = Effective, in mm; throat thickness of weld.

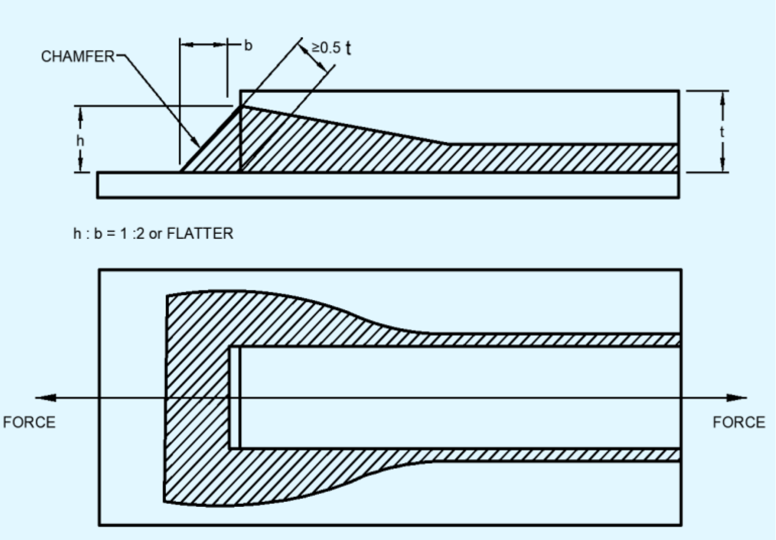


FIG. 19 END FILLET WELD NORMAL TO DIRECTION OF FORCE

17.5.10 *Combination of Stresses*

17.5.10.1 *Fillet welds*

17.5.10.1.1 When subjected to a combination of normal and shear stress, the equivalent stress f_e shall satisfy the following:

$$f_e = \sqrt{f_a^2 + 3q^2} \le \frac{f_u}{\gamma_{mw}}$$

where

f_a = normal stresses, compression or tension, due to axial force or bending moment (*see* **17.5.9**); and

q = shear stress due to shear force or tension (*see* **17.5.9**).

17.5.10.1.2 Check for the combination of stresses need not be done for:

a) side fillet welds joining cover plates and flange plates; and

b) fillet welds where algebraic sum of normal and shear stresses does not exceed f_{wd} (*see* **17.5.7.1.1**).

17.5.10.2 *Butt welds*

17.5.10.2.1 Check for the combination of stresses in butt welds need not be carried out provided that:

a) butt welds are axially loaded; and

b) in single and double bevel welds the algebraic sum of normal and shear stresses does not exceed the design normal stress, and the shear stress does not exceed 50 percent of the design shear stress.

17.5.10.2.2 *Combined bearing, bending and shear*

Where bearing stress, f_{br} is combined with bending (tensile or compressive), f_b and shear stresses, q under the most unfavorable conditions of loading in butt welds, the equivalent stress, f_e as obtained from the following formula, shall not exceed the values allowed for the parent metal:

$$f_e = \sqrt{{f_b}^2 + {f_{br}}^2 - f_b\, f_{br} + 3q^2}$$

where

f_b = calculated, in N/mm^2; stress due to bending;

f_{br} = calculated, in N/mm^2, stress due to bearing;

f_e = equivalent stress; and

q = shear, in N/mm^2, stress.

17.5.11 Where a packing is welded between two members and is less than 6 mm thick, or is too thin to allow provision of adequate welds or to prevent buckling, the packing shall be trimmed flush with the edges of the element subject to the design action and the size of the welds along the edges shall be increased over the required size by an amount equal to the thickness of the packing. Otherwise, the packing shall extend beyond the edges and shall be fillet welded to the pieces between which it is fitted.

17.6 Design of Connections

Each element in a connection shall be designed so that the structure is capable of resisting the design actions. Connections and adjacent regions of the members shall be designed by distributing the design action effects such that the following requirements are satisfied:

a) Design action effects distributed to various elements shall be in equilibrium with the design action effects on the connection;

b) Required deformations in the elements of the connections are within their deformations capacities;

c) All elements in the connections and the adjacent areas of members shall be capable of resisting the design action effects acting on them; and

d) Connection elements shall remain stable under the design action effects and deformations.

17.6.1 Connections can be classified as rigid, semi-rigid and flexible for the purpose of analysis and design as per the recommendation in Annex F. Connections with sufficient rotational stiffness may be considered as rigid. Examples of rigid connections include flush end-plate connection and extended end-plate connections. Connections with negligible rotational stiffness may be considered as flexible (pinned). Examples of flexible connections include single and double web angle connections and header plate connections. Where a connection cannot be classified as either rigid or flexible, it shall be assumed to be semi-rigid. For Example, of semi-rigid connections include top and seat angle connection and top and seat angle with single/double web angles.

17.6.2 Design shall be on the basis of any rational method supported by experimental evidence. Residual stresses due to installation of bolts or welding normally need not be considered in statically loaded structures. Connections in cyclically loaded structures shall be designed considering fatigue as given under **19**. For earthquake load combinations, the connections shall be designed to withstand the calculated design action effects as specified in **18**.

17.6.3 Beam and column splice shall be designed in accordance with the recommendation given in **F-2** and **F-3**.

17.7 Minimum Design Action on Connection

Connections carrying design action effects, except for lacing connections, connections of sag rods, purlins and girts, shall be designed to transmit the greater of:

a) the design action in the member; and

b) The minimum design action effects expressed either as the value or the factor times the member design capacity for the minimum size of member required by the strength limit state, specified as follows:

1) *Connections in rigid construction* — A bending moment of at least 0.5 times the member design moment capacity;

2) *Connections to beam in simple construction* — A shear force of at least 0.15 times the member design shear capacity or 40 kN, whichever is lesser;

3) *Connections at the ends of tensile or compression member* — A force of at least 0.3 times the member design capacity;

4) *Splices in members subjected to axial tension* — A force of at least 0.3 times the member design capacity in tension;

5) *Splices in members subjected to axial compression* — For ends prepared for full contact in accordance with **24.7.1**, it shall be permissible to carry compressive actions by bearing on contact surfaces. When members are prepared for full contact to bear at splices, there shall be sufficient fasteners to hold all parts securely in place. The fasteners shall be sufficient to transmit a force of at least 0.15 times the member design capacity in axial compression;

   When members are not prepared for full contact, the splice material and its fasteners shall be arranged to hold all parts in line and shall be designed to transmit a force of at least 0.3 times the member design capacity in axial compression.

   In addition, splices located between points of effective lateral support shall be designed for the design axial force, P_d plus a design bending moment, not less than the design bending moment $M_d = P_d l_s / 1\,000$ where, l_s is the distance between points of effective lateral support.

6) *Splices in flexural members* — A bending moment of 0.3 times the member design capacity in bending. This provision shall not apply to splices designed to transmit shear force only; and

   A splice subjected to a shear force only shall be designed to transmit the design shear force together with any bending moment resulting from the eccentricity of the force with respect to the centroid of the group.

7) *Splices in members subject to combined actions* — A splice in a member subject to a combination of design axial tension or design axial compression and design bending moment shall satisfy requirements in (4), (5) and (6) above, simultaneously.

17.8 Intersections

Members or components meeting at a joint shall be arranged to transfer the design actions between the parts, wherever practicable, with their centroidal axes meeting at a point. Where there is eccentricity at joints, the members and components shall be designed for the design bending moments which result due to eccentricity.

The disposition of fillet welds to balance the design actions about the centroidal axis or axes for end connections of single angle, double angle and similar type members is not required for statically loaded members but is required for members, connection components subject to fatigue loading.

Eccentricity between the centroidal axes of angle members and the gauge lines for their bolted end connections may be neglected in statically loaded members, but shall be considered in members and connection components subject to fatigue loading.

17.9 Choice of Fasteners

Where slip in the serviceability limit state is to be avoided in a connection, high-strength bolts in a friction-type joint, fitted bolts or welds shall be used.

Where a joint is subjected to impact or vibration, either high strength bolts in a friction type joint or ordinary bolts with locking devices or welds shall be used.

17.10 Connection Components

Connection components (cleats, gusset plates, brackets and the like) other than connectors, shall have their capacities assessed using the provisions of 12, 13, 14, 15 and 16, as applicable.

17.11 Analysis of a Bolt/Weld Group

17.11.1 *Bolt/Weld Group Subject to In-plane Loading*

17.11.1.1 *General method of analysis*

The design force in a bolt/weld or design force per unit length in a bolt/weld group subject to in-plane loading shall be determined in accordance with the following:

a) The connection plates shall be considered to be rigid and to rotate relative to each other about a point known as the instantaneous centre of rotation of the group;

b) In the case of a group subject to a pure couple only, the instantaneous centre of rotation coincides with the group centroid. In the case of in-plane shear force applied at the group centroid, the instantaneous centre of the rotation is at infinity and the design force is uniformly distributed throughout the group. In all other cases, either the results of independent analyses for a pure couple alone and for an in-plane shear force applied at the group centroid shall be superposed, or a recognized method of analysis shall be used; and

c) The design force in a bolt or design force per unit length at any point in the group shall be assumed to act at right angles to the radius from that point to the instantaneous centre, and shall be taken as proportional to that radius.

17.11.2 *Bolt/Weld Group Subject to Out-of-Plane Loading*

17.11.2.1 *General method of analysis*

The design force of a bolt in bolt group or design force per unit length in the fillet weld group subject to out-of-plane loading shall be determined in accordance with the following:

a) Design force in the bolts or per unit length in the fillet weld group resulting from any shear force or axial force shall be considered to be equally shared by all bolts in the group or uniformly distributed over the length of the fillet weld group; and

b) Design force resulting from a design bending moment shall be considered to vary linearly with distance from the relevant centroidal axes. The following shall also be considered:

   1) in bearing type of bolt group plates in the compression side of the neutral axis and only bolts in the tension side of the neutral axis may be considered for calculating the neutral axis and second moment of area;

   2) in the friction grip bolt group, only the bolts shall be considered in the calculation of neutral axis and second moment of area; and

   3) the fillet weld group shall be considered in isolation from the connected element; for the calculation of centroid and second moment of the weld length.

17.11.2.2 *Alternative analysis*

The design force per unit length in a fillet weld/bolt group may alternatively be determined by considering the fillet weld group as an extension of the connected member and distributing the design forces among the welds of the fillet weld group so as to satisfy equilibrium between the fillet weld group and the elements of the connected member.

17.11.3 *Bolt/Weld Group Subject to In-plane and Out-of-Plane Loading*

17.11.3.1 *General method of analysis*

The design force in a bolt or per unit length of the weld shall be determined by the superposition of analysis for in-plane and out-of-plane cases discussed in 17.11.1 and 17.11.2.

17.11.3.2 *Alternative analysis*

The design force in a bolt or per unit length in the fillet weld group may alternatively be determined by considering the fillet weld group as an extension of the connected member and proportioning the design force per bolt or unit length in the weld group to satisfy equilibrium between the bolt/weld group and the elements of the connected member.

Force calculated in the most stressed bolt or highest force per unit length of the weld shall satisfy the strength requirements of **17.3**, **17.4** or **17.5**, as appropriate.

17.12 Lug Angles

17.12.1 Lug angles connecting outstanding leg of a channel-shaped member shall, as far as possible, be disposed symmetrically with respect to the section of the member.

17.12.2 In the case of angle members, the lug angles and their connections to the gusset or other supporting member shall be capable of developing a strength not less than 20 percent in excess of the force in the outstanding leg of the member, and the attachment of the lug angle to the main angle shall be capable of developing a strength not less than 40 percent in excess of the force in the outstanding leg of the angle.

17.12.3 In the case of channel members and the like, the lug angles and their connection to the gusset or other supporting member shall be capable of developing a strength of not less than 10 percent in excess of the force not accounted for by the direct connection of the member, and the attachment of the lug angles to the member shall be capable of developing 20 percent in excess of that force.

17.12.4 In no case shall fewer than two bolts, rivets or equivalent welds be used for attaching the lug angle to the gusset or other supporting member.

17.12.5 The effective connection of the lug angle shall, as far as possible terminate at the end of the member connected, and the fastening of the lug angle to the main member shall preferably start in advance of the direct connection of the member to the gusset or other supporting member.

17.12.6 Where lug angles are used to connect an angle member, the whole area of the member shall be taken as effective notwithstanding the requirements given under **13**.

18 DESIGN AND DETAILING FOR EARTHQUAKE EFFECTS

18.1 General

18.1.1 Earthquake is a ‘displacement loading’ on a structure. This implies that ‘displacements’ are ‘imposed’ under a structure during earthquake shaking and ‘forces’ are induced in it. Thus, a structure is allowed to be designed to have lesser strength capacity than that required if it were to remain elastic. And, only chosen types of damage are permitted to be accrued in select components of a structure during strong earthquake shaking.

Thus, reliance is placed on the nonlinear response of a structure, especially on its deformation and ductility capacities. These must be achieved by adopting special design and detailing practices. Therefore, steel frames shall be so designed and detailed as to give them stability, and adequate stiffness, strength, and ductility capacities to resist severe earthquake shaking without collapse in all earthquake zones mentioned in **5** of Part C ‘Structural Design/Section 1 Loads and Load Effects’ of this NBCS.

18.1.2 Steel frames required to resist earthquake effects in all earthquake zones shall satisfy the requirements specified in good practice [C-6A(42)]. Frames are classified into two types, one which have minimal inelastic deformation and ductility capacities, called ordinary frames, and one with higher deformation and ductility capacities, called special frames. For earthquake zones III and above, only special frames are permitted to be used.

18.1.3 For earthquake zone II, ordinary frames, namely ordinary moment frames (OMF) and ordinary concentrically braced frames (OCBF), are permitted to be used. In design and detailing of OMFs and OCBFs, specific requirements of this Section shall be satisfied along with other provisions of this NBCS, in addition to the earthquake demand and design criteria requirements of **5** of Part C ‘Structural design/Section 1 Loads and Load Effects’ of this NBCS.

18.1.4 Frames, which are a part of the gravity load resisting system and are not intended to resist the lateral earthquake forces, need not satisfy the requirements of this section, provided they can accommodate the resulting earthquake shaking induced deformation without premature failure.

18.2 Loads and Load Combinations

18.2.1 Earthquake loads shall be calculated as per **5** of Part C 'Structural design/Section 1 Loads and Load Effects' of this NBCS, except that the reduction factors recommended in **18.3** may be used.

18.2.2 In the limit state design of frames resisting earthquake loads, the load combinations shall conform to Table 4.

18.2.3 In addition the following load combination shall be considered as required in **18.5.1.1**, **18.7.3.1**, **18.11.2.2** and **18.11.3.4**:

a) 1.2 Dead Load (DL) + 0.5 Imposed Load (IL) ± 2.5 Earthquake Force (E); and

b) 0.9 Dead Load (DL) ± 2.5 Earthquake Force (E).

18.3 Response Reduction Factor

18.3.1 For structures designed and detailed in accordance with the provisions of this Section, the response reduction factors specified herein may be used for calculating the design earthquake forces, in conjunction with the provisions of **5** of Part C 'Structural Design/Section 1 Loads and Load Effects' of this NBCS.

18.3.2 For braced frame systems, the response reduction factor (R) for ordinary concentrically braced frames (OCBF), for special concentrically braced frames (SCBF) and for special eccentrically braced frames (SEBF) shall be taken from **5** of Part C 'Structural Design/Section 1 Loads and Load Effects' of this NBCS. The response reduction factor (R) for ordinary eccentrically braced frames (OEBF) shall be taken as 4.5.

18.3.3 For moment frame systems, the response reduction factor (R) for special moment frames (SMF) shall be taken from **5** of Part C 'Structural Design/Section 1 Loads and Load Effects' of this NBCS. For the Ordinary Moment Frames (OMF) designed as per **18.10**, the response reduction factor (R) shall be taken as 4.0.

18.3.4 For non-ductile frames (NDF), the response reduction factor (R) shall be taken as 1.5.

18.3.5 The braced and moment resisting frames in single storey industrial buildings can be designed as non-ductile frames (NDF), if their overall height to overall width ratio does not exceed 1.0. Such frames need not meet the ductility requirements of other types of frames as specified in **18.4** to **18.12**.

18.4 Connections, Joints and Fasteners

18.4.1 All bolts used in critical zones of frames designed to resist earthquake effects shall be fully tensioned high strength friction grip (HSFG) bolts or turned and fitted bolts. The critical zones of frames are zones of plastic hinges of moment resisting frames and beam to columns as well as bracing and their connections of braced frames. The plastic hinge zones shall be taken as a distance equal to 2 times the depth of the member from the section of maximum bending moment.

18.4.2 All welds used in frames designed to resist earthquake effects shall be complete penetration butt welds, except in column splices, which shall conform to **18.5.2**.

18.4.3 Bolted joints shall be designed not to share load in combination with welds on the same faying surface.

18.5 Columns

18.5.1 *Column Strength*

When P_u/P_d *is* greater than 0.4, the requirements in **18.5.1.1** and **18.5.1.2** shall be met.

Where

P_u = required ultimate compressive strength of the member; and

P_d = design resistance in axial compression as obtained from **14.1.2**.

18.5.1.1 The required axial compressive and axial tensile strength in the absence of applied moment, shall be determined from the load combination in **18.2.3**.

18.5.1.2 The required strength determined in **18.5.1.1** need not exceed either of the maximum load transferred to the column considering 1.2 times the nominal strength of the connecting beam or brace element, or the resistance of the foundation to uplift.

18.5.2 *Column Splice*

18.5.2.1 A partial-joint penetration groove weld may be provided in column splice, such that the design strength of the joints shall be at least equal to 200 percent of the required strength.

18.5.2.2 The minimum required strength for each flange splice shall be 1.2 times $A_f f_y$ as shown Fig. 20, where A_f is the area of each flange in the smaller connected column.

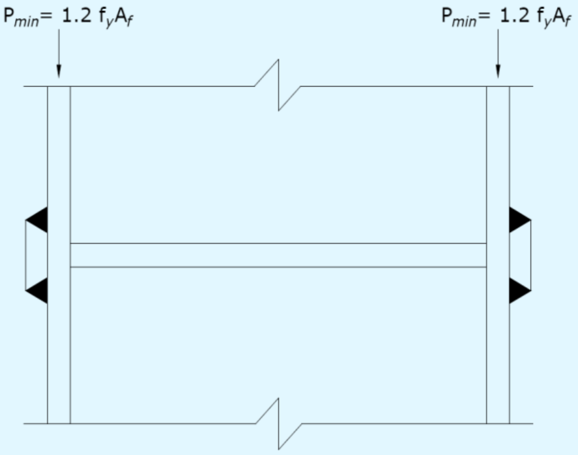


FIG. 20 PARTIAL PENETRATION GROOVE WELD IN COLUMN SPLICES

18.6 Storey Drift

The storey drift limits shall conform to **5** of Part C 'Structural design/Section 1 Loads and Load Effects' of this NBCS. The deformation compatibility of members not designed to resist seismic lateral load shall also conform to **5** of Part C 'Structural design/Section 1 Loads and Load Effects' of this NBCS.

18.7 Ordinary Concentrically Braced Frames (OCBF)

18.7.1 Ordinary concentrically braced frames (OCBF) should be shown to withstand inelastic deformation a moment of 1.2 times the full plastic moment of the corresponding to a joint rotation of at least 0.02 radians without degradation in strength and stiffness below the full yield value. Ordinary concentrically braced frames meeting the requirements of this section shall be deemed to satisfy the required inelastic deformation.

18.7.1.1 Ordinary concentrically braced frames shall not be used in seismic zones IV and above and for buildings with importance factor greater than unity (1 > 1.0) in
seismic zone III.

18.7.1.2 The provision in this section apply for diagonal and X-bracing only. Specialist literature may be consulted for V and inverted V-type bracing. K-bracing shall not be permitted in systems to resist earthquake.

18.7.2 *Bracing Members*

18.7.2.1 The slenderness of bracing members shall not exceed 120.

18.7.2.2 The required compressive strength of bracing member shall not exceed 0.8 times P_d, where P_d is the design strength in axial compression (*see* **14.1.2**).

18.7.2.3 Along any line of bracing, braces shall be provided such that for lateral loading in either direction, the tension braces will have to resist between 30 to 70 percent of the total lateral load.

18.7.2.4 Bracing cross-section can be plastic, compact or semi-compact, but not slender, as defined in **10.8.2**.

18.7.2.5 For all built-up braces, the spacing of tack fasteners shall be such that the unfavorable slenderness ratio of individual element, between such fasteners, shall not exceed 0.4 times the governing slenderness ratio of the brace itself. Bolted connections shall be avoided within the middle one-fourth of the clear brace length (0.25 times the length in the middle).

18.7.2.6 The bracing members shall be designed so that gross area yielding (*see* **13.2**) and not the net area rupture (*see* **13.3**) would govern the design tensile strength.

18.7.3 *Bracing Connections*

18.7.3.1 End connections in bracings shall be designed to withstand the minimum of the following:

a) A tensile force in the bracing equal to 1.2 $f_y A_g$;

b) Force in the brace due to load combinations in **18.2.3**; and

c) Maximum force that can be transferred to the brace by the system.

18.7.3.2 The connection should be checked for tension rupture and block shear under the load determined in **18.7.3.1**.

18.7.3.3 The connection shall be designed to withstand should be shown to withstand inelastic deformation a moment of 1.2 times the full plastic moment of the corresponding to a joint rotation of at least 0.02 radians braced section about the buckling axis.

18.7.3.4 Gusset plates shall be checked for buckling out of their plane.

18.8 Special Concentrically Braced Frames (SCBF)

18.8.1 Special concentrically braced frames (SCBF) should be shown to withstand inelastic deformation corresponding to a joint rotation of at least 0.04 radians without degradation in strength and stiffness below the full yield value. Special concentrically braced frames meeting the requirements of this section shall be deemed to satisfy the required inelastic deformation.

18.8.1.1 Special concentrically braced frames (SCBF) may be used in any seismic zone as defined in **5** of Part C 'Structural design/Section 1 Loads and Load Effects' of this NBCS and for any building.

18.8.1.2 The provision in this section apply for diagonal and X-bracing only. Specialist literature may be consulted for V and inverted V-type bracing. K-bracing shall not be permitted in system to resist earthquake.

18.8.2 *Bracing Members*

18.8.2.1 Bracing members shall be made of E 250B steel of accepted standard [C-6A(6)] only.

18.8.2.2 The slenderness of bracing members shall not exceed 160 (only hangers).

18.8.2.3 The required compressive strength of bracing member shall not exceed the design strength in axial compression P_d (*see* **14.1.2**).

18.8.2.4 Along any line of bracing, braces shall be provided such that for lateral loading in either direction, the tension braces will resist between 30 percent to 70 percent of the load.

18.8.2.5 Braced cross-section shall be plastic as defined in **10.8.2**.

18.8.2.6 In built-up braces, the spacing of tack connections shall be such that the slenderness ratio individual element between such connections shall not exceed 0.4 times the governing slenderness ratio of the brace itself. Bolted connection shall be avoided.

18.8.3.4 Gusset plates shall be checked for buckling out of their plane.

18.8.4 ***Column***

18.8.4.1 The column sections used in special concentrically braced frames (SCBF) shall be plastic as defined in **10.8.2**.

18.8.4.2 Splices shall be located within the middle one-third of the column clear height. Splices shall be designed for the forces that can be transferred to it. In addition, splices in columns shall be designed to develop at least the nominal shear strength of the smaller connected section.

18.9 Eccentrically Braced Frames (EBF)

18.9.1 Ordinary eccentrically braced frames (OEBF) and Special eccentrically braced frames (SEBF) shall be designed in accordance with specialist literature.

18.10 Ordinary Moment Frames (OMFs)

Ordinary moment frames (OMFs) of structural steel shall be designed to satisfy the requirements of this section.

18.10.1 *Basis of Design*

Ordinary moment frames designed in accordance with these provisions are expected to possess limited inelastic deformation capacity through flexural yielding of the beams, panel zones, and columns.

18.10.2 *Analysis*

When two moment frames oriented in orthogonal directions intersect, the possibility of beam yielding in both orthogonal directions simultaneously shall be considered in the estimation of design demand on the common column.

18.10.3 *Member Requirements*

The requirements specified hereunder shall be satisfied by the component or member.

18.10.3.1 *Beams*

Beam cross-section shall be plastic or compact, as defined in **10.8.2**.

18.10.3.2 *Columns*

Column cross-section shall be plastic or compact, as defined in **10.8.2**.

18.10.4 *System Requirements*

It is preferable to plan buildings to have independent lateral load resisting moment frames in the vertical plane along each principal plan direction. Also, the requirements given hereunder shall be satisfied by the building system.

18.10.4.1 *Beam-to-column connections*

Beam-to-column connections may be rigid or semi-rigid moment connections, but shall satisfy the following criteria:

a) Rigid moment connections shall be designed to withstand a moment of at least 1.2 times of either the full plastic moment of the connected beam or the maximum moment that can be delivered by the beam to the joint due to the induced weakness at the ends of the beam, whichever is less.

b) Semi-rigid connections shall be designed and to withstand either a moment of at least 0.5 times the full plastic moment of the connected beam or the maximum moment that can be delivered by the system, whichever is less. The design moment shall be achieved within a rotation of 0.01 radians. The information given in Annex F may be used for checking.

c) The stiffness and strength of semi-rigid connections shall be accounted for in the design and the overall stability of the frame shall be ensured.

d) The rigid and semi-rigid connections shall be designed to withstand a shear resulting from the load combination 1.2 DL + 0.5 LL plus the shear corresponding to the design moment defined in **(a)** and **(b)**, respectively.

e) In rigid fully welded connections, continuity plates of thickness equal to or greater than the thickness of the beam flange shall be provided and welded to the column flanges and web.

18.10.4.2 *Column to beam strength ratio*

At a beam–column joint, strong column - weak beam design shall be adopted, suitably accounting for the reduction in moment capacity of columns due to axial load.

18.11 Special Moment Frames (SMF)

18.11.1 Special moment frames (SMF) shall be made of E250B steel of accepted standard [C-6A(6)] and should be shown to withstand inelastic deformation corresponding to a joint rotation of 0.04 radians without degradation in strength and stiffness below the full yield value (M_P). Special moment frames meeting the requirements of this section shall be deemed to satisfy the required inelastic deformation.

18,11.1.1 Special moment frames (SMF) maybe used in any seismic zone and for any buildings.

18.11.2 *Beam-to-Column Joints and Connections*

18.11.2.1 All beam-to-column connections shall be rigid (*see* Annex F) and designed to withstand a moment of at least 1.2 times the full plastic moment of the connected beam. When a reduced beam section is used, its minimum flexural strength shall be at least equal to 0.8 times the full plastic moment of the unreduced section.

18.11.2.2 The connection shall be designed to withstand a shear resulting from the load combination 1.2 DL + 0.5LL plus the shear resulting from the application of $1.2M_P$ in the same direction, at each end of the beam (causing double curvature bending). The shear strength need not exceed the required value corresponding to the load combination in **18.2.3**.

18.11.2.3 In column strong axis connections (beam and column web in the same plane), the panel zone shall be checked for shear buckling in accordance with **15.4.2** at the design shear defined in **18.11.2.2**. Column web doubler plates or diagonal stiffeners may be used to strengthen the web against shear buckling.

18.11.2.4 The individual thickness of the column webs and doubler plates (*see* Fig. 21), shall satisfy the following:

$$t \geq (d_P + b_P)/90$$

where

t = Thickness of the column web or doubler plate

d_P = Panel zone depth between continuity plates

b_P = Panel zone width between column flanges

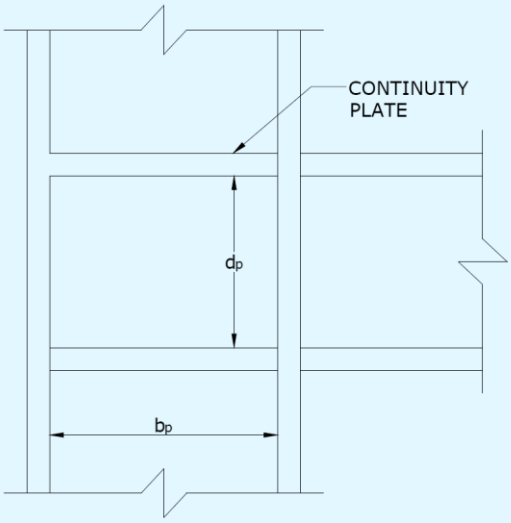


FIG. 21 CONTINUITY PLATES

18.11.2.5 Continuity plates (tension stiffener) (*see* **15.7**) shall be provided in all strong axis welded connections except in end plate connection.

18.11.3 *Beam and Column Limitation*

18.11.3.1 Beam and column sections shall be either plastic or compact as defined in **10.8.2**. At potential plastic hinge locations, they shall necessarily be plastic**.**

18.11.3.2 The section selected for beams and columns shall satisfy the following relation:

$$\frac{\sum M_{\mathrm{Pc}}}{\sum M_{\mathrm{Pb}}} \geq 1.2$$

where

M_{Pc}= sum of the moment capacity in the column above and below the beam centreline; and

M_{Pb} = sum of the moment capacity in the beams at the intersection of the beam and column centrelines.

In tall buildings, higher mode effects shall be accounted for in accordance with specialist literature.

18.11.3.3 Lateral support to the column at both top and bottom beam flange levels shall be provided so as to resist at least 2 percent of the beam flange strength, except for the case described in **18.11.3.4**.

18.11.3.4 A plane frame designed as non-sway in the direction perpendicular to its plane, shall be checked for buckling, under the load combination specified in **18.2.3**.

18.12 Column Bases

18.12.1 Fixed column bases and their anchor bolts should be designed to withstand a moment of 1.2 times the full plastic moment capacity of the column section. The anchor bolts shall be designed to withstand the combined action of shear and tension as well as prying action, if any.

18.12.2 Both fixed and hinged column bases shall be designed to withstand the full shear under any load case or 1.2 times the shear capacity of the column section, whichever is higher.

18.13 Industrial Structures

18.13.1 Single storey industrial buildings with frame height to span ratio less than 1.0 and with regular configuration need not meet the ductility requirements of other types of frames specified in **18.3**, **18.4** or in good practice[C-6A(42)], provided they satisfy the requirements in **18.13.2** and **18.13.3**.

18.13.2 Braced frames or moment frames are permitted as lateral force resisting system and shall be designed using R = 1.5 as prescribed for NDF.

18.13.3 Connections in lateral force resisting systems to resist earthquake shall be designed for full member capacity except those in earthquake zone V, where the connections shall be designed for 50 percent extra force.

19 FATIGUE

19.1 General

Structure and structural elements subject to loading that could lead to fatigue failure shall be designed against fatigue as given in this section. This shall however not cover the following:

a) Corrosion fatigue;
b) Low cycle (high stress) fatigue;
c) Thermal fatigue;
d) Stress corrosion cracking;
e) Effects of high temperature (> 150 °C); and
f) Effects of low temperature (< brittle transition temperature).

For the purpose of design against fatigue, different details (of members and connections) are classified under different fatigue class. The design stress range corresponding to various number of cycles, are given for each fatigue class. The requirements of this Section shall be satisfied with, at each critical location of the structure subjected to cyclic loading, considering relevant number of cycles and magnitudes of stress range expected to be experienced during the life of the structure.

19.2 Design

19.2.1 *Reference Design Condition*

The standard S-N curves for each detail category are given for the following conditions:

a) Detail is located in a redundant load path, wherein local failure at that detail alone will not lead to overall collapse of the structure;
b) Nominal stress history at the local point in the detail is estimated/evaluated by a conventional method without taking into account the local stress concentration effects due to the detail;
c) Load cycles are not highly irregular;
d) Details are accessible for and subject to regular inspection;
e) Structure is exposed to only mildly corrosive environment as in normal atmospheric condition and suitably protected against corrosion (pit depth < 1 mm);

f) Structure is not subjected to temperature exceeding 150 °C; and

g) Transverse fillet or butt weld connects plates of thickness not greater than 25 mm.

19.2.1.1 *Thickness correction factor*

The values obtained from the standard S-N curve shall be modified by a capacity reduction factor μ_r, when plates greater than 25 mm in thickness are joined together by transverse fillet or butt welding, given by:

$$\mu_r = (25/t_p)^{0.25} \leq 1.0$$

where

t_p = actual thickness of the thicker plate being joined, in mm.

No thickness correction is necessary when full penetration butt weld reinforcements are machined flush and proved free of defect through nondestructive testing.

19.2.1.2 *Necessity for fatigue assessment*

a) Fatigue assessment is not normally required for building structures except as follows; and
   1) Members supporting lifting or rolling loads;
   2) Member subjected to repeated stress cycles from vibrating machinery;
   3) Members subjected to wind induced oscillations of a large number of cycles in life; and
   4) Members subjected to crowd induced oscillations of a large number of cycles in life.

b) No fatigue assessment is necessary if the following conditions are satisfied.
   1) The highest normal stress range $f_{\mathrm{f\,max}}$ satisfies:

$$f_{\mathrm{fmax}} \leq 27\mu_{\mathrm{r}} / \gamma_{\mathrm{mft}}$$

   2) The highest shear stress range τ_{fmax} satisfies:

$$\tau_{\mathrm{fmax}} \leq 67\mu_r / \gamma_{\mathrm{mft}}$$

   3) The total number of actual stress cycles N_{SC}, satisfies:

$$N_{\mathrm{SC}} \leq 5\times10^6 \left(\frac{27\mu_r}{\gamma_{\mathrm{mft}}\ f_{\mathrm{feq}}} \right)^3$$

where

f_{feq} = equivalent constant amplitude stress range, in MPa, given by.

$$f_{\mathrm{feq}} = \left[\frac{\sum_{i=1}^{r5} n_i f_{\mathrm{i}}^3 + \sum_{j=\mathrm{r}5}^{r} n_{\mathrm{j}} f_{\mathrm{j}}^5}{n} \right]^{1/3}$$

where

$f_{\mathrm{i}}, f_{\mathrm{j}}$ = stress ranges falling above and below the ffn, the stress range corresponding to the detail at 5 × 10^6 number of life cycles.

$$n = \sum_{i=1}^{r} n_{\mathrm{i}}$$

19.2.2 *Design Spectrum*

19.2.2.1 *Stress evaluation*

Design stress shall be determined by elastic analysis of the structure to obtain stress resultants and the local stresses may be obtained by a conventional stress analysis method. The normal and shear stresses shall be determined considering all design actions on the members, but excluding stress concentration due to the geometry of the detail. The stress concentration effect is accounted for in detail category classification (*see* Table 26). The stress concentration, however, not characteristic of the detail shall be accounted for separately in the stress calculation.

In the fatigue design of trusses made of members with open sections, in which the end connections are not pinned, the stresses due to secondary bending moments shall be taken into account, unless the slenderness ratio (KL/r), of the member is greater than 40.

In the determination of stress range at the end connections between hollow sections, the effect of connection stiffness and eccentricities may be disregarded, provided:

a) the calculated stress range is multiplied by appropriate factor given in Table 24(A) in the case of circular hollow section connections and Table 24(B) in the case of rectangular hollow section connections; and
b) the design throat thickness of fillet welds in the joints is greater than the wall thickness of the connected member.

19.2.2.2 *Design stress spectrum*

In the case of loading events producing non-uniform stress range cycle, the stress spectrum may be obtained by a rational method, such as ‘rain flow counting’ or an equivalent method.

Table 24(A) Multiplying Factors for Calculated Stress Range
(Circular Hollow Sections)

(*Clause* 19.2.2.1)

Sl No. (1)	Type of Connection (2)		Chords (3)	Verticals (4)	Diagonals (5)
i)	Gap connections	K type	1.5	1.0	1.3
		N type	1.5	1.8	1.4
ii)	Overlap connections	K type	1.5	1.0	1.2
		N type	1.5	1.65	1.25

Table 24(B) Multiplying Factors for Calculated Stress Range
(Rectangular Hollow Sections)

(*Clause* 19.2.2.1)

Sl No. (1)	Types of Joint (2)		Chords (3)	Verticals (4)	Diagonals (5)
i)	Gap connections	K type	1.5	1.0	1.5
		N type	1.5	2.2	1.6
ii)	Overlap connections	K type	1.5	1.0	1.3
		N type	1.5	2.0	1.4

19.2.3 *Partial Safety Factors*

19.2.3.1 *Partial safety factor for actions and their effects* (γ_{fft})

Unless and otherwise the uncertainty in the estimation of the applied actions and their effects demand a higher value, the partial safety factor for loads in the evaluation of stress range in fatigue design shall be taken as 1.0.

19.2.3.2 *Partial safety factor for fatigue strength* (γ_{mft})

Partial safety factor for strength is influenced by consequences of fatigue damage and level of inspection capabilities.

19.2.3.3 Based on consequences of fatigue failure, component details have been classified as given in the Table 25 and the corresponding partial safety factor for fatigue strength shall be used:

a) failsafe structural component/detail is the one where local failure of one component due to fatigue crack does not result in the failure of the structure due to availability of alternate load path (redundant system); and

b) non-failsafe structural component/detail is the one where local failure of one component leads rapidly to failure of the structure due to its non-redundant nature.

Table 25 Partial Safety Factors for Fatigue Strength (γ_{mft})

(*Clauses* 19.2.3.3, 19.5.1 *and* 19.5.2.3)

Sl No.	**Inspection and Access**	**Consequence of Failure**	
		Failsafe	Non-failsafe
(1)	(2)	(3)	(4)
i)	Periodic inspection, maintenance and accessibility to detail is good	1.00	1.25
ii)	Periodic inspection, maintenance and accessibility to detail is poor	1.15	1.35

19.3 Detail Category

Table 26(A) to Table 26 (D) indicate the classification of different details into various categories for the purpose of assessing fatigue strength. Details not classified in the table may be treated as the lowest detail category of a similar detail, unless superior fatigue strength is proved by testing and/or analysis.

Holes in members and connections subjected to fatigue loading shall not be made:

a) using punching in plates having thickness greater than 12 mm unless the holes are sub-punched and subsequently reamed to remove the affected material around the punched hole; and

b) using gas cutting unless the holes are reamed to remove the material in the heat affected zone.

19.4 Fatigue Strength

The fatigue strength of the standard detail for the normal or shear fatigue stress range, not corrected for thickness effects discussed in 19.2.1, is given below (*see* also Fig. 22 and Fig. 23):

a) Normal stress range:

1) when $N_{\mathrm{SC}} \leq 5 \times 10^6$

$$f_{\mathrm{f}} = f_{fn} \sqrt[3]{5 \times 10^6 / N_{\mathrm{sc}}}$$

2) when $5 \times 10^6 \leq N_{\mathrm{SC}} \leq 10^8$

$$f_f = f_{fn}\sqrt[5]{5\times10^6/N_{sc}}$$

b) Shear stress:

$$\tau_f = \tau_{fn}\sqrt[5]{5\times10^6/N_{sc}}$$

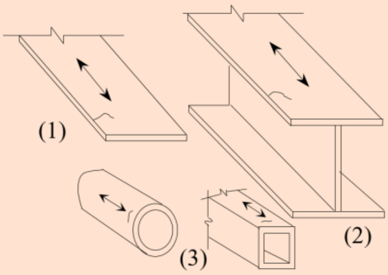
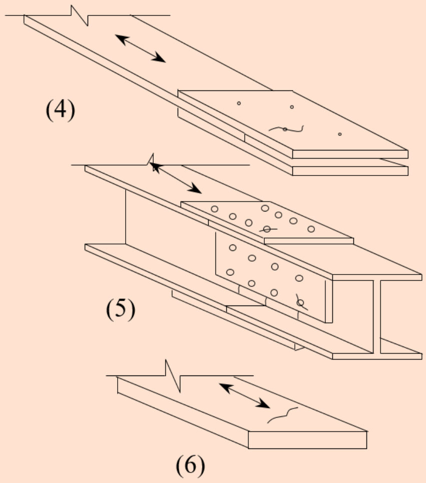
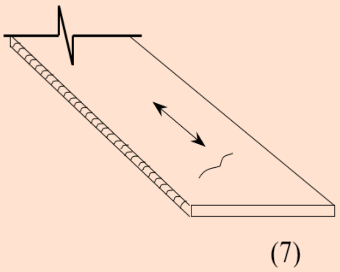
where

f_f, τ_f = design normal and shear fatigue stress range of the detail, respectively, for life cycle of N_{SC}; and

f_{fn}, τ_{fn} = normal and shear fatigue strength of the detail for 5 × 10^6 cycles, for the detail category (*see* Table 26).

Table 26(A) Detail Category Classification, Group 1 Non-Welded Details (f_{fn})

(*Clauses* 19.2.2.1, 19.3 *and* 19.4)

Sl No.	Detail Category	Constructional Details	
		Illustration (*see* Note)	Description
(1)	(2)	(3)	(4)
i)	118		Rolled and extruded products: a) Plates and flats (1); b) Rolled sections (2); and c) Seamless tubes (3) Sharp edges, surface and rolling flaws to be removed by grinding in the direction of applied stress
ii)	103		a) Bolted connections: (4) and (5) — Stress range calculated on the gross section and on the net section Unsupported one-sided cover plate connections shall be avoided or the effect of the eccentricity taken into account in calculating stresses b) Material with gas-cut or sheared edges with no draglines: (6) — All hardened material and visible signs of edge discontinuities to be removed by machining or grinding in the direction of applied stress
iii)	92		c) Material with machine gas-cut edges with draglines or manual gas-cut material: (7) — Corners and visible signs of edge discontinuities to be removed by grinding in the direction of the applied stress

NOTE — The arrow indicates the location and direction of the stresses acting in the basic material for which the stress range is to be calculated on a plane normal to the arrow.

Table 26(B) Detail Category Classification, Group 2 Welded Details - Not in Hollow Sections (f_{fn})

(*Clauses* 19.2.2.1, 19.3 *and* 19.4)

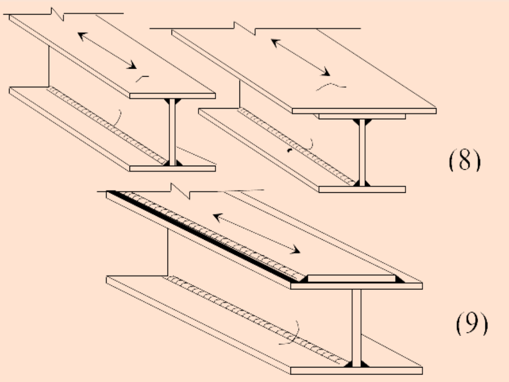
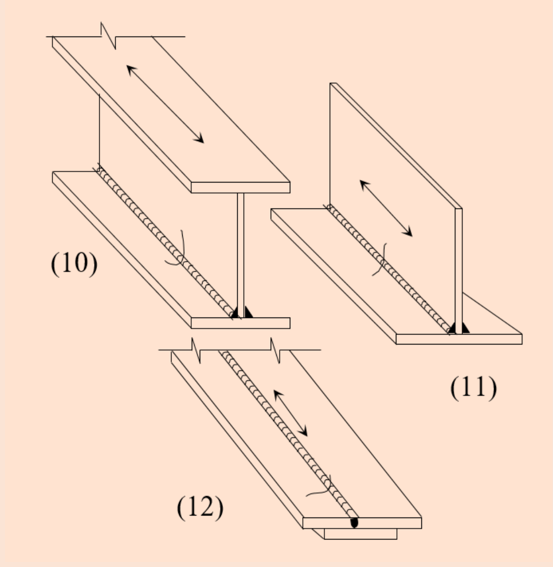
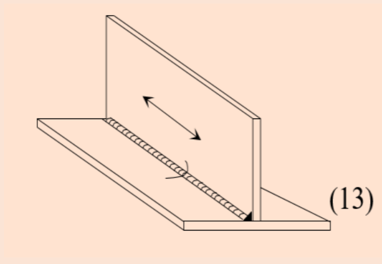
Sl No.	**Detail Category**	**Constructional Details**	
		Illustration (*see* Note)	Description
(1)	(2)	(3)	(4)
i)	92		Welded plate I-section and box girders with continuous longitudinal welds: (8) and (9) — Zones of continuous automatic longitudinal fillet or butt welds carried out from both sides and all welds not having un-repaired stop-start positions
ii)	83		Welded plate I-section and box girders with continuous longitudinal welds: (10) and (11) — Zones of continuous automatic butt welds made from one side only with a continuous backing bar and all welds not having un-repaired stop-start positions (12) — Zones of continuous longitudinal fillet or butt welds carried out from both sides but containing stop-start positions. For continuous manual longitudinal fillet or butt welds carried out from both sides, use Detail Category 92
iii)	66		Welded plate I-section and box girders with continuous longitudinal welds: (13) — Zones of continuous longitudinal welds carried out from one side only, with or without stop-start positions

Table 26(B) (*Continued*)

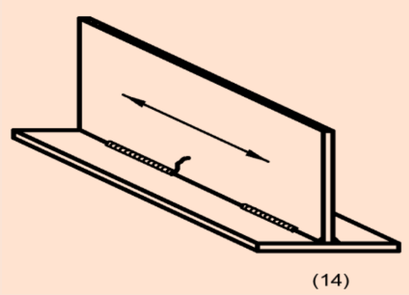
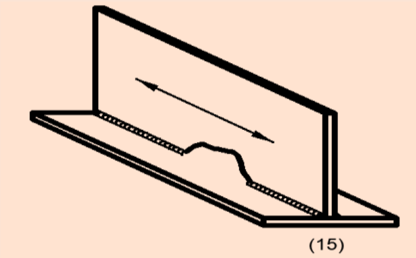
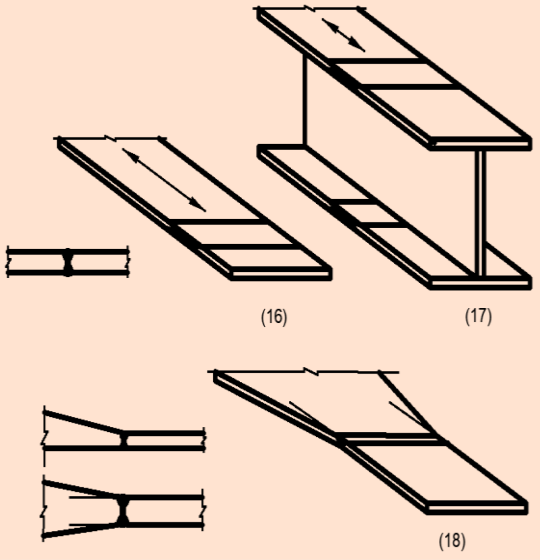
Sl No.	**Detail Category**	**Constructional Details**	
		Illustration (*see* Note)	Description
(1)	(2)	(3)	(4)
iv)	59		Intermittent longitudinal welds: (14) — Zones of intermittent longitudinal welds
v)	52		Intermittent longitudinal welds: (15) — Zones containing cope holes in longitudinally welded T-joints. Cope hole not to be filled with weld
vi)	83		Transverse butt welds (complete penetration): Weld run-off tabs to be used, subsequently removed and ends of welds ground flush in the direction of stress. Welds to be made from two sides (16) — Transverse splices in plates, flats and rolled sections having the weld reinforcement ground flush to plate surface. 100 percent NDT inspection, and weld surface to be free of exposed porosity in the weld metal (17) — Plate girders welded as in (16) before assembly (18) — Transverse splices as in (16) with reduced or tapered transition with taper ≤ 1 : 4

Table 26(B) (*Continued*)

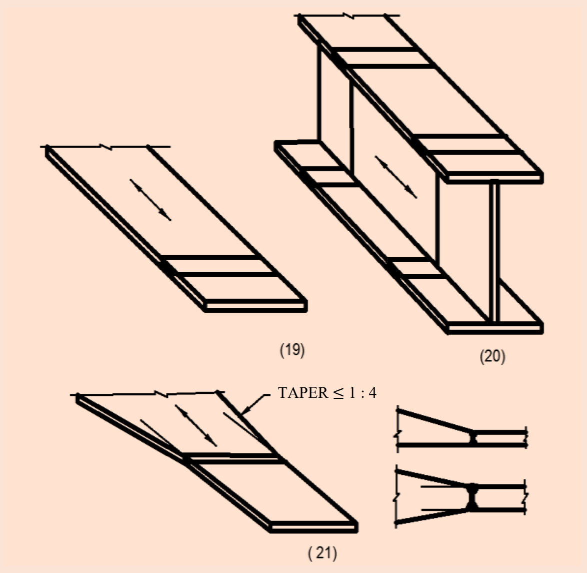
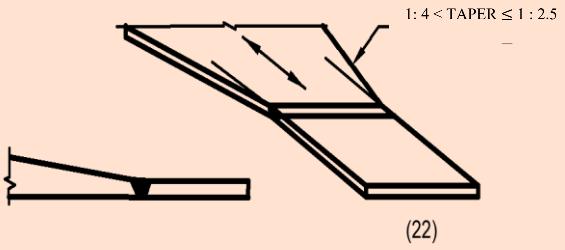
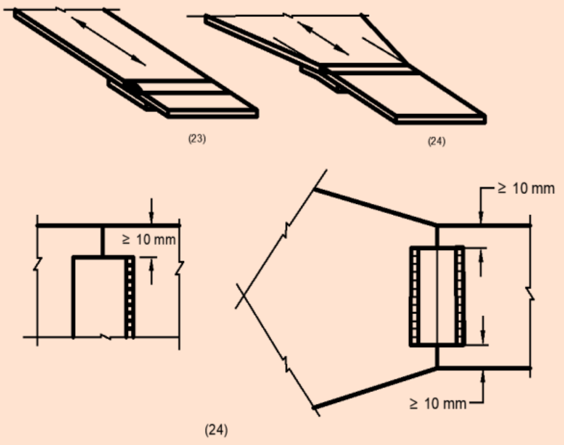
Sl No.	**Detail Category**	**Constructional Details**	
		Illustration (*see* Note)	Description
(1)	(2)	(3)	(4)
vii)	66		Transverse butt welds (complete penetration): Welds run-off tabs to be used, subsequently removed and ends of welds ground flush in the direction of stress. Welds to be made from two sides (19) — Transverse splices of plates, rolled sections or plate girders (20) — Transverse splice of rolled sections or welded plate girders, without cope hole. With cope hole use Detail Category 52, as in (15) (21) — Transverse splices in plates or flats being tapered in width or in thickness where the taper is ≤ 1 : 4
viii)	59		Transverse butt welds (complete penetration): Weld run-off tabs to be used, subsequently removed and ends of welds ground flush in the direction of stress. Welds to be made from two sides (22) — Transverse splices as in (21) with taper in width or thickness >1 : 4 but ≤1 : 2.5
ix)	52		Transverse butt welds (complete penetration): (23) — Transverse butt-welded splices made on a backing bar. The end of the fillet weld of the backing strip shall stop short by more than 10 mm from the edges of the stressed plate (24) — Transverse butt welds as per (23) with taper on width or thickness < 1 : 2.5

Table 26(B) (*Continued*)

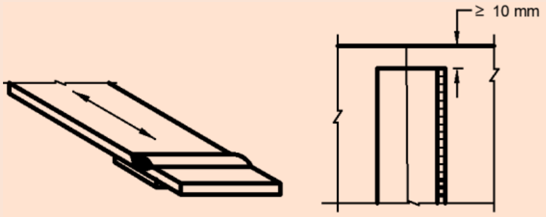
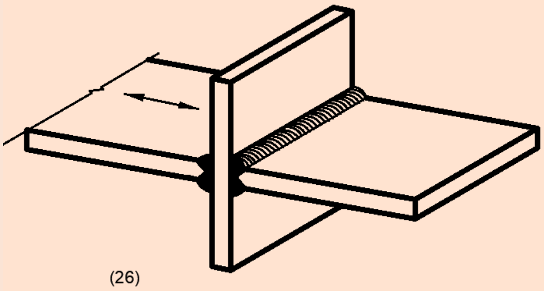
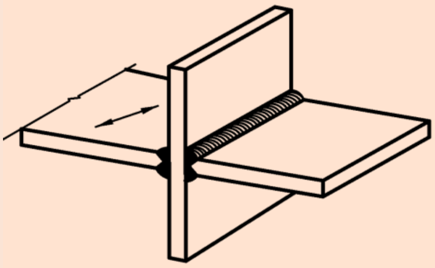
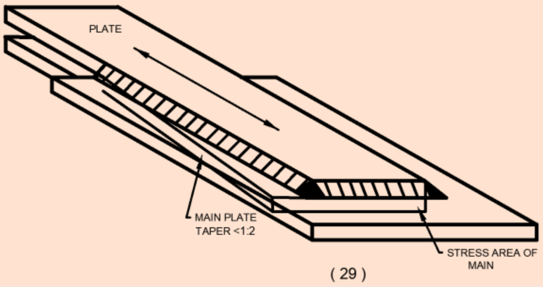
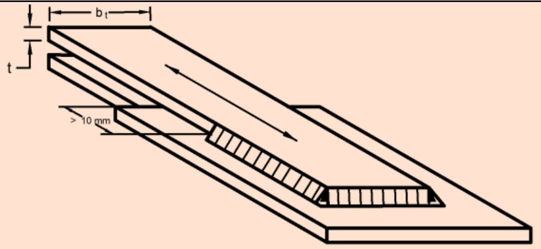
Sl No.	Detail Category		Constructional Details	
			Illustration (*see* Note)	Description
(1)	(2)		(3)	(4)
x)	37		 (25)	Transverse butt welds (complete penetration): (25) — Transverse butt welds as in (23) where fillet welds end closer than 10 mm to plate edge
xi)	52		 (26)	Cruciform joints with load-carrying welds: (26) — Full penetration welds with intermediate plate NDT inspected and free of defects. Maximum misalignment of plates either side of joint to be < 0.15 times the thickness of intermediate plate
xii)	41	(27)	 (27) and (28)	(27) — Partial penetration or fillet welds with stress range calculated on plate area
	27	(28)		(28) — Partial penetration or fillet welds with stress range calculated on throat area of weld
xiii)	46		 (29)	Overlapped welded joints: (29) — Fillet welded lap joint, with welds and overlapping elements having a design capacity greater than the main plate. Stress in the main plate to be calculated on the basis of area shown in the illustration
xiv)	41	(30)	 (30) and (31)	Overlapped weld joints: (30) — Fillet welded lap joint, with welds and main plate both having a design capacity greater than the overlapping elements
xv)	33	31		31 — Fillet welded lap joint, with main plate and overlapping elements both having a design capacity greater than the weld

Table 26(B) (*Continued*)

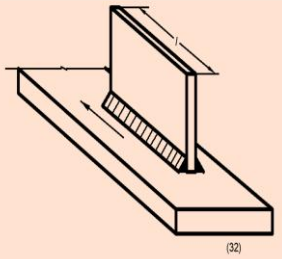
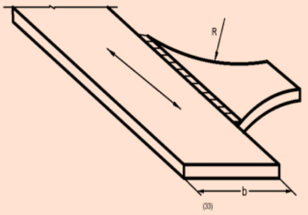
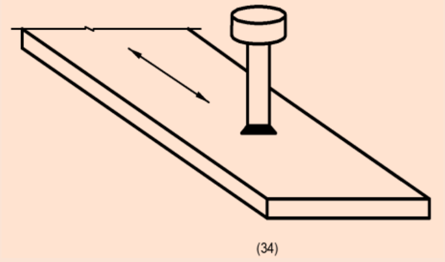
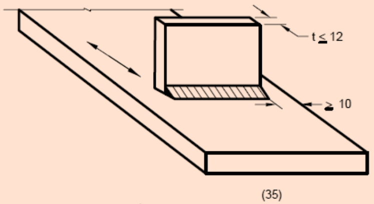
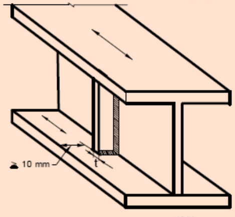
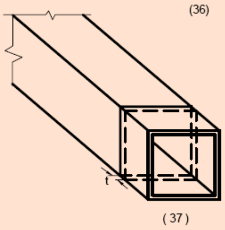
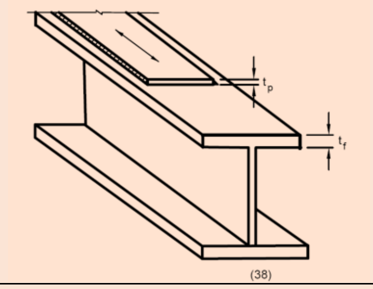
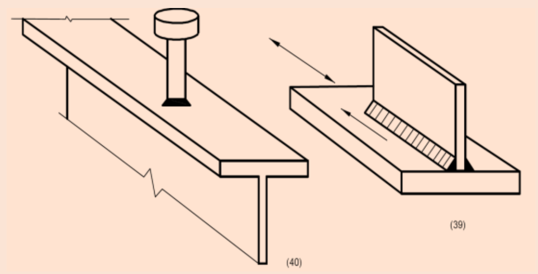
Sl No.	**Detail Category**	**Constructional Details**			
		Illustration (*see* Note)			Description
(1)	(2)	(3)			(4)
xvi)	66	(32)	(33)	 	Welded attachments (non-load carrying welds) — Longitudinal welds: (32) — Longitudinal fillet welds. Class of detail varies according to the length of the attachment weld as noted (33) — Gusset welded to the edge of a plate or beam flange. Smooth transition radius (*r*), formed by machining or flame cutting plus grinding. Class of detail varies according to *r*/*b* ratio as noted
		—	1/3 ≤ *r*/*b*		
	59	*l* ≤ 50mm	—		
	52	50 < *l* ≤ 100 mm	1/6 ≤ *r*/*b* < 1/3		
	37	100 mm < *l*	—		
	33	—	*r*/*b* < 1/6		
xvii)	59				Welded attachments: (34) — Shear connectors on base material (failure in base material)
xviii)	59	*t* ≤ 12 mm	  		Transverse welds: (35) — Transverse fillet welds with the end of the weld ≥10 mm from the edge of the plate (36) — Vertical stiffeners welded to a beam or plate girder flange or web by continuous or intermittent welds. In the case of webs carrying combined bending and shear design actions, the fatigue strength shall be determined using the stress range of the principal stresses (37) — Diaphragms of box girders welded to the flange or web by continuous or intermittent welds
	52	*t* > 12 mm			

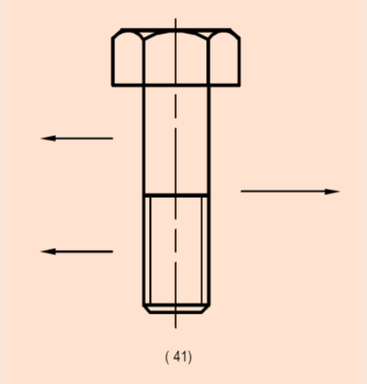
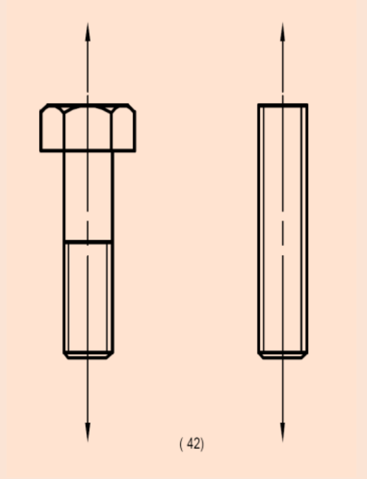
Table 26(B) (*Continued*)

Sl No.	Detail Category	Constructional Details		
		Illustration (*see* Note)		Description
(1)	(2)	(3)		(4)
xix)	37	t_f or $t_p \le$ 25mm		Cover plates in beams and plate girders: (38) — End zones of single or multiple welded cover plates, with or without a weld across the end. For a reinforcing plate wider than the flange, an end weld is essential
	27	t_f or t_p >25 mm		
xx)	67			Welds loaded in shear: (39) — Fillet welds transmitting shear. Stress range to be calculated on weld throat area (40) — Stud welded shear connectors (failure in the weld) loaded in shear (the shear stress range to be calculated on the nominal section of the stud)

NOTE — The arrow indicates the location and direction of the stresses acting in the basic material for which the stress range is to be calculated on a plane normal to the arrow.

Table 26(C) Detail Category Classification, Group 3 Bolts

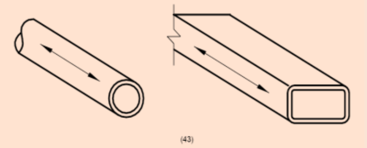
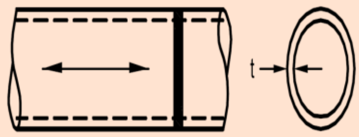
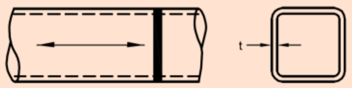
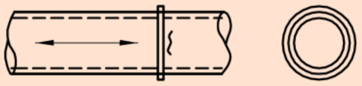
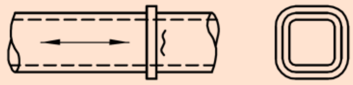
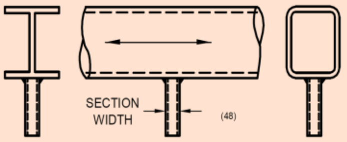
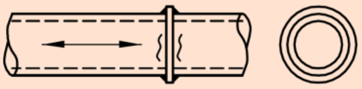
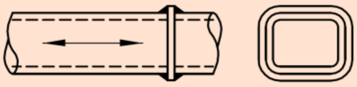
(*Clauses* 19.2.2.1, 19.3 *and* 19.4)

Sl No.	**Detail Category**	**Constructional Details**	
		Illustration (*see* Note)	Description
(1)	(2)	(3)	(4)
i)	83		Bolts in shear (8.8/TB Bolting category only): (41) — Shear stress range calculated on the minor diameter area of the bolt (A_c) NOTE — If the shear on the joint is insufficient to cause slip of the joint the shear in the bolt need not be considered in fatigue
ii)	27		Bolts and threaded rods in tension (tensile stress to be calculated on the tensile stress area, A_t): (42) — Additional forces due to prying effects shall be taken into account. For tensional bolts, the stress range depends on the connection geometry NOTE — In connections with tensioned bolts, the change in the force in the bolts is often less than the applied force, but this effect is dependent on the geometry of the connection. It is not normally required that any allowance for fatigue be made in calculating the required number of bolts in such connections

NOTE — The arrow indicates the location and direction of the stresses acting in the basic material for which the stress range is to be calculated on a plane normal to the arrow.

Table 26(D) Detail Category Classification, Group 4 Welded details — in Hollow Sections (f_{fn})

(*Clauses* 19.2.2.1, 19.3 *and* 19.4)

Sl No.	**Detail Category**	**Constructional Details**	
		Illustration (*see* Note)	Description
(1)	(2)	(3)	(4)
i)	103	 (43)	Continuous automatic longitudinal welds: (43) — No stop-starts, or as manufactured, proven free to detachable discontinuities.
ii)	66 ($t \geq 8$ mm) 52 ($t < 8$ mm)	 (44)	Transverse butt welds: (44) — Butt-welded end-to-end connection of circular hollow sections NOTE — Height of the weld reinforcement less than 10 percent of weld with smooth transition to the plate surface. Welds made in flat position and proven free to detachable discontinuities)
iii)	52 ($t \geq 8$ mm) 41 ($t < 8$ mm)	 (45)	(45) — Butt-welded end-to-end connection of rectangular hollow sections
iv)	41 ($t \geq 8$ mm) 37 ($t < 8$ mm)	 (46)	Butt welds to intermediate plate: (46) — Circular hollow sections, end-to-end butt-welded with an intermediate plate
v)	37 ($t \geq 8$ mm) 30 ($t < 8$ mm)	 (47)	(47) — Rectangular hollow sections, end-to-end butt welded with an intermediate plate
vi)	52		Welded attachments (non-load-carrying): (48) — Circular or rectangular hollow section, fillet welded to another section. Section width parallel to stress direction ≤100mm
vii)	33 ($t < 8$ mm) 29 ($t < 8$ mm)	 (49)	Fillet welds to intermediate plate: (49) — Circular hollow sections, end-to-end fillet welded with an intermediate plate
viii)	29 ($t \geq 8$ mm) 27 ($t < 8$ mm)	 (50)	(50) — Rectangular hollow sections, end-to-end fillet welded with an intermediate plate

NOTE — The arrow indicates the location and direction of the stresses acting in the basic material for which the stress range is to be calculated on a plane normal to the arrow.

19.5 Fatigue Assessment

19.5.1 The design fatigue strength for N_{SC} life cycles (f_{fd}, τ_{fd}) may be obtained from the standard fatigue strength for N_{SC} cycles by multiplying with correction factor, μ_r, for thickness, as mentioned in **19.2.1** and dividing by partial safety factor given in Table 25.

19.5.2 *Stress Limitations*

19.5.2.1 The maximum (absolute) value of the normal and shear stresses shall never exceed the elastic limit (f_y, τ_y) for the material under cyclic loading.

19.5.2.2 The maximum stress range shall not exceed 1.5 f_y for normal stresses and 1.5 $f_y/\sqrt{3}$ for the shear stresses under any circumstance.

19.5.2.3 *Constant stress range*

The actual normal and shear stress range f and τ at a point of the structure subjected to N_{SC} cycles in life shall satisfy:

$$f \leq f_{fd} = \mu_r f_f / \gamma_{mft}$$

$$\tau \leq \tau_{fd} = \mu_r \tau_f / \gamma_{mft}$$

where

f_f, τ_f = normal and shear fatigue strength ranges for the actual life cycle, N_{SC}, obtained from **19.4**;

μ_r = correction factor (*see* **19.2.1**); and

γ_{mf} = partial safety factor against fatigue failure, given in Table 25.

19.5.2.4 *Variable stress range*

Fatigue assessment at any point in a structure, wherein variable stress ranges f_i or τ_i for n_i number of cycles (i =1 to r) are encountered, shall satisfy the following:

a) For normal stress (f):

$$\frac{\sum_{i=1}^{r_5} n_i f_i^3}{5\times10^6\left(\mu_r f_{fn}/\gamma_{mft}\right)^3} + \frac{\sum_{j=r_5}^{r} n_j f_j^5}{5\times10^6\left(\mu_r f_{fn}/\gamma_{mft}\right)^5} \leq 1.0$$

b) For shear stresses (τ):

$$\sum_{i=0}^{r} n_i \tau_i^5 \leq 5 \times 10^6 (\mu_r \tau_{fn}/\gamma_{mft})$$

Where r_5 is the summation upper limit of all the normal stress ranges (f_i) having magnitude lesser than ($\mu_r f_{fn}/\gamma_{mft}$) for that detail and the lower limit of all the normal stress ranges (f_j) having magnitude greater than ($\mu_r f_{fn}/\gamma_{mft}$) for the detail. In the above summation all normal stress ranges, f_i, and shear stress ranges τ_i having magnitude less than $0.55\mu_r f_{fn}$, and $0.55\mu_r \tau_{fn}$, respectively may be disregarded.

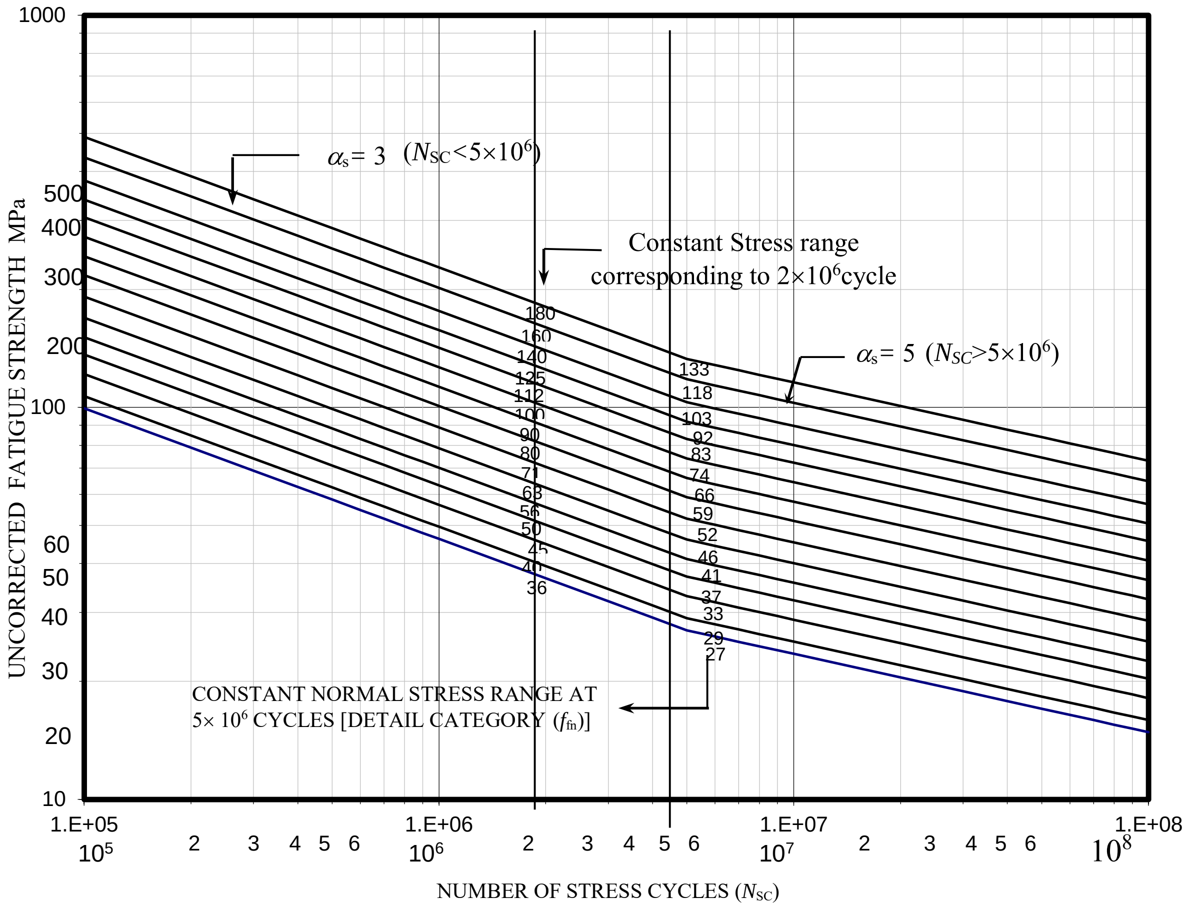


FIG. 22 S-N CURVE FOR NORMAL STRESS

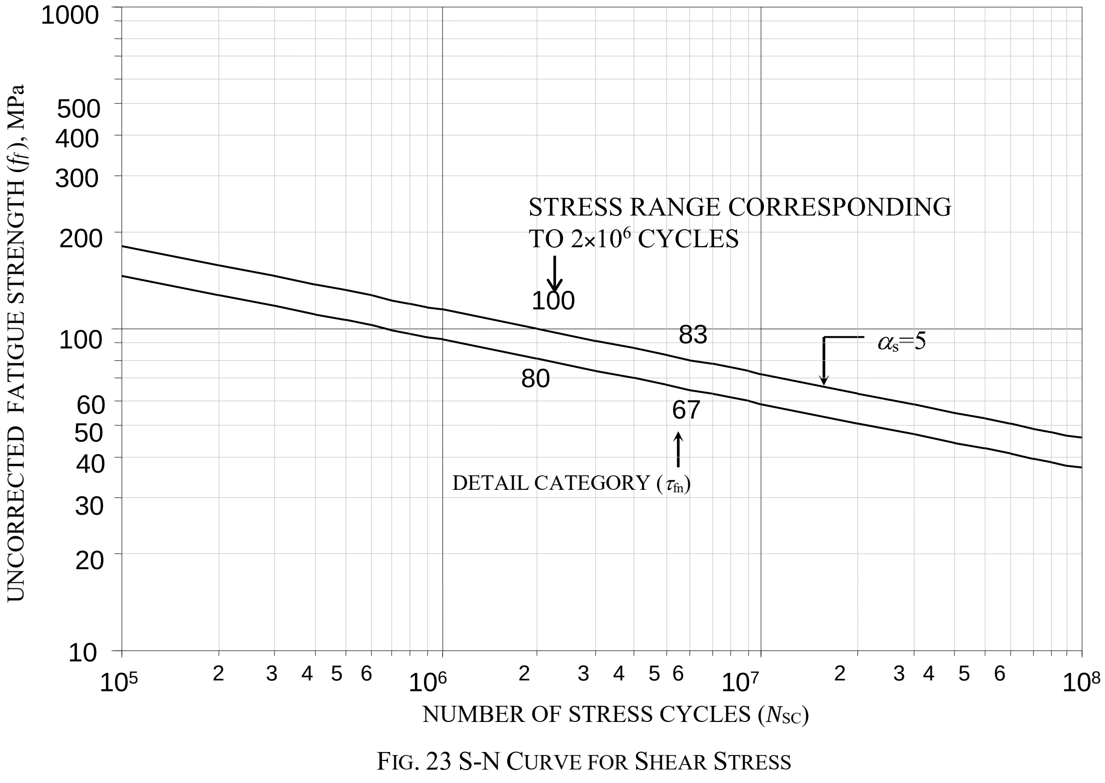


FIG. 23 S-N CURVE FOR SHEAR STRESS

20 DESIGN ASSISTED BY TESTING

20.1 Need for Testing

Testing of structures, members or components of structures is not required when designed in accordance with this standard. Testing may be accepted as an alternative to calculations or may become necessary in special circumstances.

Testing of a structural system, member or component may be required to assist the design in the following cases:

a) when the calculation methods available are not adequate for the design of a particular structure, member or component, testing shall be undertaken in place of design by calculation or to supplement the design by calculation;

b) where rules or methods for design by calculation would lead to uneconomical design, experimental verification may be undertaken to avoid conservative design;

c) when the design or construction is not entirely in accordance with sections of this standard, experimental verification is recommended;

d) when confirmation is required on the consistency of production of material, components, members or structures originally designed by calculations or testing; and

e) when the actual performance of an existing structure capacity is in question, testing shall be used to confirm it.

20.1.1 Testing of structural system, member or component shall be of the following categories:

a) *Proof testing* — The application of test loads to a structure, sub-structure, member or connection to ascertain the structural characteristics of only that specific unit; and

b) *Prototype testing* — Testing of structures, sub-structures, members or connections is done to ascertain the structural characteristics of a class of such structures, sub-structures members or connection, which are nominally identical to the units tested.

20.2 Types of Test

20.2.1 *Acceptance Test*

This is intended as a non-destructive test for confirming structural performance. It should be recognized that the loading applied to certain structures might cause permanent distortions. Such effects do not necessarily indicate structural failure in acceptance test. However, the possibility of their occurrence should be agreed to before testing.

The load for acceptance test, $F_{\text{test,a}}$ shall be determined from:

$$F_{\text{test,a}} = (\text{Self weight}) + (1.15 \times \text{Remainder of the permanent load}) + (1.25 \times \text{Variable load})$$

The assembly shall satisfy the following criteria:

a) it shall demonstrate substantially linear behaviour under test loading; and

b) on removal of the test load, the residual deflection shall not exceed 20 percent of the maximum-recorded deflection.

If the above criteria are not satisfied the test may be repeated one more time only, when the assembly shall satisfy the following criteria:

a) it shall demonstrate substantially linear behaviour on the second application of test loading; and

b) corresponding recorded residual deflection in the second test shall not exceed 10 percent of the maximum deflection during the test.

20.2.2 *Strength Test*

Strength test is used to confirm the calculated resistance of a structure or component. Where a number of items are to be constructed to a common design, and one or more prototypes are tested to confirm their strength, the others may be accepted without any additional test, provided they are similar in all relevant respects to the prototype.

Before carrying out the strength test, the specimen should first be subjected to and satisfy the acceptance test. Since the resistance of the assembly under test depends on the material properties, the actual yield strength of all the steel materials in the assembly shall be determined from coupon {test piece as defined in the accepted standard [C-6A(7)]} tests. The mean value of the yield strength, f_{ym}, taken from such tests shall be determined with due regard to the importance of each element in the assembly. The strength test load $F_{test,s}$ (including self weight) shall be determined from:

$$F_{test,s} = \gamma_{mi} F_d (f_{ym} / f_y)$$

where

F_d = factored design load for the ultimate limit state;

f_y = characteristic yield stress of the material as assumed in the design; and

γ_{mi} = partial safety factor for the type of failure, as prescribed in this standard.

At this load there shall be no failure by buckling or rupture of any part of the structure or component tested. On removal of the test load, the deflection should decrease by at least 20 percent of the maximum deflection at $F_{test,s}$.

20.2.3 *Test to Failure* (*Ultimate Strength Test*)

The objective of a test to failure is to determine the design resistance from the ultimate resistance. In this situation it is still desirable to carry out the acceptance and strength tests, before test to failure.

Not less than three tests shall be carried out on nominally identical specimens. An estimate should be made of the anticipated ultimate resistance as a basis for such tests. During a test to failure, the loading shall first be applied in increments up to the strength test load. Subsequent load increments shall then be determined from consideration of the principal load deflection plot. The test load resistance, $F_{test.R}$ shall be determined as that load at which the specimen is unable to sustain any further increase in load. At this load, gross permanent distortion is likely to have occurred and in some cases such large gross deformation may define the test limit. If the deviation of any individual test result exceeds 10 percent of the mean value obtained for all the three tests, at least three more tests shall be carried out. When the deviation from the mean does not exceed 10 percent of the mean, the design resistance may be evaluated as given below:

a) When the failure is ductile, the design resistance, F_d may be determined from:

$$F_d = 0.9 F_{test,Min} (f_y / f_{ym}) / \gamma_{m0}$$

where

$F_{test,Min}$ = minimum test result from the tests to failure;

f_{ym} = average yield strength as obtained from the material tests; and

f_y = characteristic yield stress of the grade of steel.

In the case of a sudden (brittle) rupture type failure, the design resistance may be determined from:

$$F_d = 0.9 F_{test,Min} (f_u / f_{um}) / \gamma_{ml}$$

where

f_u = characteristic ultimate stress of the grade of steel used; and

f_{um} = average ultimate tensile strength of the material obtained from tests.

b) In the case of a sudden (brittle) buckling type failure, the design resistance shall be determined from:

$$F_d = 0.75 F_{test,Min} (f_y / f_{ym}) / \gamma_{m0}$$

c) In ductile buckling type failure in which the relevant slenderness λ can be reliably assessed, the design resistance may be determined from:

$$F_d = 0.9 F_{test,Min} \left[(\chi f_y / \chi_m f_{ym}) / \gamma_{m0} \right]$$

where

χ = reduction factor for the relevant buckling curve; and

χ_m = value of χ when the yield strength is f_{ym}.

20.2.4 *Check Tests*

Where a component or assembly is designed on the basis of strength tests or tests to failure and a production run is carried out of such items, an appropriate number of samples (not less than two) shall be selected from each production batch at random for check tests.

20.2.4.1 The samples shall be carefully examined to ensure that they are similar in all respects to the prototype tested, particular attention being given to the following:

a) Dimensions of components and connections;

b) Tolerance and workmanship; and

c) Quality of steel used, checked with reference to mill test certificates.

20.2.4.2 Where it is not possible to determine either the variations or the effect of variations from the prototype, an acceptance test shall be carried out as a check test.

20.2.4.3 In this check test, the deflections shall be measured at the same positions as in the acceptance test of the prototype. The maximum measured deflection shall not exceed 120 percent of the deflection recorded during the acceptance test on the prototype and the residual deflection should not be more than 105 percent of that recorded for the prototype.

20.3 Test Conditions

Followings are the conditions for the test:

a) loading and measuring devices shall be calibrated in advance;

b) the design of the test rig shall be such that:

   1) loading system adequately simulates the magnitude and distribution of the loading;

   2) it allows the specimen to perform in a manner representative of service conditions;

   3) lateral and torsional restraint, if any, should be representative of those in service;

   4) specimen should be free to deflect under load according to service condition;

   5) loading system shall be able to follow the movements of the specimen without interruption or abnormal restraints; and

   6) inadvertent eccentricities at the point of application of the test loads and at the supports are avoided.

c) test load shall be applied to the unit at a rate as uniform as practicable;

d) deflections should be measured at sufficient points of high movements to ensure that the maximum value is determined;

e) if the magnitude of stresses in a specimen is to be determined, the strain at the desired location may be measured and the corresponding stress calculated; and

f) prior to any test, preliminary loading (not exceeding the characteristic values of the relevant loads) may be applied and then removed, in order to set the test specimen on to the test rig.

20.4 Test Loading

20.4.1 Where the self-weight of the specimen is not representative of the actual permanent load in service, allowance for the difference shall be made in the calculation of test loads to be applied.

20.4.2 On the attainment of maximum load for either acceptance or strength tests, this load shall be maintained as given below. Reading of load and deflection shall be taken at intervals of 15 min and the loading shall be maintained constant until there is no significant increase in deflection during a 15 min period or until at least 1 h has elapsed after application of maximum load.

20.4.3 The test load shall be equal to the design load for the relevant limit state in proof testing.

20.4.4 The test load in prototype testing shall be equal to the design load for the relevant limit state as multiplied by the appropriate factor given in Table 27.

20.5 Criteria for Acceptance

20.5.1 *Acceptance for Strength*

The test structure, sub-structure, member or connection shall be deemed to comply with the requirements for strength if it is able to sustain the strength test load as required in **20.4.2**.

It shall then be inspected to determine the nature and extent of any damage incurred during the test. The effects of the damage shall be considered and if necessary appropriate repairs to the damaged parts carried out.

20.5.2 *Acceptance for Serviceability*

The maximum deformation of the structure or member under the serviceability limit state test load shall be within the serviceability limit values appropriate to the structure.

Table 27 Factors to Allow for Variability of Structural Units

(*Clause* 20.4.4)

Sl No.	No. of Similar Units to be Tested	For Strength Limit State	For Serviceability Limit State
(1)	(2)	(3)	(4)
i)	1	1.5	1.2
ii)	2	1.4	1.2
iii)	3	1.3	1.2
iv)	4	1.3	1.1
v)	5	1.3	1.1
vi)	10	1.2	1.1

21 DURABILITY

21.1 General

A durable steel structure is one that performs satisfactorily the desired function in the working environment under the anticipated exposure condition during its service life, without deterioration of the cross sectional area and loss of strength due to corrosion.

The material used, the detailing, fabrication, erection and surface protection measures should all address the corrosion protection and durability requirements.

21.2 Requirements for Durability

21.2.1 *Shape, Size, Orientation of Members, Connections and Details*

The design, fabrication and erection details of exposed structures should be such that good drainage of water is ensured. Standing pool of water, moisture accumulation and rundown of water for extended duration shall be avoided.

The details of connections should ensure that:

a) all exposed surfaces are easily accessible for inspection and maintenance; and

b) all surfaces, not so easily accessible are completely sealed against ingress of moisture.

21.2.2 *Exposure Condition*

21.2.2.1 *General environment*

The general environment, to which a steel structure is exposed during its working life is classified into five levels of severity, as given in Table 28.

21.2.2.2 *Abrasion*

Specialist literature may be referred for durability of surfaces exposed to abrasive action as in machinery, conveyor belt support system, storage bins for grains or aggregates.

21.2.2.3 *Exposure to sulphate attack*

Appropriate coatings may be used when surfaces of structural steel are exposed to concentration of sulphates (SO_3) in soil, ground water, etc.

When exposed to very high sulphate concentrations of more than 2 percent in soil and 5 percent in water, some form of lining such as polyethylene, polychloroprene sheet or surface coating based on asphalt, chlorinated rubber, epoxy or polymethane material should be used to completely avoid access of the solution to the steel surface.

21.2.3 *Corrosion Protection Methods*

The methods of corrosion protection are governed by actual environmental conditions as specified in good practices [C-6A(43)]. The main corrosion protection methods are given below:

a) Controlling the electrode potential;

b) Inhibitors; and

c) Inorganic/metal coatings or organic/paint systems.

Table 28 Environmental Exposure Conditions

(*Clause* 21.2.2.1)

Sl No. (1)	Environmental Classifications (2)	Exposure Conditions (3)
i)	Mild	Surfaces normally protected against exposure to weather or aggressive condition as in interior of buildings, except when located in coastal areas
ii)	Moderate	Structural steel surfaces: a) exposed to condensation and rain; b) continuously under water; c) exposed to non-aggressive soil/groundwater; and d) sheltered from saturated salt air in coastal areas
iii)	Severe	Structural steel surfaces: a) exposed to severe frequent rain; b) exposed to alternate wetting and drying; c) severe condensation; d) completely immersed in sea water; and e) exposed to saturated salt air in coastal area
iv)	Very severe	Structural steel surface exposed to: a) sea water spray; b) corrosive fumes; and c) aggressive sub-soil or ground water.
v)	Extreme	Structural steel surfaces exposed to: a) tidal zones and splash zones in the sea; and b) aggressive liquid or solid chemicals

21.2.4 *Surface Protection*

21.2.4.1 In the case of mild exposure, a coat of primer after removal of any loose mill scale may be adequate. As the exposure condition becomes more critical, more elaborate surface preparations and coatings become necessary. In case of extreme environmental classification, protection shall be as per specialist literature. Table 29 gives guidance to protection of steelwork for different desired lives.

21.2.4.2 Steel surfaces shall be provided with at least one coat of primer immediately after its surface preparation, such as by sand blasting to remove all mill scale and rust and to expose the steel.

21.2.4.3 Steel without protective coating shall not be stored for long duration in outdoor environment.

21.2.4.4 Surfaces to transfer forces by friction as in HSFG connections shall not be painted. However, it shall be ensured that moisture is not trapped on such surfaces after pre-tensioning of bolts by proper protective measures.

21.2.4.5 Members to be assembled by welding shall not be pre-painted at regions adjacent to the location of such welds. However, after welding, appropriate protective coatings shall be applied in the region, as required by the exposure conditions. If the contact surfaces cannot be properly protected against ingress of moisture by surface coating, they may be completely sealed by appropriate welds.

21.2.4.6 Pre-painted members shall be protected against abrasion of the coating during transportation, handling and erection.

21.2.5 *Special Steels*

Steels with special alloying elements and production process to obtain better corrosion resistance may be used as per specialist literature.

Table 29(A) Protection Guide for Steel Work Application — Desired Life of Coating System in Different Environment

(*Clause* 21.2.4.1)

Sl No.	Atmospheric Condition/Environmental Classification	Coating System					
		1	2	3	4	5	6
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	Normal inland (rural and urban areas), mild	12 years	18 years	20 years	About 20 years	About 20 years	Above 20 years
ii)	Polluted inland (high airborne sulphur dioxide), moderate	10 years	15 years	12 years	About 18 years	15 to 20 years	Above 20 years
iii)	Normal coastal (as normal inland plus high airborne salt levels), severe	10 years	12 years	20 years	About 20 years	About 20 years	Above 20 years
iv)	Polluted coastal (as polluted inland plus high airborne salt levels), very severe or extreme	8 years	10 years	10 years	About 15 years	15 to 20 years	Above 20 years

Table 29(B) (i) Protection Guide for Steel Work Application — Specification for Different Coating System (Shop Applied Treatments)

(*Clause* 21.2.4.1)

Sl No.	Protection	Coating System					
		1	2	3	4	5	6
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	Surface preparation	Blast clean	Blast clean	Blast clean	Blast clean	Girt blast	Blast clean
ii)	Pre-fabrication primer	Zinc phosphate epoxy, 20 µm	2 pack zinc-rich epoxy, 20 µm	—	2 pack zinc-rich epoxy, 20 µm	—	Ethyl zinc silicate, 20 µm
iii)	Post fabrication primer	High-build zinc phosphate modified alkyd, 60 µm	2 pack zinc-rich epoxy, 20 µm	Hot dip galvanized, 85 µm	2 pack zinc-rich epoxy, 25 µm	Sprayed zinc or sprayed aluminium	Ethyl zinc silicate, 60 µm

Table 29(B) (i) (*Concluded*)

Sl No.	Protection	Coating System					
		1	2	3	4	5	6
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
iv)	Intermediate coat	—	High-build zinc phosphate, 25 µm	—	2 pack epoxy micaceous iron oxide	Sealer	Chlorinated rubber alkyd, 35 µm
v)	Top coat	—	—	—	2 pack epoxy micaceous iron oxide, 85 µm	Sealer	—

Table 29(B) (ii) Protection Guide for Steel Work Application — Specification for Different Coating System (Site Applied Treatments)

(*Clause* 21.2.4.1)

Sl No.	Protection	Coating System					
		1	2	3	4	5	6
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	Surface preparation	As necessary	As necessary	No site treatment	As necessary	No site treatment	As necessary
ii)	Primer	Touch in	Touch in	—	—	—	Touch in
iii)	Intermediate coat	—	Modified Alkydmicaceous iron oxide, 50 µm	—	Touch In	–	High-build micaceous iron oxide chlorinated rubber micaceous, 75 µm
iv)	Top coat	High-build Alkyd finish, 60µm	Modified alkyd micaceous iron oxide, 50 µm	—	High-build chlorinated rubber	—	High-build iron oxide chlorinated rubber, 75 µm

22 FIRE RESISTANCE

22.1 Requirements

The requirements shall apply to steel building elements designed to exhibit a required fire-resistance level (FRL) as per the relevant specifications. The provisions of this section are quite rudimentary and simplistic. Specialist literature for design of steel structures for fire resistance and design based on testing may be necessary for a more comprehensive design of steel buildings to resist fire.

22.1.1 For protected steel members and connections, the thickness of protection material (h_i) shall be greater than or equal to that required to give a period of structural adequacy (PSA) greater than or equal to the required FRL.

22.1.2 For unprotected steel members and connections, the exposed surface area to mass ratio (k_{sm}) shall be less than or equal to that required to give a PSA equal to the required FRL.

22.2 Fire Resistance Level

The required FRL shall be as prescribed in Part F 'Fire and Life Safety' of this NBCS and relative fire norms/ standards, as appropriate or in building specifications or as required by the user or the city ordinance. The FRL specified in terms of the duration (in min) of standard fire load without collapse depends upon;

a) the purpose for which structure is used; and

b) the time taken to evacuate in case of fire.

22.3 Period of Structural Adequacy (PSA)

22.3.1 The calculation of PSA involves:

a) calculation of the strength of the element as a function of temperature of the element and the determination of limiting temperature;

b) calculation of the thermal response of the element, that is calculation of the variation of the temperature of the element or the parts of the element with time, when exposed to fire; and

c) determination of PSA at which the temperature of the element or parts of the element reaches the limiting temperature.

22.3.2 *Determination of Period of Structural Adequacy*

The period of structural adequacy (PSA) shall be determined using one of the following methods:

a) *By calculation*:

   1) determining the limiting temperature of the steel (T_l) in accordance with 22.5; and

   2) determining the PSA as the time (t) (in min) from the start of the test to the time at which the limiting steel temperature is attained, in accordance with 22.6 for protected members and 22.7 for unprotected members.

b) By direct application of a single test in accordance with 22.8; or

c) By calculation of the temperature of the steel member by using a rational method of analysis confirmed by test data or by methods available in specialist literature.

22.4 Variation of Mechanical Properties of Steel with Temperature

22.4.1 *Variation of Yield Stress with Temperature*

The influence of temperature on the yield stress of steel shall be taken as follows for structures of mild steels and high strength low alloy steels:

$$\frac{f_y(T)}{f_y(20)} = \frac{905 - T}{690} \leq 1.0$$

where

$f_y(T)$ = yield stress of steel at T °C;

$f_y(20)$ = yield stress of steel at 20 °C (room temperature); and

T = temperature of the steel, in °C.

This relationship is shown by curve 1 in Fig. 24.

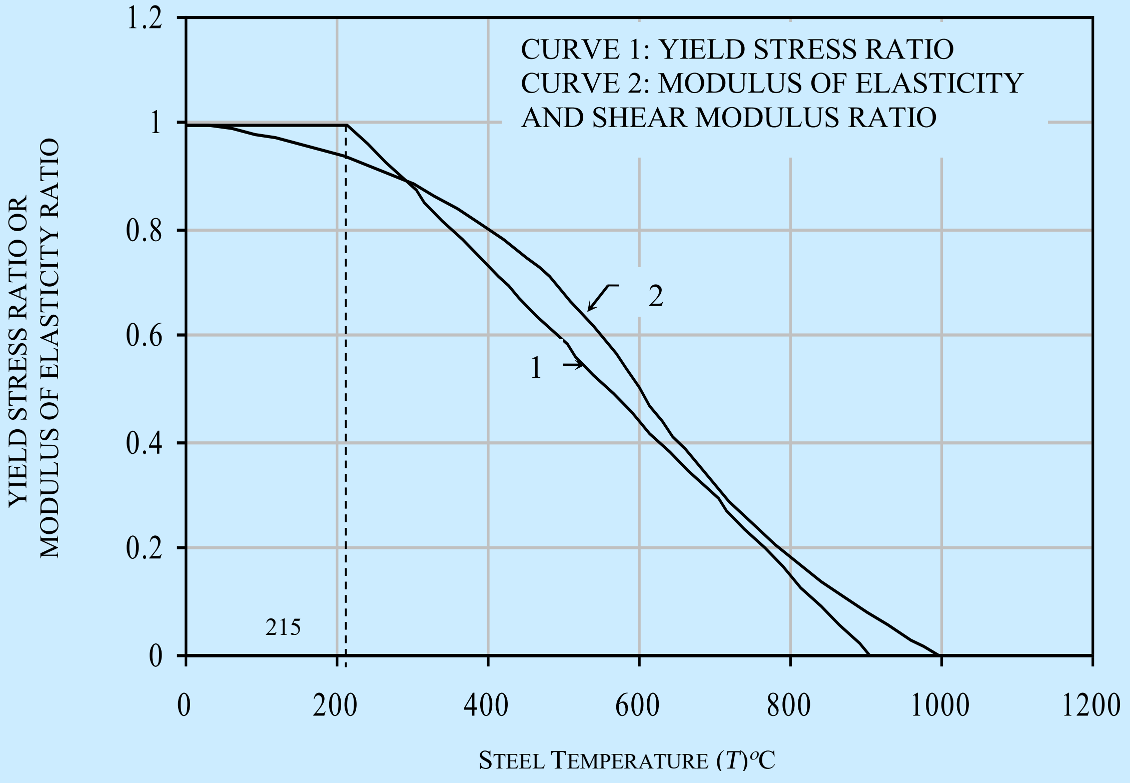


FIG. 24 VARIATION OF MECHANICAL PROPERTIES OF STEEL WITH TEMPERATURE

For temperature less than 215 °C no reduction in the yield stress need to be considered.

22.4.2 *Variation of Modulus of Elasticity and Shear Modulus with Temperature*

The influence of temperature on the modulus of elasticity shall be taken as follows for structures of mild steels and high strength low alloy steels:

$$\frac{E(T)}{E(20)} \; and \; \frac{G(T)}{G(20)} = 1.0 + \left[\frac{T}{2000\left[ln\left(\frac{T}{1\,100}\right)\right]}\right] \text{ when } 0\,°\text{C} < T \leq 600\,°\text{C}$$

$$= \frac{690\left(1 - \frac{T}{1000}\right)}{T - 53.5} \quad \text{when} \quad 600\,°\text{C} < T \leq 1000\,°\text{C}$$

where

$E(T)$ = Modulus of elasticity of steel at T °C, and

E (20) = Modulus of elasticity of steel at 20 °C (room temperature).

G (T) = Shear Modulus of steel at T °C, and

G (20) = Shear Modulus of steel at 20 °C (room temperature).

This relationship is shown by curve 2 in Fig. 24.

22.4.3 For special steel with higher temperature resistance, such as TMCP steels, the manufacturer's recommendation shall be used to obtain the variation of yield strength and modulus of elasticity of steel with temperature.

22.5 Limiting Steel Temperature

The limiting steel temperature (T_l), in °C, in the case of structural steels, shall be calculated by substituting f_y, f_u, E, and G values with $f_y(T)$, $f_y(T)$, $E(T)$, and $G(T)$ calculated in accordance with **22.4**, respectively in **13**, **14**, **15**, and **16** to calculate the design capacity of the member as a function of steel temperature. The limiting temperature (T_l) will be the temperature at which the design capacity is equal to the design action on the member.

The design action under fire shall consider the following:

a) Loads as per the load combinations for fire conditions given in Table 4;

b) Effects of restraint to expansion of the elements during fire; and

c) Reduced bond likely under fire.

Limiting steel temperature for special steels may be appropriately calculated using the thermal characteristics of the material obtained from the supplier of the steel.

22.6 Temperature Increase with Time in Protected Members

22.6.1 The time (t) at which the limiting temperature (T_l) is attained shall be determined by calculation on the basis of a suitable series of fire tests in accordance with **22.6.2** or from the results of a single test in accordance with **22.6.3**.

22.6.1.1 For beams and for all members with a four-sided fire exposure condition, the limiting temperature (T_l) shall be taken as the average of all of the temperatures measured at the thermocouple locations on all sides.

22.6.1.2 For columns with a three-sided fire exposure condition, the limiting temperature (T_l) shall be taken as the average of the temperatures measured at the thermocouple locations on the face farthest from the wall. Alternatively, the temperatures from members with a four-sided fire exposure condition and having the same surface area to mass ratio may be used.

22.6.2 *Temperature Based on Test Series*

Calculation of the variation of steel temperature with time shall be by interpolation of the results of a series of fire tests using the regression analysis equation specified in **22.6.2.1**, subject to the limitations and conditions of **22.6.2.3**.

22.6.2.1 *Regression analysis*

The relationship between temperature (T) and time (t) for a series of tests on a group shall be calculated by least-square regression as follows:

$$t = k_0 + k_1 h_i + k_2 \left(\frac{h_i}{k_{sm}} \right) + k_3 T + k_4 h_i T + k_5 \left(\frac{h_i T}{k_{sm}} \right) + k_6 \left(\frac{T}{k_{sm}} \right)$$

where

h_i = thickness of fire protection material, in mm;

k_0 to k_6 = regression coefficients from test data (*see* **22.6.2.2**);

k_{sm} = exposed surface area to mass ratio, in 10^3 mm^2/kg;

t = time from the start of the test, in min; and

T = steel temperature, in 0 °C obtained from test as given in **22.6.1**, $T > 250$ °C.

22.6.2.2 *In lieu of* test results, the values for coefficients in Table 30 may be used in the equation **22.6.2.1** when the test satisfies the conditions specified in **22.6.2.3**.

Table 30 Regression Coefficients, k

(*Clause* 22.6.2.2)

Sl No. (1)	k_0 (2)	k_1 (3)	k_2 (4)	k_3 (5)	k_4 (6)	k_5 (7)	k_6 (8)
i)	– 25.90	1.698	– 13.71	0.030 0	0.000 5	0.514 4	6.633

22.6.2.3 *Limitations and conditions on use of regression analysis*

Test data to be utilized in accordance with **22.6.2.1**, shall satisfy the following:

a) Steel members shall be protected with board, sprayed blanket or similar insulation materials having a dry density less than 1000 kg/m^3;

b) All tests shall incorporate the same fire protection system;

c) All members shall have the same fire exposure condition;

d) Test series shall include at least nine tests;

e) Test series may include prototypes which have not been loaded provided that stickability has been demonstrated; and

f) All members subject to a three-sided fire exposure condition shall be within a group in accordance with **22.9**.

The regression equation obtained for one fire protection system may be applied to another system using the same fire protection material and the same fire exposure condition provided that stickability has been demonstrated for the second system.

A regression equation obtained using prototypes with a four-sided fire exposure condition may be applied to a member with a three-sided fire exposure condition provided that stickability has been demonstrated for the three-sided case.

22.6.3 *Temperature Based on Single Test*

The variation of steel temperature with time measured in a standard fire test may be used without modification provided:

a) fire protection system is the same as the prototype;

b) fire exposure condition is the same as the prototype;

c) fire protection material thickness is equal to or greater than that of the prototype;

d) surface area to mass ratio is equal to or less than that of the prototype; and

e) where the prototype has been submitted to a standard fire test in an unloaded condition, stickability has been separately demonstrated.

22.6.4 *Parameters of Importance in the Standard Fire Test*

a) Specimen type, loading, configuration;

b) Exposed surface area to mass ratio;

c) Insulation type, thermal properties and thickness; and

d) Moisture content of the insulation material.

22.7 Temperature Increase with Time in Unprotected Members

The time (t) at which the limiting temperature (T_l) is attained shall be calculated using the following equations:

a) Three-sided fire exposure condition:

$$t = -5.2 + 0.022\ 1\,T + \left(\frac{0.433T_l}{k_{\mathrm{sm}}}\right)$$

b) Four-sided fire exposure condition:

$$t = -4.7 + 0.0263\ T + \left(\frac{0.213T_l}{k_{\mathrm{sm}}}\right)$$

where

k_{sm} = exposed surface area to mass ratio, 2×10^3 mm^2/kg $\leq k_{\mathrm{sm}} \leq 35\times10^3$ mm^2/kg;

t = time, in min, from the start of the test; and

T = steel temperature, in ºC, 500 ºC $\leq T \leq$ 750 ºC.

For temperatures below 500 ºC, linear interpolation shall be used, based on the time at 500 ºC and an initial temperature of 20 °C at t equals 0.

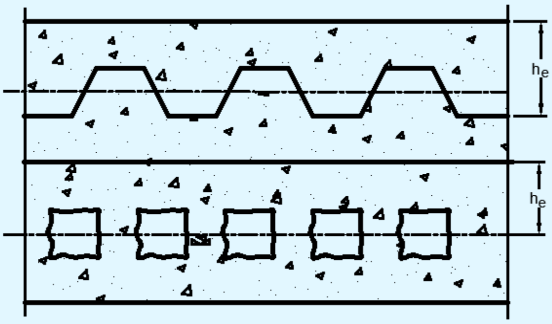
22.8 Determination of PSA from a Single Test

The period of structural adequacy (PSA) determined from a single test may be applied without modification provided:

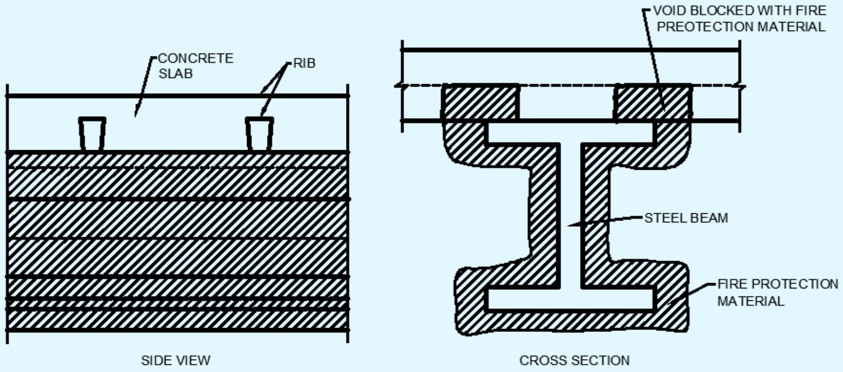
a) conditions, specified in **22.6.3** are satisfied;

b) conditions of support are the same as the prototype and the restraints are not less favourable than those of the prototype; and

c) ratio of the design load for fire to the design capacity of the member is less than or equal to that of the prototype.



23 A EFFECTIVE THICKNESS



23 B BLOCKING OF RIB VOIDS

FIG. 25 THREE SIDED FIRE EXPOSURE CONDITION REQUIREMENTS

22.9 Three-sided Fire Exposure Condition

Members subject to a three-sided fire exposure condition shall be considered in separate groups unless the following conditions are satisfied:

a) the characteristics of the members of a group as given below, shall not vary from one another by more than:

1) Concrete density: $\left(\frac{\text{highest in group}}{\text{lowest in group}}\right) \leq 1.25$; and

2) Effective thickness (h_e): $\left(\frac{\text{largest in group}}{\text{smallest in group}}\right) \leq 1.25$

where the effective thickness (h_e) is equal to the cross sectional area excluding voids per unit width, as shown in Fig. 25 (a).

b) Rib voids shall either be:

1) all open; or

2) all blocked as shown in Fig. 25 (b).

c) Concrete slabs may incorporate permanent steel deck formwork.

22.10 Special Considerations

22.10.1 *Connections*

Connections shall be protected with the maximum thickness of fire protection material required for any of the members framing into the connection to achieve their respective fire-resistance levels. This thickness shall be maintained over all connection components, including bolt heads, welds and splice plates.

22.10.2 *Web Penetrations*

The thickness of fire protection material at and adjacent to web penetrations shall be the greatest of that required, when:

a) area above the penetration is considered as a three-sided fire exposure condition (k_{sm1}) (*see* Fig. 26);

b) area below the penetration is considered as a four-sided fire exposure condition (k_{sm2}) (*see* Fig. 26); and

c) section as a whole is considered as a three-sided fire exposure condition (k_{sm}) (*see* Fig. 26).

This thickness shall be applied over the full beam depth and shall extend on each side of the penetration for a distance at least equal to the beam depth and not less than 300 mm.

22.11 Fire Resistance Rating

The fire resistance rating of various building components such as walls, columns, beams, and floors are given in Table 31 and Table 32. Fire damage assessment of various structural elements of the building and adequacy of the structural repairs can be done by the fire resistance rating for encased steel column and beam (*see* Table 31 and Table 32).

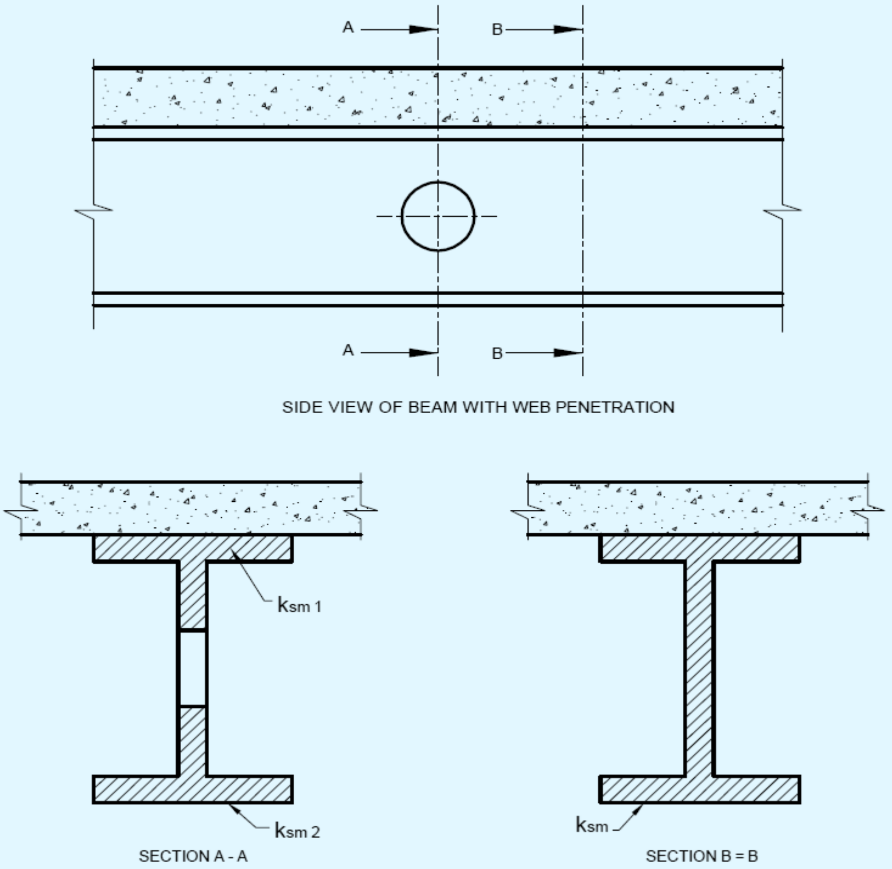


FIG. 26 WEB PENETRATION

Table 31 Encased Steel Columns, 203 mm × 203 mm (Protection Applied on Four Sides)

(*Clause* 22.11)

Sl No.	Nature of Construction and Materials	Minimum Dimensions (in mm), Excluding Any Finish, for a Fire Resistance of				
		1 h	1 ½ h	2 h	3 h	4 h
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	Hollow protection (without an air cavity over the flanges):					
	a) Metal lathing with trowelled lightweight aggregate gypsum plaster [1]	13	15	20	32	—
	b) Plasterboard with 1.6 mm wire binding at 100 mm pitch, finished with lightweight aggregate gypsum plaster less than the thickness specified:					
	1) 9.5 mm plaster board; and	10	15	—	—	—
	2) 19 mm plaster board.	10	13	20	—	—
	c) Asbestos insulating boards, thickness of board:					
	1) single thickness of board, with 6 mm cover fillets at transverse joints; and	—	19	25	—	—
	2) two layers, of total thickness.	—	—	—	38	50
	d) Solid bricks of clay, composition or sand lime, reinforced in every horizontal joint, unplastered	50	50	50	75	100
	e) Aerated concrete blocks	60	60	60	—	—
	f) Solid blocks of lightweight concrete hollow protection (with an air cavity over the flanges)	50	50	50	60	75
ii)	Asbestos insulating board screwed to 25 mm asbestos battens	12	19	—	—	—
iii)	Solid protections:					
	a) Concrete, not leaner than 1:2:4 mix (unplastered):					
	1) Concrete not assumed to be load bearing, reinforced[2]; and	25	25	25	50	75
	2) Concrete assumed to be load bearing	50	50	50	75	75
	b) Lightweight concrete, not leaner than 1 : 2 : 4 mix (unplastered) concrete not assumed to be load bearing, reinforced [2]	25	25	25	25	25

---

[1] So fixed or designed, as to allow full penetration for mechanical bond.

[2] Reinforcement shall consist of steel binding wire not less than 2.3 mm diameter, or a steel mesh weighing not less than 0.5 kg/m2. In concrete protection, the spacing of that reinforcement shall not exceed 200 mm in any direction.

Table 32 Encased Steel Beams, 406 mm × 176 mm (Protection Applied on Three Sides)

(*Clause* 22.11)

Sl No.	Nature of Construction and Materials	**Minimum Thickness** (in mm) **of Protection for a Fire Resistance of**					
		½ h	1 h	1½ h	2 h	3 h	4 h
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	Hollow protection (without an air cavity beneath the lower flanges):						
	a) Metal lathing with trowelled lightweight aggregate gypsum plaster[1]	13	13	15	20	25	—
	b) Plasterboard with 1.6 mm wire binding at 100 mm pitch, finished with lightweight aggregate gypsum plaster less than the thickness specified[2]:						
	1) 9.5 mm plaster board; and	10	10	15	—	—	—
	2) 19 mm plaster board	10	10	13	20	—	—
	c) Asbestos insulating boards, thickness of board:						
	1) single thickness of board, with 6 mm cover fillets at transverse joints	—	—	19	25	—	—
	2) two layers, of total thickness	—	—	—	—	38	50
ii)	Hollow protection (with an air cavity below the lower flange):						
	a) Asbestos insulating board screwed to 25 mm asbestos battens	9	12	—	—	—	—
iii)	Solid protections:						
	a) Concrete, not leaner than 1 : 2 : 4 mix (unplastered):						
	1) concrete not assumed to be load bearing, reinforced [3]; and	25	25	25	25	50	75
	2) concrete assumed to be load bearing	50	50	50	50	75	75
	b) Lightweight concrete, not leaner than 1 : 2 : 4 mix (unplastered) [4]	25	25	25	25	40	60

---

[1] So fixed or designed, as to allow full penetration for mechanical bond.

[2] Where wire binding cannot be used, expert advice should be sought regarding alternative methods of support to enable the lower edges of the plasterboard to be fixed together and to the lower flange, and for the top edge of the plasterboard to be held in position.

[3] Reinforcement shall consist of steel binding wire not less than 2.3 mm in diameter, or a steel mesh weighing not less than 0.5 kg/m^2. In concrete protection, the spacing of that reinforcement shall not exceed 200 mm in any direction.

[4] Concrete not assumed to be load bearing, reinforced.

23 SUSTAINABLE STEEL CONSTRUCTION

23.1 General

This Chapter specifies general requirements and practices for achieving environmentally sustainable steelwork building construction. This supplements the requirements of the other chapters of this specification.

23.2 Principles of Sustainable Steel Construction

a) The structural steel design should provide a structure capable of fulfilling its intended function while sustaining the specified loads for its intended life with due regard to sustainability, robustness, economy, health and safety. Any expected change in the intended function during its life time should also be considered;

b) In environmentally sustainable construction all stake holders should consider the broader and holistic implications of the decision, which include the whole life cycle sustainability, impacts on other parts of the building and the project, externalities, maintenance, societal cost and consequences, without impinging upon safety and efficiency of the structure;

c) All parties in the supply chain for structural steelwork should take practical steps to reduce the greenhouse gas emissions of the processes over which they have control, thus contributing to sustainable construction. Further, construction operations should avoid/minimize polluting the environment with dust, wastewater, chemicals and leaching debris;

d) Steelmaking should make full use of available secondary material (scrap) globally;

e) Structural steelwork should be designed, detailed, and constructed to minimize material use and wastage of material and facilitate its recovery for reuse at its end-of-life, as a part of the circular economy, to the extent that this is reasonably practicable; and

f) The design should consider practical aspects of construction to avoid repair and rework.

23.3 Specification Requirements from Supply Chain Members

23.3.1 *Requirements from Employer*

a) Appointment of key contractors (Architects, contractors for Steel work, cladding, glazing, Mechanical, Electrical, coating systems, etc) as early as practical to ensure decisions are fully coordinated;

b) Maximization of structural zones that facilitate lean and efficient designs; and

c) Flexibility in design, if use of reclaim materials is considered.

23.3.2 *Requirements from Main Contractor*

a) Early engagement of supply chain and subcontractors with emphasis on sustainability; and

b) Judicious site planning to receive material, use of labour and location of machinery for efficient handling and construction.

23.3.3 *Requirements from the Engineering Group*

a) Design for material efficiency, equipment efficiency, and minimal embodied energy and longevity;

b) Consider holistically the environmental impact implication of temporary works and supports;

c) Design with inbuilt flexibility and adaptability;

d) Consider the economic and environmental implications of the type of connections chosen; and

e) Assess the requirement of protective treatment against corrosion and fire to minimize the life time maintenance and avoid over-specification.

23.3.4 *Requirements from Steelwork Contractor*

Establish a carbon reduction plan in steelwork. This may include use of low carbon emission transport, maximize the steelwork loads, optimizing haulage routes, minimizing empty runs, etc.

23.4 Sustainable Design

23.4.1 *General*

The environmental impacts associated with steelwork building construction be greatly reduced during the design process by:

a) reducing the material in the structure;

b) minimizing fabrication, and avoidance of maintenance during service life; and

c) Identifying environmental improvements at the conceptual design stage requires the involvement of all the stakeholders such as architects, steelwork contractor during all design stages. Collaborative design processes result in:

   1) materials being used more efficiently;

   2) fewer on-site changes; and

   3) reduced environmental impacts.

Greenhouse gas or carbon emissions currently being the priority, action is required by all parts of the supply chain for the sector to decarbonize in line with global targets. This includes supply-side measures, in particularly decarbonizing steel-making and also demand-side measures including more efficient design and design for longevity, deconstruction and reuse.

Greenhouse gas emission should be based on life cycle assessment, which should include emissions in material manufacturing, transport, fabrication, erection, finishing, commissioning, maintenance during life and finally at the end of useful life deconstruction and disposal of the materials as waste or through recycling and reuse.

Further, environmentally friendly designs should be implemented in the construction projects and pollution of the environment during the process of construction should be avoided, if not minimized.

23.4.2 *Minimizing Material Consumption through Design*

Minimizing material consumption through design may be achieved by:

a) Avoiding over-specification of design loads;

b) Optimizing spans and grids: and adapting the building layout to take full advantage of the structural steelwork's attributes;

c) Minimizing complex load paths and transfers in order to maximize direct load paths to ground;

d) Ensuring that structural deflection and vibration criteria, coordination zones and member depths are appropriate and allow for efficient structural solutions that avoid excessive material use;

e) Aiming to design for utilizations as close to 1.0 as practically possible, with due regard to permanent and temporary conditions;

f) Specifying higher strength steel grades in members or part of members not governed by serviceability criteria;

g) Considering key load paths, anticipated connection types and accurate loading criteria, in order to facilitate lean design principles;

h) Avoiding the over rationalization of steel member sizes to ensure efficient use of material, with due consideration of minimum economic quantities for procurement;

j) Reviewing section sizes and minimizing weight, whilst complying with safe methods of erection and fire protection requirements; and

k) Semi-continuous design, which assumes that the joints transfer moments from the beam to the column and allow rotation between the connected members as the load is resisted.

NOTE — Historically, steelwork design and fabrication has mainly been driven by cost however, sustainability and particularly the climate emergency, are likely to change this with more clients willing or mandated to pay more for sustainable and low carbon buildings. Reducing the carbon impact of steel structures through lean and less conservative design is technically achievable but can require more design effort and more complex fabrication.

23.4.3 *Design for Adaptability and Deconstruction*

Design engineer should review design options with the steelwork contractor that may contribute to future flexibility, adaptability, deconstruction and reuse of the building structure, such as:

a) how the building design and information records about the materials and members can facilitate future, remodelling, deconstruction and recovery for reuse and recycling;

b) ensuring accessibility to members and connections to allow for deconstruction and for ease of strengthening in the future; and

c) greater standardization of sections sizes, lengths and connections, if appropriate from adaptability and deconstruction.

23.5 Sustainable Fabrication

23.5.1 *Information Records*

A non-exhaustive checklist of information to be communicated in sustainable fabrication are given below:

a) Sustainability information to be provided to the steelwork contractor:
   1) any part of the steelwork that is to incorporate reclaimed steel products;
   2) any part of the steelwork that is to be left untreated;
   3) any details of the fire design, namely the design utilization per section size in the fire condition;
   4) any workshop waste targets;
   5) a life cycle assessment of the whole building; and
   6) any specific material sourcing requirements.

b) Sustainability information to be provided by the steelwork contractor:
   1) All relevant EPDs for the steel and other products;
   2) The embodied carbon of the fabricated steelwork;
   3) Digital records of the 'As erected' structure, which should include all condition of structures, survey, metadata, etc;
   4) Material quality and quantity data, including batch traceability for main structural members to facilitate future reuse (to be included in the operation and maintenance manual; and
   5) Documentation of evidence of an active environmental management system.

23.5.2 *Fabrication Waste Management*

Strategies for fabrication waste management include:

a) ordering directly from mills to minimize offcuts;

b) using stock lengths as ordered efficiently to minimize waste. Where possible, splice locations in steel members should be coordinated to fall within standard stock length sizes;

c) recycling and reusing steel fabrication waste, for example, off-cuts, swarf, etc;

d) considering use off-cuts of material, particularly from plate, elsewhere, for example, temporary works, connection fittings, shims, packs, rather than simply scrapping for recycling. Always prioritized reuse over recycling;

e) considering use of machines that facilitate common line cutting of fittings;

f) minimizing coating waste and coating packaging waste, by using intermediate bulk; and

g) Minimizing/ avoiding overspray of coatings should ensure operators are properly trained and the appropriate and properly maintained equipment is used.

23.5.3 *Sustainable Welding*

Strategies for sustainable welding include:

a) Avoiding low productivity processes and using automatic and semi-automatic processes with continuous wire feed, thus using material efficiently and avoiding energy waste;

b) Adopting energy-saving processes such as, inverter-based power sources instead of older regulator/rectifier-based sources, electrically powered pre-heating with temperature control instead of gas flame;

c) Minimizing pre-heat in the welding procedure specification and welding continuously to avoid the need to re-heat; and

d) Periodically reviewing welding techniques and weld procedures to make the best use of the latest advancements in welding equipment and consumables, including the selection of joint set-ups and consumables that allow for deeper penetration fillet welds to be achieved, thus potentially reducing the number of weld runs required.

23.5.4 *Sustainable Fire and Corrosion Protection Systems*

23.5.4.1 *Untreated steelwork*

Any part of the steelwork such as steelwork in a less corrosivity category, that is to be left untreated shall be identified in the Project Specification.

23.5.4.2 *Paint systems*

The protective coating system shall satisfy the requirements given in **21**.

23.5.4.3 *Intumescent systems*

For the same fire resistance water-based acrylic intumescent likely to have a lower environmental impact, when compared to solvent-based acrylic intumescent.

23.5.4.4 *Hot-dip galvanizing*

Requirements for thicker coatings, for example, by prior grit blasting, should be avoided by prior assessment of the predicted galvanized coating life and the minimum thickness required to avoid over-specification. For certain steel members (for example, with higher reactivity during galvanizing and/or larger section thickness), thicker coatings may also be achieved without grit blasting. Design and fabrication considerations for hot dip galvanizing should ensure adequate drainage and optimize material efficiency. Plan should optimize transport distances and provide direct delivery to the construction works, where feasible.

24 FABRICATION AND ERECTION

24.1 General

Tolerances for fabrication of steel structures shall conform to the accepted standard [C-6A(44)]. Tolerances for erection of steel structures shall conform to the accepted standard [C-6A(45)]. For general guidance on fabrication by welding, reference may be made to good practice [C-6A(46)].

In addition to the above, the following requirements shall also be considered:

a) The designer shall, in conjunction with the floor framing and vertical framing/stacking arrangements of the project, provide suitable tolerance mitigation measures. Such measures may include the use of slotted or oversized holes in beams and columns, use of HSFG bolts, or other appropriate detailing. These provisions need not be adopted for all members; however, they shall be judiciously incorporated in selected connections and splices to achieve the desired tolerance accommodation.

b) The structural designer shall coordinate with other disciplines, such as façade, building services, and transportation systems, and ensure that the specified tolerances for steel structures are compatible with their requirements. Where the design necessitates tolerances more stringent than those specified in the relevant codes, such requirements shall be clearly indicated in the drawings and specifications. However, in no case shall the specified tolerances be more stringent than the applicable mill rolling tolerances.

c) The designer shall specify the permissible overall horizontal and vertical tolerances for the completed building structure, in accordance with the design intent. While [C-6A(45)] specifies tolerances for erected elements, it does not address the overall geometrical accuracy of the completed structure. Therefore, the structural designer shall, in coordination with the architect and other relevant disciplines, define the acceptable limits of overall as-built accuracy. These limits shall be clearly specified so as to enable proper planning and execution by the contractor at all stages of construction.

24.2 Fabrication Procedures

24.2.1 *Straightening*

Material shall be straightened or formed to the specified configuration by methods that will not reduce the properties of the material below the values used in design. Local application of pressure at room or at elevated temperature or other thermal means may be used for straightening, provided the above is satisfied.

24.2.2 *Clearances*

The erection clearance for cleated ends of members, connecting steel to steel should preferably be not greater than 2.0 mm at each end. The erection clearance at ends of beams without web cleats should be not more than 3 mm at each end. Where for practical reasons, greater clearance is necessary, suitably designed seating should be provided.

24.2.2.1 The holes for bolts may be made as given in Table 20 of **17.2.1**, unless otherwise specified by the engineer. The hole diameter in base plates shall not exceed the anchor bolt diameter by more than 6 mm.

24.2.2.2 In friction type of connection clearance may be maintained, unless specified otherwise in the design document.

24.2.3 *Cutting*

Cutting shall be effected by sawing, shearing, cropping, machining or thermal cutting process. Shearing, cropping and gas cutting shall be clean, reasonably square, and free from any distortion. Should the inspector find it necessary, the edges shall be ground after cutting. Planning or finishing of sheared or gas-cut edges of plates or shapes shall not be required, unless specially noted on drawing or included in stipulated edge preparation for welding or when specifically required in the following section.

Re-entrant corners shall be free from notches and shall have largest practical radii with a minimum radius of 15 mm.

24.2.3.1 *Shearing*

Shearing of items over 16 mm thick to be galvanized and subject to tensile force or bending moment shall not be carried out, unless the item is stress relieved subsequently.

The use of sheared edges in the tension area shall be avoided in location subject to plastic hinge rotation at factored loading.

24.2.3.2 *Thermal cutting*

Gas cutting of high tensile steel by mechanically controlled torch may be permitted, provided special care is taken to leave sufficient metal to be removed by machining, so that all metal that has been hardened by flame is removed. Hand flame cutting may be permitted only subject to the approval of the inspecting authority.

Except where the material is subsequently joined by welding, no load shall be transmitted through a gas cut surface.

Thermally cut free edges, which shall be subject to calculated static tensile stress shall be free from round bottom gouges greater than 5 mm deep. Gouges greater than 5 mm deep and notches shall be removed by grinding.

24.2.4 *Holing*

24.2.4.1 Holes through more than one thickness of material for members, such as compound stanchion and girder flanges, shall be where possible, drilled after the members are assembled and tightly clamped or bolted together. A round hole for a bolt shall either be machine flame cut, or drilled full size, or sub-punched 3 mm undersize and reamed to size or punched full size.

Hand flame cutting of a bolt hole shall not be permitted except as a site rectification measure for holes in column base plates.

24.2.4.2 *Punching*

A punched hole shall be permitted only in material whose yield stress (f_y) does not exceed 360 MPa and where thickness does not exceed ($5600/f_y$) mm. In cyclically loaded details, punching shall be avoided in plates with thickness greater than 12 mm.

For greater thickness and cyclically loaded details, holes shall be either drilled from the solid or sub-punched or sub drilled and reamed.

The die for all sub-punched holes or the drill for all sub-drilled holes shall be at least 3 mm smaller than the required diameter of finished hole.

24.2.4.3 *Oversize holes*

A special plate washer of minimum thickness 4 mm shall be used under the nut, if the hole diameter is larger than the bolt diameter by 3 mm or more.

Oversize hole shall not exceed $1.25d$ or ($d + 8$) mm in diameter, were d is the nominal bolt diameter, in mm.

A short slotted hole shall not exceed the appropriate hole size in width and $1.33d$, in length. A long slotted hole shall not exceed the appropriate hole size in width and $2.5d$, in length. If the slot length is larger than those specified, shear transfer in the direction of slot is not admissible even in friction type of connection.

Slotted holes shall be punched either in one operation or else formed by punching or drilling two round holes apart and completed by high quality mechanically controlled flame cutting and dressing to ensure that bolt can freely travel the full length of the slot.

24.2.4.4 *Fitted bolt holes*

Holes for turned and fitted bolts shall be drilled to a diameter equal to the nominal diameter of the shank or barrel subject to tolerance specified in the accepted standards [C-6A(47)]. Preferably, parts to be connected with close tolerance or barrel bolts shall be firmly held together by tacking bolts or clamps and the holes drilled through all the thicknesses at one operation and subsequently reamed to size. All holes not drilled through all thicknesses at one operation shall be drilled to a smaller size and reamed out after assembly. Where this is not practicable, the parts shall be drilled and reamed separately through hard bushed steel jigs.

24.2.4.5 Holes for rivets or bolts shall not be formed generally by gas cutting process. However, advanced gas cutting processes such as plasma cutting may be used to make holes in statically loaded members only. In cyclically loaded members subjected to tensile stresses which are vulnerable under fatigue, gas cutting shall not be used unless subsequent reaming is done to remove the material in the heat affected zone around the hole.

24.3 Assembly

All parts of bolted members shall be pinned or bolted and rigidly held together during assembly.

The component parts shall be assembled and aligned in such a manner that they are neither twisted nor otherwise damaged, and shall be so prepared that the specified camber, if any, is provided.

24.3.1 *Holes in Assembly*

When holes are drilled in one operation through two or more separable parts, these parts, when so specified by the engineer, shall be separated after drilling and the burrs removed.

Matching holes for rivets and black bolts shall register with each other so that a gauge of 1.5 mm or 2.0 mm (as the case may be, depending on whether the diameter of the rivet or bolt is less than or more than 25 mm) less in diameter than the diameter of the hole will pass freely through the assembled members in the direction at right angle to such members.

Drilling done during assembly to align holes shall not distort the metal or enlarge the holes.

Holes in adjacent part shall match sufficiently well to permit easy entry of bolts. If necessary, holes except oversize or slotted holes may be enlarged to admit bolts, by moderate amount of reaming.

24.3.2 *Thread Length*

When design is based on bolts with unthreaded shanks in the shear plane, appropriate measures shall be specified to ensure that, after allowing for tolerance, neither the threads nor the thread run-out be in the shear plane.

The length of bolt shall be such that at least one clear thread shows above the nut and at least one thread plus the thread run out is clear beneath the nut after tightening. One washer shall be provided under the rotated part.

24.3.3 *Assembly Subjected to Vibration*

When non-preloaded bolts are used in a structure subject to vibration, the nuts shall be secured by locking devices or other mechanical means. The nuts of preloaded bolts may be assumed to be sufficiently secured by the normal tightening procedure.

24.3.4 *Washers*

Washers are not normally required on non-preloaded bolts, unless specified otherwise. Tapered washers shall be used where the surface is inclined at more than 3° to a plane perpendicular to the bolt axis.

Hardened washer shall be used for preloaded bolts or the nut, whichever is to be rotated.

All material within the grip of the bolt shall be steel and no compressible material shall be permitted in the grip.

24.4 Riveting

24.4.1 Rivets shall be heated uniformly throughout their length, without burning or excessive scaling, and shall be of sufficient length to provide a head of standard dimensions. These shall, when driven, completely fill the holes and, if countersunk, the countersinking shall be fully filled by the rivet. If required, any protrusion of the countersunk head shall be dressed off flush.

24.4.2 Riveted member shall have all parts firmly drawn and held together before and during riveting, and special care shall be taken in this respect for all single-riveted connections. For multiple riveted connections, a service bolt shall be provided in every third or fourth hole.

24.4.3 Wherever practicable, machine riveting shall be carried out by using machines of the steady pressure type.

24.4.4 All loose, burned or otherwise defective rivets shall be cut out and replaced before the structure is loaded, and special care shall be taken to inspect all single riveted connections.

24.4.5 Special care shall be taken in heating and driving long rivets.

24.5 Bolting

24.5.1 In all cases where the full bearing area of the bolt is to be developed, the bolt shall be provided with a washer of sufficient thickness under the nut to avoid any threaded portion of the bolt being within the thickness or the parts bolted together, unless accounted for in design.

24.5.2 Pre-tensioned bolts shall be subjected to initial tension (the proof stress) by an appropriate pre-calibrated method.

24.6 Welding

24.6.1 Welding shall be in accordance with good practices [C-6A(48)], as appropriate.

24.6.2 For welding of any particular type of joint, welders shall give evidence acceptable to the purchaser of having satisfactorily completed appropriate tests as prescribed in good practices [C-6A(49)], as relevant.

24.6.3 Assembly and welding shall be carried out in such a way to minimize distortion and residual stress and that the final dimensions are within appropriate tolerances.

24.7 Machining of Butts, Caps and Bases

24.7.1 Column splices and butt joints of struts and compression members, depending on contact for stress transmission, shall be accurately machined and close-butted over the whole section with a clearance not exceeding 0.2 mm locally, at any place. Sum of all such clearance shall not be more than 30 percent of the contact area for stress transmission. In column caps and bases, the ends of shafts together with the attached gussets, angles, channels, etc; after connecting together should be accurately machined so that clearance between the contact surfaces shall not exceed 2 mm locally, subject further to the condition that sum total of all such clearance shall not exceed 30 percent of the total contact area for stress transmission. Care should be taken that these gussets, connecting angles or channels are fixed with such accuracy that they are not reduced in thickness by machining by more than 2.0 mm.

24.7.2 Where sufficient gussets and rivets or welds are provided to transmit the entire loading (*see* provisions under **11**), the column ends need not be machined.

24.7.3 *Slab Bases and Caps*

Slab bases and slab caps, except when cut from material with true surfaces, shall be accurately machined over the bearing surfaces and shall be in effective contact with the end of the stanchion, the bearing face which is to be grouted to fit tightly at both top and bottom, unless welds are provided to transmit the entire column face.

24.7.4 To facilitate grouting, sufficient gap shall be left between the base plates and top of pedestal and holes shall be provided where necessary in stanchion bases for the escape of air.

24.8 Painting

24.8.1 Painting shall be done in accordance with the good practice good practices [C-6A(50)].

22.8.2 All surfaces, which are to be painted, oiled or otherwise treated, shall be dry and thoroughly cleaned to remove all loose scale and loose rust.

24.8.3 Shop contact surfaces need not be painted unless specified. If so specified, they shall be brought together while the paint is still wet.

24.8.4 Surfaces not in contact, but inaccessible after shop assembly, shall receive the full specified protective treatment before assembly. This does not apply to the interior of sealed hollow sections.

24.8.5 Chequered plates shall be painted but the details of painting shall be specified by the purchaser.

24.8.6 In case of surfaces to be welded, the steel shall not be painted or metal coated within a suitable distance of any edge to be welded, if the paint specified or the metal coating is likely to be harmful to welders or impair the quality of the welds.

24.8.7 Welds and adjacent parent metal shall not be painted prior to de-slagging, inspection and approval.

24.8.8 Parts to be encased in concrete shall not be painted or oiled.

24.8.9 Contact surface in friction type connection shall not be painted in advance.

24.9 Marking

Each piece of steel work shall be distinctly marked before dispatch, in accordance with a marking diagram and shall bear such other marks as will facilitate erection.

24.10 Shop Erection

24.10.1 The steel work shall be temporarily shop erected complete or as arranged with the inspection agency so that accuracy of fit may be checked before dispatch. The parts shall be shop assembled with sufficient numbers of parallel drifts to bring and keep the parts in place.

24.10.2 In the case of parts drilled or punched, through steel jigs with bushes resulting in all similar parts being interchangeable, the steelwork may be shop erected in such position as arranged with the inspection agency.

24.10.3 In case of shop fabrication using numerically controlled machine data generated by computer software (like CAD), the shop erection may be dispensed with at the discretion of the inspector.

24.11 Packing

All projecting plates or bars and all ends of members at joints shall be stiffened, all straight bars and plates shall be bundled, all screwed ends and machined surfaces shall be suitably packed and all rivets, bolts, nuts, washers and small and loose parts shall be packed separately in cases, so as to prevent damage or distortion during transit.

24.12 Inspection and Testing

24.12.1 The inspecting authority shall have free access at all reasonable times to those parts of the manufacturer’s works which are concerned with the fabrication of the steelwork and shall be afforded all reasonable facilities for satisfying himself that the fabrication is being undertaken in accordance with the provisions of this section.

24.12.2 Unless specified otherwise, inspection shall be made at the place of manufacture prior to dispatch and shall be conducted so as not to interfere unnecessarily with the operation of the work.

24.12.3 The manufacturer shall guarantee compliance with the provisions of this standard, if required to do so by the purchaser.

24.12.4 Should any structure or part of a structure be found not to comply with any of the provisions of this section, it shall be liable to rejection. No structure or part of the structure, once rejected shall be resubmitted for test, except in cases where the purchaser or his authorized representative considers the defect as rectifiable.

24.12.5 Defects, which may appear during fabrication, shall be made good with the consent of and according to the procedure laid down by the inspecting authority.

24.12.6 All gauges and templates necessary to satisfy the inspection authority shall be supplied by the manufacturer. The inspecting authority may, at his discretion, check the test results obtained at the manufacturer’s works by independent testing at outside laboratory, and should the material so tested be found to be unsatisfactory, the cost of such tests shall be borne by the manufacturer, and if found satisfactory, the cost shall be borne by the purchaser.

24.13 Site Erection

24.13.1 *Plant and Equipment*

The suitability and capacity of all plant and equipment used for erection shall be to the satisfaction of the engineer.

24.13.2 *Storing and Handling*

All structural steel should be so stored and handled at the site that the members are not subjected to excessive stresses and damage by corrosion due to exposure to environment.

24.13.3 *Setting Out*

The positioning and leveling of all steelwork, the plumbing of stanchions and the placing of every part of the structure with accuracy shall be in accordance with the approved drawings and to the satisfaction of the engineer in accordance with the deviation permitted below.

24.13.3.1 *Erection tolerances*

Unloaded steel structure, as erected, shall satisfy the tolerance criteria specified in the accepted standards [C-6A(47)].

24.13.4 *Safety during Fabrication and Erection*

24.13.4.1 All steel materials including fabricated structures, either at fabrication shop or at erection site, shall be handled only by a worker skilled in such jobs; where necessary with load tested lifting devices, having tested wire rope slings of correct size. The devices should be well maintained and operated by experienced operators.

24.13.4.2 Oxygen and acetylene cylinders and their hoses shall have distinctive colours. Cylinders should be stored in upright position in well-ventilated rooms or in open air, not exposed to flames, naked lights or extreme heat and should also be in upright position when they are being used. All gas cutting works shall be done only by experienced skilled gas cutters, equipped with gloves, boots, aprons, goggles and good cutting sets of approved make.

24.13.4.3 While doing any welding work, it should be ensured that the welding machine is earthed and the welding cables are free from damage. The welder and his assistant shall use a face shield or head shield with a welding lens and clear cover glass and their hands, legs and bodies shall be well protected by leather gloves, shoes and aprons. Combustible materials should be kept away from the sparks and globules of molten metals generated in any arc welding. In case of welding in a confined place, it should be provided with an exhaust system to take care of the harmful gases, fumes and dusts generated.

24.13.4.4 In addition to precautions against all the hazards mentioned above, erection workers shall also be protected in the following manner:

a) all workers shall wear helmets and shall also be provided with gloves and shoes. In addition those working at heights shall use safety belts;

b) all structures shall be so braced/guyed during erection that there is no possibility of collapse before erection work is completed; and

c) warning signs such as 'DANGER', 'CAUTION', '440 V', 'DO NOT SMOKE', 'LOOK AHEAD', etc; should be displayed at appropriate places.

24.13.4.5 For detailed safety precautions during erection, reference shall be made to the good practice [C-6A(51)].

24.13.5 *Field Connections*

24.13.5.1 *Field riveting*

Rivets driven at the site shall be heated and driven with the same care as those driven in the shop.

24.13.5.2 *Field bolting*

Field bolting shall be carried out with the same care as required for shop bolting.

24.13.5.3 *Fillet welding*

Field assembly and welding shall be executed in accordance with the requirements for shop fabrications excepting such as manifestly apply to shop conditions only. Where the steel has been delivered painted, the paint shall be removed for a distance of at least 50 mm on either side of the joint.

24.14 Painting after Erection

24.14.1 Before painting of such steel which is delivered unpainted is commenced, all surfaces to be painted shall be dry and thoroughly cleaned from all loose scale and rust, as required by the surface protection specification.

24.14.2 The specified protective treatment shall be completed after erection. All rivet and bolt heads and the site welds after de-slagging shall be cleaned. Damaged or deteriorated paint surfaces shall first be made good with the same type of paint as the shop coat. Where specified, surfaces which will be in contact after site assembly, shall receive a coat of paint (in addition to any shop priming) and shall be brought together while the paint is still wet. No painting shall be used on contact surfaces in the friction connection, unless specified otherwise by the design document.

24.14.3 Where the steel has received a metal coating in the shop, this coating shall be completed on site so as to be continuous over any welds and site rivets or bolts, subject to the approval of the engineer. Painting on site may complete protection. Bolts, which have been galvanized or similarly treated, are exempted from this requirement.

24.14.4 Surface, which will be inaccessible after site assembly, shall receive the full-specified protective treatment before assembly.

24.14.5 Site painting should not be done in frosty or foggy weather, or when humidity is such as to cause condensation on the surfaces to be painted.

24.15 Bedding Requirement

24.15.1 Bedding shall be carried out with Portland cement grout or mortar, as described under **24.15.4** or fine cement concrete in accordance with good practice [C-6A(52)].

24.15.2 For multistoried buildings, this operation shall not be carried out until a sufficient number of bottom lengths of stanchions have been properly lined, levelled and plumbed and sufficient floor beams are in position.

24.15.3 Whatever method is employed, the operation shall not be carried out until the steelwork has been finally levelled and plumbed, stanchion bases being supported meanwhile by steel wedges or nuts; and immediately before grouting, the space under the steel shall be thoroughly cleaned.

24.15.4 Bedding of structure shall be carried out with grout or mortar, which shall be of adequate strength and shall completely fill the space to be grouted and shall either be placed under pressure or by ramming against fixed supports. The grouts or mortar used shall be non-shrinking variety.

24.16 Steelwork Tenders and Contracts

A few recommendations are given in Annex H for general information.

ANNEX A

(*Clause* 4)

SYMBOLS

Symbols used in this section shall have the following meanings with respect to the structure or member or condition, unless otherwise defined elsewhere in this Section:

A = area of cross section;

A_c = area at root of threads;

A_e = effective cross sectional area;

A_{ef} = reduced effective flange area;

A_f = total flange area;

A_g = gross cross sectional area;

A_{gf} = gross cross sectional area of flange;

A_{go} = gross cross sectional area of outstanding (not connected) leg of a member;

A_n = net area of the total cross section;

A_{nb} = net tensile cross sectional area of bolt;

A_{nc} = net cross sectional area of the connected leg of a member;

A_{nf} = net cross sectional area of each flange;

A_{no} = net cross sectional area of outstanding (not connected) leg of a member;

A_{pb} = nominal bearing area of bolt on any plate;

A_q = cross sectional area of a bearing (load carrying) stiffener in contact with the flange;

A_s = tensile stress area;

A_{sb} = gross cross sectional area of a bolt at the shank;

A_{tg} = gross sectional area in tension from the centre of the hole to the toe of the angle section/channel section, etc (block shear failure, *see* **13.4**) perpendicular to the line of force;

A_{tn} = net sectional area in tension from the centre of the hole to the toe of the angle perpendicular to the line of force block shear failure (*see* **13.4**);

A_v = shear area;

A_{vg} = gross cross sectional area in shear along the line of transmitted force (*see* **13.4**);

A_{vn} = net cross sectional area in shear along the line of transmitted force (*see* **13.4**);

a, b = larger and smaller projection of the slab base beyond the rectangle circumscribing the column, respectively (*see* **14.4**);

a_o = peak acceleration;

a_1 = unsupported length of individual elements being laced between lacing points;

B = length of side of cap or base plate of a column;

b = outstand/width of the element;

b_1 = stiff bearing length;

b_e = effective width of flange between pair of bolts;

b_f = width of the flange;

b_i = width of flange as an internal element;

b_o = width of flange outstand;

b_p = panel zone width between column flanges at beam-column junction;

b_s = shear lag distance;

b_t = width of tension field;

b_w = width of outstanding leg;

C = centre to centre longitudinal distance of battens;

C_m = coefficient of thermal expansion;

c = spacing of transverse stiffener;

c_b = moment amplification factor for braced member;

c_m = moment reduction factor for lateral torsional buckling strength calculation;

c_s = moment amplification factor for sway frame;

D = overall depth/diameter of the cross section;

d = depth of web, Nominal diameter;

d_2 = twice the clear distance from the compression flange angles, plates or tongue plates to the neutral axis;

d_h = diameter of a bolt/rivet hole;

d_o = nominal diameter of the pipe column or the dimensions of the column in the depth direction of the base plate;

d_p = panel zone depth in the beam-column junction;

E = modulus of elasticity for steel;

$E\ (T)$ = modulus of elasticity of steel at T ºC;

E (20) = modulus of elasticity of steel at 20 ºC;

E_p = modulus of elasticity of the panel material;

F_{cdw} = buckling strength of un-stiffened beam web under concentrated load;

F_d = factored design load;

F_n = normal force;

F_o = minimum proof pretension in high strength friction grip bolts;

F_{psd} = bearing capacity of load carrying stiffener;

F_q = stiffener force;

F_{qd} = stiffener buckling resistance;

F_{test} = test load;

$F_{test,a}$ = load for acceptance test;

$F_{test,\ Min}$ = minimum test load from the test to failure;

$F_{test,\ R}$ = test load resistance;

$F_{test,\ S}$ = strength test load;

F_w = design capacity of the web in bearing;

F_x = external load, force or reaction;

F_{xd} = buckling resistance of load carrying web stiffener;

f = actual normal stress range for the detail category;

f_1 = frequency for a simply supported one way system;`

f_2 = frequency of floor supported on steel girder perpendicular to the joist;

f_a = calculated stress due to axial force at service load;

f_{abc} = permissible bending stress in compression at service load;

f_{ac} = permissible compressive stress at service load;

f_{abt} = permissible bending stress in tension at service load;

f_{apb} = permissible bearing stress of the bolt at service load;

f_{asb} = permissible stress of the bolt in shear at service load;

f_{at} = permissible tensile stress at service load;

f_{atb} = permissible tensile stress of the bolt at service load;

f_{aw} = permissible stress of the weld at service load;

f_b = actual bending stress at service load;

f_{bc} = actual bending stress in compression at service load;

f_{bd} = design bending compressive stress corresponding to lateral buckling;

f_{br} = actual bearing stress due to bending at service load;

f_{bt} = actual bending stress in tension at service load;

f_{bs} = permissible bending stress in column base at service load;

f_c = actual axial compressive stress at service load;

f_{cr} = elastic buckling stress of a column, Euler buckling stress;

f_{cd} = design compressive stress;

$f_{cr,b}$ = extreme fibre compressive stress corresponding to elastic lateral buckling moment;

f_e = equivalent stress at service load;

f_f = fatigue stress range corresponding to 5×10^6 cycles of loading;

f_{feq} = equivalent constant amplitude stress;

f_{fd} = design normal fatigue strength;

$f_{f,\ Max}$ = highest normal stress range;

f_{fn} = normal fatigue stress range;

f_{nw} = normal stress in weld at service load;

f_o = proof stress;

f_p = actual bearing stress at service load;

f_{pb} = actual bearing stress in bending at service load;

f_{psd} = bearing strength of the stiffeners;

f_r = frequency;

f_{sb} = actual shear stress in bolt at service load;

f_t = actual tensile stress at service load;

f_{tb} = actual tensile stress of the bolt at service load;

f_u = characteristic ultimate tensile stress;

f_{ub} = characteristic ultimate tensile stress of the bolt;

f_{um} = average ultimate stress of the material as obtained from test;

f_{up} = characteristic ultimate tensile stress of the connected plate;

f_v = applied shear stress in the panel designed utilizing tension field action;

f_w = actual stress of weld at service load;

f_{wd} = design stress of weld at service load;

f_{wn} = nominal strength of fillet weld;

f_x = maximum longitudinal stress under combined axial force and bending;

f_y = characteristic yield stress;

$f_y(T)$ = yield stress of steel at T °C;

$f_y(20)$ = yield stress of steel at 20 °C ;

f_{yb} = characteristic yield stress of bolt;

f_{yf} = characteristic yield stress of flange;

f_{ym} = average yield stress as obtained from test;

f_{yp} = characteristic yield stress of connected plate;

f_{yq} = characteristic yield stress of stiffener material;

f_{yw} = characteristic yield stress of the web material;

G = modulus of rigidity for steel;

g = gauge length between centres of the holes perpendicular to the load direction, acceleration due to gravity;

h = depth of the section;

h_b = total height from the base to the floor level concerned;

h_c = height of the column;

h_e = effective thickness;

h_f = centre to centre distance of flanges;

h_i = thickness of fire protection material;

h_L = height of the lip;

h_s = storey height;

h_y = distance between shear centre of the two flanges of a cross section;

I = moment of inertia of the member about an axis perpendicular to the plane of the frame;

I_{fc} = moment of inertia of the compression flange of the beam about the axis parallel to the web;

I_f = moment of inertia of the tension flange of the beam about minor axis;

I_q = moment of inertia of a pair of stiffener about the centre of the web, or a single stiffener about the face of the web;

I_s = second moment of inertia;

I_{so} = second moment of inertia of the stiffener about the face of the element perpendicular to the web;

I_T = transformed moment of inertia of the one way system (in terms of equivalent steel, assuming the concrete flange of width equal to the spacing of the beam to be effective);

I_t = St. Venant’s torsion constant;

I_w = warping constant;

I_y = moment of inertia about the minor axis of the cross section;

I_z = moment of inertia about the major axis of the cross section;

K_b = effective stiffness of the beam and column;

K_h = reduction factor to account for the high strength friction grip connection bolts in oversized and slotted holes Effective length of the member;

KL = appropriate effective slenderness ratio of the section;

KL/r = effective slenderness ratio of the section about the minor axis of the section;

KL/r = effective slenderness ratio of the section about the major axis of the section;

$\left(\frac{KL}{r}\right)_o$ = actual maximum effective slenderness ratio of the laced column;;

$\left(\frac{KL}{r}\right)_e$ = effective slenderness ratio of the laced column accounting for shear deformation;

K_v = shear buckling co-efficient;

K_w = warping restraint factor;

k = regression coefficient;

k_{sm} = exposed surface area to mass ratio;

K_y, K_z, K_{LT} = moment amplification factors;

L = actual length, unsupported length, length centre to centre distance of the intersecting members, cantilever length;

L_c = length of end connection in bolted and welded members, taken as the distance between outermost fasteners in the end connection, or the length of the end weld, measured along the length of the member;

L_{LT} = effective length for lateral torsional buckling;

L_m = maximum distance from the restraint to the compression flange at the plastic hinge to an adjacent restraint (limiting distance);

L_o = length between points of zero moment (inflection) in the span;

l = centre to centre length of the supporting member;

l_e = distance between prying force and bolt centre line;

l_g = grip length of bolts in a connection;

l_j = length of the joint;

l_s = length between points of lateral support to the compression flange in a beam;

l_v = distance from bolt centre line to the toe of fillet weld or to half the root radius for a rolled section;

l_w = length of weld;

M = bending moment;

M_a = applied bending moment;

M_{cr} = elastic critical moment corresponding to lateral torsional buckling of the beam;

M_d = design flexural strength;

M_{dv} = moment capacity of the section under high shear;

M_{dy} = design bending strength about the minor axis of the cross section;

M_{dz} = design bending strength about the major axis of the cross section;

M_{eff} = reduced effective moment;

M_{fr} = reduced plastic moment capacity of the flange plate;

M_{fd} = design plastic resistance of the flange alone;

M_{nd} = design bending strength under combined axial force and uniaxial moment;

M_{ndy}, M_{ndz} = design bending strength under combined axial force and the respective uniaxial moment acting alone;

M_p = plastic moment capacity of the section;

M_{pb} = moment in the beam at the intersection of the beam and column centre lines;

M_{pc} = moments in the column above and below the beam surfaces;

M_{pd} = plastic design strength;

M_{pdf} = plastic design strength of flanges only;

M_q = applied moment on the stiffener;

M_s = Moment at service (working) load

M_{tf} = moment resistance of tension flange;

M_y = factored applied moment about the minor axis of the cross section;

M_{yq} = moment capacity of the stiffener based on its elastic modulus;

M_z = factored applied moment about the major axis of the cross section;

N = number of parallel planes of battens;

N_d = design strength in tension or in compression;

N_f = axial force in the flange;

N_{SC} = number of stress cycles;

n = number of bolts in the bolt group/critical section;

n_e = number of effective interfaces offering frictional resistance to slip;

n_n = number of shear planes with the threads intercepting the shear plane in the bolted connection;

n_s = number of shear planes without threads intercepting the shear plane in the bolted connection;

P = factored applied axial force;

P_{cr} = elastic buckling load

P_d = design axial compressive strength;

P_{dy}, P_{dz} = design compression strength as governed by flexural buckling about the respective axis;

P_e = elastic Euler buckling load;

P_{min} = minimum required strength for each flange splice;

P_r = required compressive strength;

P_s = actual compression at service load;

P_y = yield strength of the cross section under axial compression;

p = pitch length between centres of holes parallel to the direction of the load;

p_s = staggered pitch length along the direction of the load between lines of the bolt holes (*see* Fig. 5);

Q = prying force;

Q_a = accidental load (Action);

Q_c = characteristic loads (Action);

Q_d = design load (Action);

Q_p = permanent loads (Action);

Q_v = variable loads (Action);

q = shear stress at service load;

R = ratio of the mean compressive stress in the web (equal to stress at mid depth) to yield stress of the web; reaction of the beam at support ;

R_d = design strength of the member at room temperature ;

R_i = net shear in bolt group at bolt 'i';

R_r = response reduction factor;

R_{tf} = flange shear resistance;

R = ultimate strength of the member at room temperature;

u = appropriate radius of gyration;

r = minimum radius of gyration of the individual element being laced together;

r_1 = ratio of the design action on the member under fire to the design capacity;

r_f = radius of gyration about the minor axis (v-v) of angle section;

r_{vv} = radius of gyration about the minor axis;

r_y = radius of gyration about the major axis;

r_z = minimum transverse distance between the centroid of the rivet or bolt group or weld group;

S = constant stress range;

S_c = design strength;

S_d = original cross sectional area of the test specimen;

S_o = spring stiffness;

S_p = ultimate strength;

S_u = anchorage length of tension field along the compression flange;

s_c = anchorage length of tension field along the tension flange;

s_t = actual stiffener spacing;

s_a = ratio of the mean compressive stress in the web (equal to stress at mid depth) to yield stress of the web; reaction of the beam at support;

T = temperature in degree Celsius; Factored tension;

T_b = applied tension in bolt;

T_{cf} = thickness of compression flange;

T_d = design strength under axial tension;

T_{dg} = yielding strength of gross section under axial tension;

T_{dn} = rupture strength of net section under axial tension;

T_{db} = design strength of bolt under axial tension, Block shear strength at end connection;

T_e = externally applied tension;

T_f = factored tension force of friction type bolt;

T_l = limiting temperature of the steel;

T_{nb} = nominal strength of bolt under axial tension;

T_{nd} = design tension capacity;

T_{ndf} = design tension capacity of friction type bolt;

T_{nf} = nominal tensile strength of friction type bolt;

T_s = actual tension under service load;

t = thickness of element/angle, time in minutes;

t_f = thickness of flange;

t_p = thickness of plate;

t_{pk} = thickness of packing;

t_q = thickness of stiffener;

t_s = thickness of base slab;

t_t = effective throat thickness of welds;

t_w = thickness of web;

V = factored applied shear force;

V_b = shear in batten plate;

V_{bf} = factored frictional shear force in friction type connection;

V_{cr} = critical shear strength corresponding to web buckling;

V_d = design shear strength;

V_{db} = block shear strength;

V_n = nominal shear strength of bolt;

V_{nbf} = bearing capacity of bolt for friction type connection;

V_p = plastic shear resistance under pure shear;

V_n = nominal shear strength;

V_{npb} = nominal bearing strength of bolt;

V_{nsb} = nominal shear capacity of a bolt;

V_{nsf} = nominal shear capacity of bolt as governed by slip in friction type connection;

V_s = transverse shear at service load;

V_{sb} = factored shear force in the bolt;

V_{sd} = design shear capacity;

V_{sdf} = design shear strength in friction type bolt;

V_{sf} = factored design shear force of friction bolts;

V_t = applied transverse shear;

V_{tf} = shear resistance in tension field;

W = total load;

w = uniform pressure from below on the slab base due to axial compression under the factored load;

w_{tf} = width of tension field;

x_t = torsional index;

Z_e = elastic section modulus;

Z_{ec} = elastic section modulus of the member with respect to extreme compression fibre;

Z_{et} = elastic section modulus of the member with respect to extreme tension fibre;

Z_p = plastic section modulus;

Z_v = contribution to the plastic section modulus of the total shear area of the cross section;

y_g = distance between point of application of the load and shear centre of the cross section;

y_s = co-ordinate of the shear centre in respect to centroid;

α = imperfection factor for buckling strength in columns and beams;

α_t = coefficient of thermal expansion;

β_M = ratio of smaller to the larger bending moment at the ends of a beam column;

β_{My}, β_{Mz} = equivalent uniform moment factor for flexural buckling for y-y and axes, respectively;

β_{MLT} = equivalent uniform moment factor for lateral torsional buckling;

χ = strength reduction factor to account for buckling under compression;

χ_m = strength reduction factor, χ, at f_{ym};

χ_{LT} = strength reduction factor to account for lateral torsional buckling of beams;

δ = storey deflection;

δ_L = horizontal deflection of the bottom of storey due to combined gravity and notional load;

δ_p = load amplification factor;

δ_u = horizontal deflection of the top of storey due to combined gravity and notional load;

ϕ = inclination of the tension field stress in web;

γ = unit weight of steel;

γ_L = partial safety factor for load;

γ_m = partial safety factor for material;

γ_{m0} = partial safety factor against yield stress and buckling;

γ_{m1} = partial safety factor against ultimate stress;

γ_{mb} = Partial safety factor for bolted connection with bearing type bolts;

γ_{mf} = partial safety factor for bolted connection with high strength friction grip bolts;

γ_{fft} = partial safety factor for fatigue load;

γ_{mft} = partial safety factor for fatigue strength;

γ_{mv} = partial safety factor against shear failure;

γ_{mw} = partial safety factor for strength of weld;

ε = yield stress ratio, $(250 / f_y)^{1/2}$;

λ = Non dimensional slenderness ratio $= \sqrt{f_y (KL/r)^2 / \pi^2 E} = \sqrt{f_y / f_{cr}} = \sqrt{P_y / P_{cr}}$

λ_{cr} = elastic buckling load factor;

λ_e = equivalent slenderness ratio;

λ_{LT} = non-dimensional slenderness ratio in lateral bending;

λ_{scr} = elastic buckling load factor of each storey;

μ = poisson's ratio;

μ_c = correction factor;

μ_f = coefficient of friction (slip factor);

μ_r = capacity reduction factor;

θ = ratio of the rotation at the hinge point to the relative elastic rotation of the far end of the beam segment containing plastic hinge;

ρ = unit mass of steel;

τ = actual shear stress range for the detail category;

τ_{b} = buckling shear stress;

τ_{ab} = permissible shear stress at the service load;

$\tau_{cr,e}$ = elastic critical shear stress;;

τ_{f} = fatigue shear stress range;

$\tau_{f, Max}$ = highest shear stress range;

τ_{fd} = design shear fatigue strength;

τ_{fn} = fatigue shear stress range at N_{SC} cycle for the detail category;

τ_{v} = actual shear stress at service load;

ψ = ratio of the moments at the ends of the laterally unsupported length of a beam; and

Γ = frame buckling load factor.

NOTE — The subscripts y, z denote the y-y and z-z axes of the section, respectively. For symmetrical sections, y-y denotes the minor principal axis whilst z-z denotes the major principal axis (*see* **8**).

ANNEX B

[*Clauses* 11.1.1(c) *and* 11.7.2.1(b)]

ANALYSIS AND DESIGN METHODS

B-1 ADVANCED STRUCTURAL ANALYSIS AND DESIGN

B-1.1 Analysis

For a frame, comprising members of compact section with full lateral restraint, an advanced structural analysis may be carried out, provided the analysis can be shown to accurately model the actual behaviour of that class of frames. The analysis shall take into account the relevant material properties, residual stresses, geometrical imperfections, reduction in stiffness due to axial compression, second-order effects, section strength and ductility, erection procedures and interaction with the foundations.

Advanced structural analysis for earthquake loads shall take into account provisions of **5** of Part C 'Strucutral design/Section 1 Loads and Load Effects' of this NBCS.

B-1.2 Design

For the strength limit state, it shall be sufficient to satisfy the section capacity requirements given under **15** for the members subjected to bending, under **14** for axial members, under **16** for combined forces and under **17** for connections. Effect of moment magnification given in **16**, instability given in **14** and lateral buckling given in **15** need not be considered while designing the member, since advanced analysis methods directly consider these.

B-2 SECOND ORDER ELASTIC ANALYSIS AND DESIGN

B-2.1 Analysis

In a second-order elastic analysis, the members shall be assumed to remain elastic, and changes in frame geometry under the design load and changes in the effective stiffness of the members due to axial forces shall be accounted for. In a frame where the elastic buckling load factor (λ_{cr}) of the frame as determined in accordance with **11.6** is greater than 5, the changes in the effective stiffness of the members due to axial forces may be neglected.

B-2.2 Design Bending Moment

The design bending moment under factored load shall be taken as the maximum bending moment in the length of the member. It shall be determined either:

a) directly from the second-order analysis; or

b) approximately, if the member is divided into a sufficient number of elements, as the greatest of the element end bending moments, or;

c) by amplifying the calculated design bending moment, taken as the maximum bending moment along the length of a member as obtained by superposition of the simple beam bending moments determined by the analysis.

For a member with zero axial force or a member subject to axial tension, the factored design bending moment shall be calculated as the moment obtained from second-order analysis without any amplification.

For a member with a design axial compressive force as determined from the analysis, the factored design bending moment shall be calculated as follows:

$$M = \delta_b M_m$$

where

δ_b = moment amplification factor for a braced member determined in accordance with **16**.

B-3 FRAME INSTABILITY ANALYSIS

B-3.1 Analysis

Frame instability, as treated here, is related to the design of multi-storey rigid-jointed frames subject to side sway. The elastic critical load factor, λ_{cr} may be determined using the deflection method as given in **B-3.2** or any other recognized method. This is used to calculate the amplified sway moments for elastic designs and to check frame stability in plastic designs. The elastic critical load factor, λ_{cr} of a frame is the ratio by which each of the factored loads would have to be increased to cause elastic instability.

B-3.2 Deflection Method

An accurate method of analysis (ordinary linear elastic analysis) should be used to determine the horizontal deflections of the frame due to horizontal forces applied at each floor level, which is equal to the notional horizontal load in **11.3.6**. Allowance should be made for the degree of rigidity of the base as given in **B-3.2** in this deflection calculation.

The base stiffness should be determined by reference to **11.3.4**.
The elastic critical load factor, λ_{cr} is calculated as:

$$\lambda_{cr} = \frac{1}{200\phi_{s,Max}}$$

where
$\phi_{s,Max}$ = largest value of the sway index where, ϕ_s given by:

$$\phi_{si} = \frac{\delta_{ui} - \delta_{Li}}{h_i}$$

where

h_i = storey height;

δ_{ui} = horizontal deflection of the top of the storey due to the combined gravity and notional loads; and

δ_{Li} = horizontal deflection of the bottom of the storey due to gravity and notional load.

B-3.3 Partial Sway Bracing

In any storey the stiffening effect of infill wall panels may be allowed for by introducing a diagonal strut in that storey of area *A*, given by:

$$A = \frac{k_3 \sum K_c}{h(h/b)} \left[1 + (h/b)^2\right]^{3/2}$$

where

h = storey height;

b = width of the braced bay;

$\sum K_c$ = sum of the stiffness *I/L*, of the columns in that storey;

$k_3 = \frac{h^2 \sum S_p}{80E \sum K_C} \le 2$; and

$\sum S_p$ = Sum of spring stiffness (horizontal force per unit horizontal deflection of all the panels in that storey determined from:

$$S_p = \frac{0.6h/b}{\left[1 + (h/b)^2\right]^2} \, t_p E_p$$

where

t_p = thickness of the wall panel; and

E_p = modulus of elasticity of the panel material.

ANNEX C

[*Clauses* 12.2.2.2 *and* 12.6.2]

DESIGN AGAINST FLOOR VIBRATION

C-1 GENERAL

Floor with longer spans of lighter construction and less inherent damping are vulnerable to vibrations under normal human activity. Natural frequency of the floor system corresponding to the lowest mode of vibration, damping characteristics, are important characteristics in floor vibration. Open web steel joists (trusses) or steel beams on the concrete deck may experience walking vibration problem. Fatigue, overloading of floor systems and vibrations due to rhythmic activities such as aerobic or dance classes are not within the scope of this annex.

C-2 ANNOYANCE CRITERIA

In the frequency range of 2 to 8 Hz in which people are most sensitive to vibration, the threshold level corresponds approximately to 0.5 percent *g*, where *g* is the acceleration due to gravity. Continuous vibration is generally more annoying than decaying vibration due to damping. Floor systems with the natural frequency less than 8 Hz in the case of floors supporting rhythmic activity and 5 Hz in the case of floors supporting normal human activity should be avoided. However, if it is unavoidable, recommendations of specialist literature may be followed.

C-3 FLOOR FREQUENCY

The fundamental natural frequency can be estimated by assuming full composite action, even in non-composite construction. This frequency, f_1 for a simply supported one way system is given by:

$$f_1 = 156 \sqrt{EI_T / WL^4}$$

where

E = modulus of elasticity of steel, in MPa;

I_T = transformed moment of inertia of the one way system (in terms of equivalent steel) assuming the concrete flange of width equal to the spacing of the beam to be effective, in mm^4;

L = span length, in mm; and

W = dead load of the one way joist, in N/mm.

If the one way joist system is supported by a flexible beam running perpendicular with the natural frequency f_2, the floor frequency may be reduced to f_r, given by:

$$\frac{1}{f_r^2} = \frac{1}{f_1^2} + \frac{1}{f_2^2}$$

C-4 DAMPING

The percentage of critical damping may be assumed approximately as given below:

Sl No. (1)	*System* (2)	*Critical Damping* Percent (3)
i)	Fully composite construction	2
ii)	Bare steel beam and concrete deck	3 to 4
iii)	Floor with finishes, false ceiling, fire proofing, ducts, furniture	6
iv)	Partitions not located along a support or not spaced farther apart than 6 m and partitions oriented in orthogonal directions	Up to 12

C-5 ACCELERATION

The peak acceleration a_o, from heel impact for floors of spans greater than 7m and natural frequency f_1, less than 10 Hz may be calculated as:

$$a_o/g = 600\, f_r / W$$

where

W = total weight of floors plus contents over the span length and equivalent floor width (b), in N;

$b = 40t_s$ ($20\, t_s$ when overhang is only on one side of the beam);

t_s = equivalent thickness of the slab, averaging concrete in slab and ribs; and

g = acceleration due to gravity.

ANNEX D

(*Clause* 14.2.2)

DETERMINATION OF EFFECTIVE LENGTH OF COLUMNS

D-1 METHOD FOR DETERMINING EFFECTIVE LENGTH OF COLUMNS IN FRAMES

In the absence of a more exact analysis, the effective length of columns in framed structures may be obtained by multiplying the actual length of the column between the centres of laterally supporting members (beams) given in Fig. 27 and Fig. 28 with the effective length factor *K*, calculated by using the equations given below, provided the connection between beam and column is rigid type:

a) *Non-sway frames* (*braced frame*) [(*see* **11.1.2** (a)]

A frame is designated as non-sway frame if the relative displacement between the two adjacent floors is restrained by bracings or shear walls (*see* **11.1.2**). The effective length factor, *K*, of column in non-sway frames is given by (*see* Fig. 27):

$$K = \frac{[1 + 0.145(\beta_1 + \beta_2) - 0.265\beta_1\beta_2]}{[2 - 0.364(\beta_1 + \beta_2) - 0.247\beta_1\beta_2]}$$

b) *Sway frames* (*moment resisting frames*) [*see* **11.1.2** (b)]

The effective length factor *K*, of column in sway frames is given by (*see* Fig. 28):

$$K = \left[\frac{1 - 0.2(\beta_1 + \beta_2) - 0.12\beta_1\beta_2}{1 - 0.8(\beta_1 + \beta_2) + 0.6\beta_1\beta_2}\right]^{0.5}$$

where

β_1, β_2 are given, $\beta = \frac{\sum K_c}{\sum K_c + \sum K_b}$

K_c, K_b = Effective flexural stiffness of the columns and beams meeting at the joint at the two ends of the columns and rigidly connected at the joints, and these are calculated by:

$$K_c \text{ and } K_b = C\,(I/L)$$

I = moment of inertia of the member about an axis perpendicular to the plan of the frame,

L = length of the member equal to centre to centre distance of the intersecting member, and

C = correction factor as shown in Table 33.

Table 33 Correction Factors for Effective Flexural Stiffness

(*Clause* D-1)

Sl No.	**Far End Condition**	**Correction Factor, C**	
		Braced Frame	Unbraced Frame
(1)	(2)	(3)	(4)
i)	Pinned	$0.67(1 - \bar{n})$	$0.75(1 - \bar{n})$
ii)	Rigidly connected to column	$0.5(1 - \bar{n})$	$1.5(1 - 0.2\bar{n})$
iii)	Fixed	$1.0(1 - 0.4\bar{n})$	$1.0(1 - 0.4\bar{n})$

NOTE — $\bar{n} = \frac{P}{P_e}$

where

P_e = elastic buckling load, and

P = applied load.

D-2 METHOD FOR DETERMINING EFFECTIVE LENGTH FOR STEPPED COLUMNS (*see* **14.2.2**)

D-2.1 Single Stepped Columns

Effective length in the plane of stepping (bending about axis *z-z*) for bottom and top parts for single stepped column shall be taken as given in Table 34.

NOTE — The provisions of **D-2.1** are applicable to intermediate columns as well with stepping on either side, provided appropriate values of $I_1$and I_2 are taken.

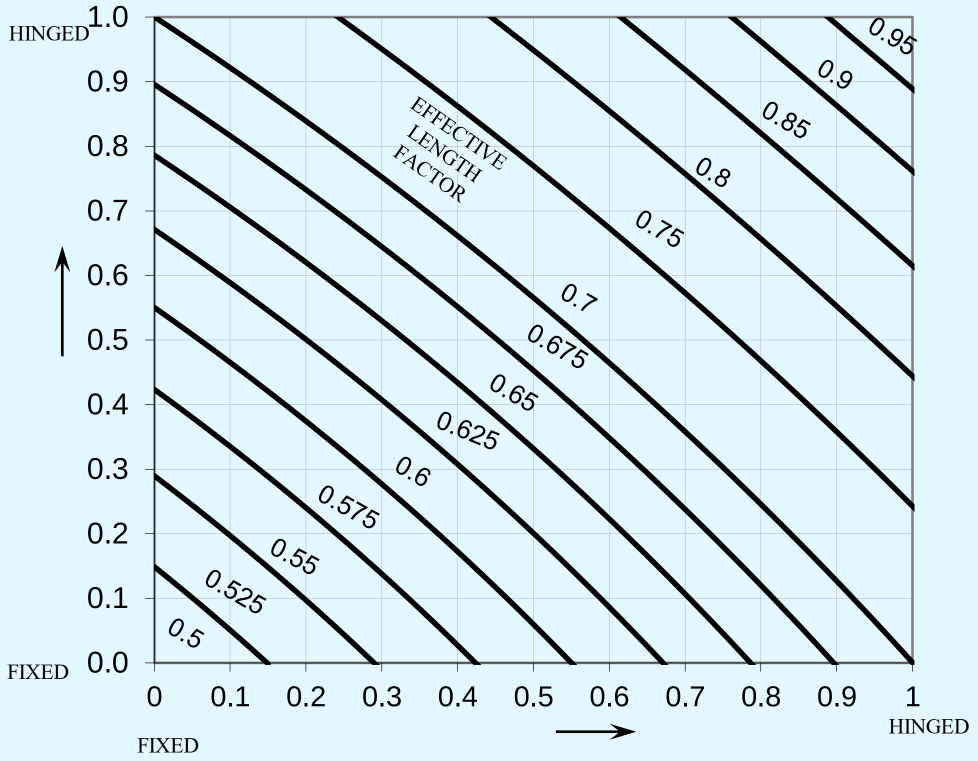


FIG. 27 COLUMN EFFECTIVE LENGTH FACTOR — NON SWAY FRAME

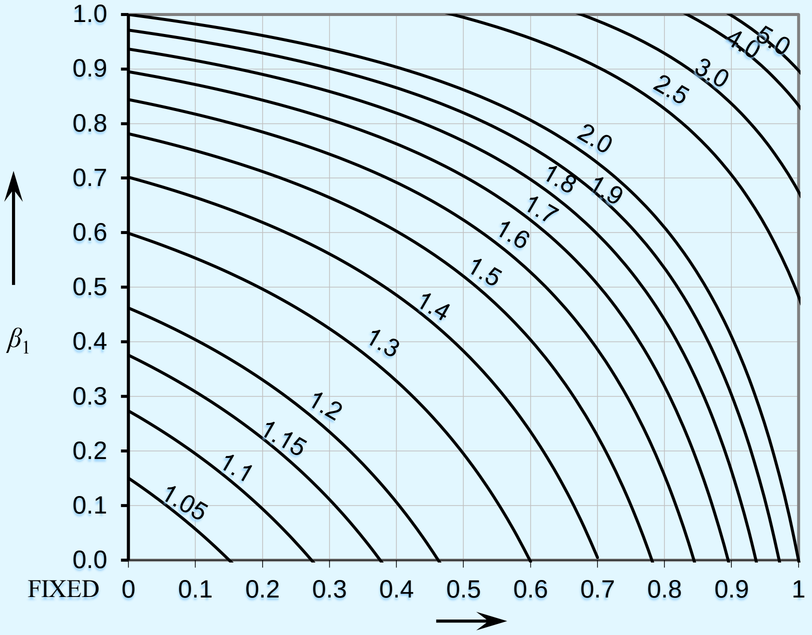


FIG. 28 COLUMN EFFECTIVE LENGTH FACTOR — SWAY FRAME

Table 34 Effective Length of Singled Stepped Columns

(*Clause* D-2.1)

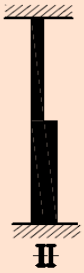
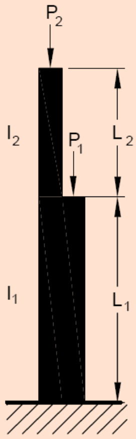
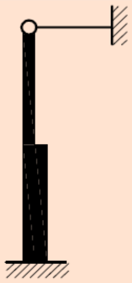
Sl No.	Degree of End Restraint	Sketch	Effective Length Coefficients	Column Parameters for all Cases
(1)	(2)	(3)	(4)	(5)
i)	Effectively held in position and restrained against rotation at both ends		$K_1 = \sqrt{\dfrac{K_{12}{}^2 + K_{11}{}^2(\alpha - 1)}{\alpha}}$ $K_2 = \dfrac{K_1}{C_1} \le 3$ where K_{12} and K_{11} are to be taken as per Table 35	
ii)	Effectively held in position at both ends and restrained against rotation at bottom end only		$K_1 = \sqrt{\dfrac{K_{12}{}^2 + K_{11}{}^2(\alpha - 1)}{\alpha}}$ $K_2 = \dfrac{K_1}{C_1} \le 3$ where K_{12} and K_{11} are to be taken as per Table 36	

Table 34 (*Concluded*)

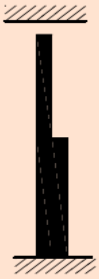
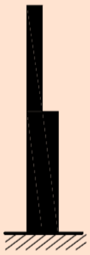
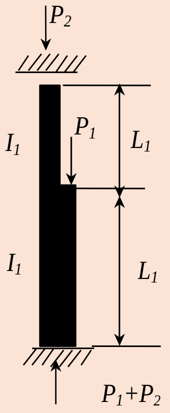
Sl No.	Degree of End Restraint	Sketch	Effective Length Coefficients	Column Parameters for all Cases
(1)	(2)	(3)	(4)	(5)
iii)	Effectively held in position and restrained against rotation at bottom end, and top end held against rotation but not held in position		K_1 to be taken as per Table 37 $K_2 = \frac{K_1}{C_1} \leq 3$	$\alpha = \frac{P_1 + P_2}{P_2}$ $C_1 = \frac{L_2}{L_1}\sqrt{\frac{I_1}{I_2 \alpha}}$ $\frac{i_2}{i_1} = \frac{I_2}{L_2} \times \frac{L_1}{I_1}$ Effective length of bottom part of column in plane of stepping = $K_1 L_1$
iv)	Effectively held in position and restrained against rotation at bottom end, and top end neither held against rotation nor held in position		K_1 to be taken as per Table 38 $K_2 = \frac{K_1}{C_1} \leq 3$	Effective length of top part of column in plane of stepping = $K_2 L_2$

Table 35 Coefficients of Effective Lengths K_{12} And K_{11} for Columns with Both Ends Effectively Held in Position and Restrained Against Rotation

(Table 34)

	Coefficients K_{12} and K_{11} for L_2/L_1 Equal to														
I_2/I_1	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.4	1.6	1.8	2.0
	Coefficient K_{12} (P_1 = 0)														
0.05	0.74	0.94	1.38	1.60	1.87	2.07	2.23	2.39	2.52	2.67	3.03	3.44	3.85	4.34	4.77
0.1	0.67	0.76	1.00	1.20	1.42	1.61	1.78	1.92	2.04	2.20	2.40	2.60	2.86	3.18	3.41
0.2	0.64	0.70	0.79	0.93	1.07	1.23	1.41	1.50	1.60	1.72	1.92	2.11	2.28	2.45	2.64
0.3	0.62	0.68	0.74	0.85	0.95	1.06	1.18	1.28	1.39	1.48	1.67	1.82	1.96	2.12	2.20
0.4	0.60	0.66	0.71	0.77	0.82	0.93	0.99	1.08	1.17	1.23	1.39	1.53	1.66	1.79	1.92
0.5	0.59	0.65	0.70	0.77	0.82	0.93	0.99	1.08	1.17	1.23	1.39	1.53	1.66	1.79	1.92
1.0	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00	1.10	1.20	1.30	1.40	1.50
	Coefficient K_{11} (P_2 = 0)														
0.05	0.65	0.67	0.71	0.85	1.01	1.17	1.31	1.41	1.50	1.57	1.67	1.74	1.78	1.82	1.86
0.1	0.64	0.65	0.65	0.65	0.78	0.92	1.05	1.15	1.25	1.33	1.45	1.55	1.62	1.68	1.71
0.2	0.62	0.64	0.65	0.65	0.66	0.73	0.83	0.92	1.01	1.09	1.23	1.33	1.41	1.48	1.54
0.3	0.60	0.63	0.64	0.65	0.66	0.67	0.73	0.81	0.89	0.94	1.09	1.20	1.28	1.35	1.41
0.4	0.58	0.63	0.63	0.64	0.64	0.66	0.68	0.75	0.82	0.88	1.01	1.10	1.19	1.26	1.32
0.5	0.57	0.61	0.63	0.64	0.64	0.65	0.68	0.72	0.77	0.83	0.94	1.04	1.12	1.19	1.25
1.0	0.55	0.58	0.60	0.61	0.62	0.63	0.65	0.67	0.70	0.73	0.80	0.88	0.93	1.01	1.05



NOTE — Intermediate value may be obtained by interpolation

Table 36 Coefficients of Effective Lengths K_{12} And K_{11} for Columns with Both Ends Effectively Held in Position and Restrained Against Rotation at Bottom End Only

(*Table 34*)

	Coefficients K_{12} and K_{11} for L_2/L_1 Equal to														
I_2/I_1	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.4	1.6	1.8	2.0
	Coefficient K_{12} (P_1 = 0)														
0.05	0.97	1.66	2.10	2.43	2.72	2.92	3.08	3.24	3.48	3.73	4.22	4.85	5.36	6.00	6.58
0.1	0.83	1.21	1.57	1.95	2.14	2.33	2.46	2.60	2.76	2.91	3.28	3.61	4.03	4.43	4.85
0.3	0.78	0.90	1.09	1.27	1.44	1.60	1.74	1.86	1.98	2.11	2.35	2.51	2.76	2.99	3.25
0.5	0.78	0.86	0.99	1.10	1.22	1.35	1.47	1.57	1.67	1.76	1.96	2.15	2.34	2.50	2.76
1.0	0.78	0.85	0.92	0.99	1.06	1.13	1.20	1.27	1.34	1.41	1.54	1.68	1.82	1.97	2.10
	Coefficient K_{11} (P_2 = 0)														
0.05	0.67	0.67	0.82	1.16	1.35	1.48	1.58	1.65	1.69	1.74	1.81	1.84	1.86	1.88	1.90
0.1	0.67	0.67	0.73	0.93	1.11	1.25	1.36	1.45	1.52	1.57	1.66	1.72	1.77	1.80	1.82
0.3	0.67	0.67	0.67	0.71	0.80	0.90	0.99	1.08	1.15	1.22	1.33	1.41	1.48	1.54	1.59
0.5	0.67	0.67	0.67	0.69	0.73	0.81	0.87	0.94	1.01	1.07	1.17	1.26	1.33	1.39	1.44
1.0	0.67	0.67	0.67	0.68	0.71	0.74	0.78	0.82	0.87	0.91	0.99	1.07	1.13	1.19	1.24

NOTE — Intermediate value may be obtained by interpolation.

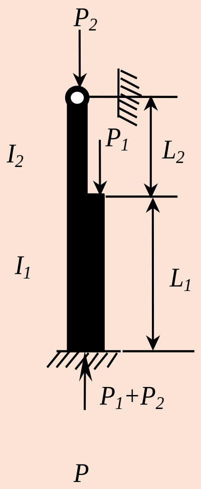


Table 37 Coefficients of Effective Lengths K_1 for Columns Effectively Held in Position and Restrained Against Rotation at Bottom End and Top End Held Against Rotation but not Held in Position

(Table 34)

C_1	**Coefficients K_1 for I_2 / I_1 Equal to**														
	0.1	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1.0**	**1.2**	**1.4**	**1.6**	**1.8**	**2.0**
0	2.0	1.86	1.7	1.67	1.6	1.55	1.50	1.4	1.43	1.4	1.37	1.3	1.1	1.10	1.0
0.5	2.0	1.90	1.8	1.74	1.6	1.65	1.61	1.5	1.55	1.5	---	---	---	----	----
1.0	2.0	2.00	2.0	2.00	2.0	2.00	----	----	----	----	----	----	----	----	----
1.5	2.0	2.25	2.3	2.48	----	----	----	----	----	----	----	----	----	----	----
2.0	2.0	2.66	2.91	----	----	----	----	----	----	----	----	----	----	----	----
2.5	2.5	3.17	3.50	----	----	----	----	----	----	----	----	----	----	----	----
3.0	3.0	3.70	4.12	----	----	----	----	---	----	----	----	----	----	----	----

NOTE — Intermediate values may be obtained by interpolation.

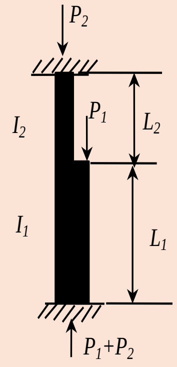
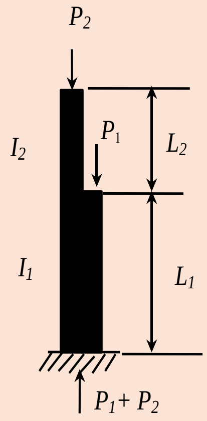


Table 38 Coefficients of Effective Lengths K_1 for Columns with Top Ends Free and Bottom End Effectively Held in Position and Restrained Against Rotation

(Table 34)

C_1	**Coefficients K_1 for I_2/I_1 Equal to**														
	0.1	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.5	5.0	10	20
0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
0.5	2.0	2.14	2.24	2.36	2.47	2.57	2.67	2.76	2.85	2.94	3.02	---	---	---	----
1.0	2.0	2.73	3.13	3.44	3.74	4.00	----	----	----	----	----	----	----	----	----
1.5	3.0	3.77	4.35	4.86	----	----	----	----	----	----	----	----	----	----	----
2.0	4.0	4.90	5.67	----	----	----	----	----	----	----	----	----	----	----	----
2.5	5.0	6.08	7.00	----	----	----	----	----	----	----	----	----	----	----	----
3.0	6.0	7.25	----	----	----	----	----	----	----	----	----	----	-----	----	----

NOTE — Intermediate values may be obtained by interpolation.



D-3 Effective Length for Double Stepped Columns

Effective lengths in the plane of steppings (bending about axis *z-z*) for bottom, middle and top parts for a double stepped column shall be taken as follows (*see also* Fig. 29):

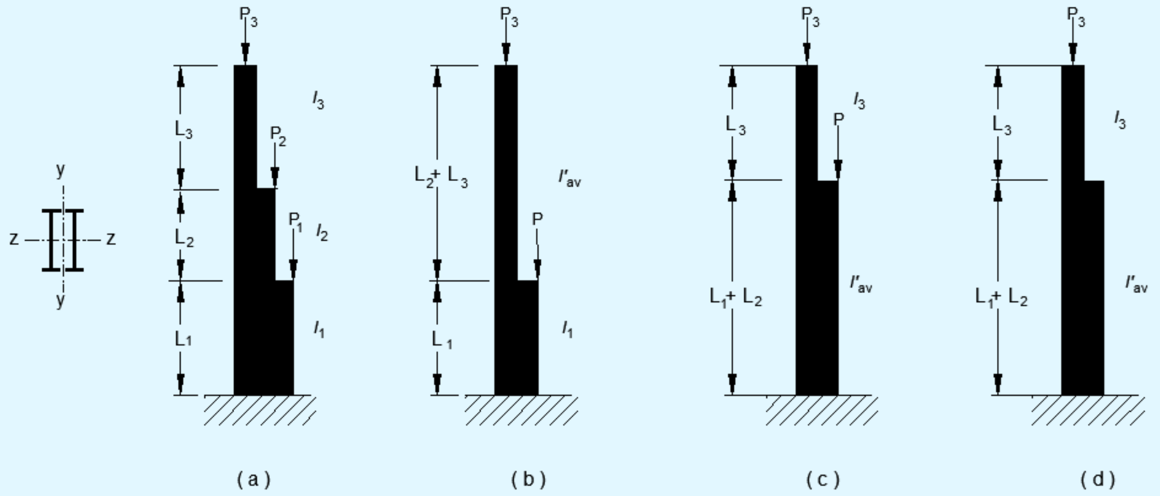


FIG. 29 EFFECTIVE LENGTH OF DOUBLE STEPPED COLUMNS

Coefficient K_1 for effective length of bottom part of double stepped column shall be taken from the formula:

$$K_1 = \sqrt{\frac{t_1 K_1^{\,2} + \left(t_2 K_2^{\,2} + K_3^{\,2}\right) \times \left(1 + n_2\right)^2 \times \dfrac{I_1}{I'_{\text{av}}}}{1 + t_1 + t_2}}$$

where

K_1, K_2, and K_3 are taken from Table 39.

$$t_1 = \frac{P_1}{P_3}, \qquad t_2 = \frac{P_2}{P_3},$$

I'_{av} = average value of moment of inertia for the lower and middle parts

$$= \frac{I_1 L_1 + I_2 L_2}{L_1 + L_2}$$

I'_{av} = average value of moment of inertia for the middle and top parts

$$= \frac{I_2 L_2 + I_3 L_3}{L_2 + L_3}$$

Value of coefficient K_2 for middle part of column is given by formula:

$$K_2 = \frac{K_1}{C_2}, \quad \text{and}$$

Value of coefficient K_3 for the top part of the column is given by:

$$K_3 = \frac{K_1}{C_3} \leq 3$$

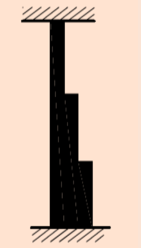
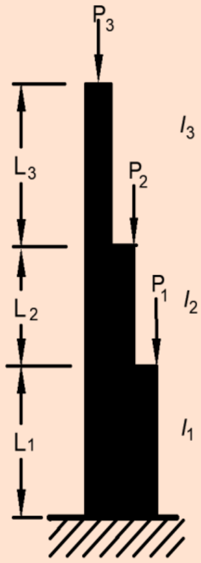
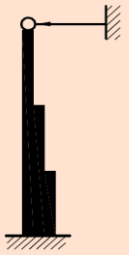
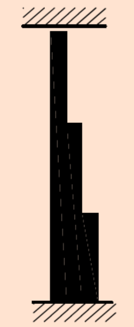
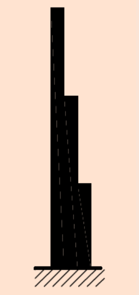
where

$$C_2 = \frac{L_2}{L_1}\sqrt{\frac{I_1(P_2+P_3)}{I_2(P_1+P_2+P_3)}}\ ,\ C_3 = \frac{L_3}{L_1}\sqrt{\frac{I_1 P_3}{I_3(P_1+P_2+P_3)}}$$

NOTE — The provisions of **D-3** are applicable to intermediate columns as well with steppings on either side, provided appropriate values of I_1, I_2 and I_3 are taken.

Table 39 Values of K_1, K_2 and K_3

(*Clause* D-3)

Sl No.	Degree of End Restraint	Sketch	K_1	K_2	K_3	**Column Parameters for all Cases**
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	Effectively held in position and restrained against rotation at both ends		$K_1 = K_{11}$ where K_{11} is taken from Table 35	$K_2 = K_{11}$ where K_{11} is taken from Table 35	$K_3 = K_{12}$ where K_{12} is taken from Table 35	
ii)	Effectively held in position at both ends and restrained against rotation at bottom end only		$K_1 = K_{11}$ where K_{11} is taken from Table 36	$K_2 = K_{11}$ where K_{11} is taken from Table 36	$K_3 = K_{12}$ where K_{12} is taken from Table 36	
iii)	Effectively held in position and restrained against rotation at bottom end, and top end held against rotation but not held in position		$K_1 = K_1$ where K_1 is taken from Table 37 with $C_1 = 0$	$K_2 = K_1$ where K_1 is taken from Table 37 with $C_1 = 0$	$K_3 = K_1$ where K_1 is taken from Table 37 with $C_1 = \frac{L_3}{L_1+L_2}\sqrt{\frac{I_{av}}{I_3}}$	
iv)	Effectively held in position and restrained against rotation at bottom end, and top end neither held against rotation nor against translation		$K_1 = 2$	$K_2 = 2$	$K_3 = K_1$ where K_1 is taken from Table 38 with $C_1 = \frac{L_3}{L_1+L_2}\sqrt{\frac{I_{av}}{I_3}}$	

ANNEX E

(*Clause* 15.2.2.1)

ELASTIC LATERAL TORSIONAL BUCKLING

E-1 ELASTIC CRITICAL MOMENT

E-1.1 General

The elastic critical moment is affected by the following:

a) Moment gradient in the unsupported length;

b) Boundary conditions at the lateral support points;

c) Non-symmetric and non-prismatic nature of the member; and

d) Location of transverse load with respect to shear centre.

The boundary conditions at the lateral supports have two components:

1) *Torsional restraint* — where the cross section is prevented from rotation about the shear centre; and

2) *Warping restraint* — where the flanges are prevented from rotating in their own plane about an axis perpendicular to the flange.

The elastic critical moment corresponding to lateral torsional buckling of a doubly symmetric prismatic beam subjected to uniform moment in the unsupported length and torsionally restraining lateral supports is given by:

$$M_{\mathrm{cr}} = \frac{\pi^2 E I_{\mathrm{y}}}{(L_{\mathrm{LT}})^2}\left[\frac{I_{\mathrm{w}}}{I_{\mathrm{y}}} + \frac{G\,I_{\mathrm{t}}\,(L_{\mathrm{LT}})^2}{\pi^2 E\,I_{\mathrm{y}}}\right]^{0.5}$$

where

I_{y}, I_{w}, I_{t} = moment of inertia about the minor axis, warping constant and St.Venant's torsion constant of the cross section, respectively (*see* accepted standards [C-6A(36)] for properties of sections);

G = modulus of rigidity; and

L_{LT} = effective length against lateral torsional buckling (*see* **15.3**).

This equation in simplified form for I-section has been presented in **15.2.2.1**.

While the simplified equation is generally on the safe side, there are many situations where this may be very conservative. More accurate calculation of the elastic critical moment for general case of unsymmetrical sections, tapered members, loading away from shear centre and beams with moment gradient can be obtained from specialist literature, by using an appropriate computer program or equations given below.

E-1.2 Elastic Critical Moment of a Section Symmetrical About Minor Axis

In case of a beam which is symmetrical only about the minor axis, and bending about major axis, the elastic critical moment for lateral torsional buckling is given by the general equation below,

$$M_{\mathrm{cr}} = c_1 \frac{\pi^2 E I_{\mathrm{y}}}{(L_{\mathrm{LT}})^2}\left\{\left[\left(\frac{K}{K_{\mathrm{w}}}\right)^2 \frac{I_{\mathrm{w}}}{I_{\mathrm{y}}} + \frac{G\,I_{\mathrm{t}}\,(L_{\mathrm{LT}})^2}{\pi^2 E\,I_{\mathrm{y}}} + (c_2 y_{\mathrm{g}} - c_3 y_{\mathrm{j}})^2\right]^{0.5} - (c_2 y_{\mathrm{g}} - c_3 y_{\mathrm{j}})\right\}$$

where

c_1, c_2, c_3 = factors depending upon the loading and end restraint conditions (*see* Table 40);

K = effective length factors of the unsupported length accounting for boundary conditions at the end lateral supports. The effective length factor K varies from 0.5 for complete restraint against rotation about weak axis to 1.0 for free rotate about weak axis, with 0.7 for the case of one end fixed and other end free. It is analogous to the effective length factors for compression members with end rotational restraint;

K_w = warping restraint factor. Unless special provisions to restrain warping of the section at the end lateral supports are made, K_w should be taken as 1.0;

y_g = y distance between the point of application of the load and the shear centre of the cross section and is positive when the load is acting towards the shear centre from the point of application;

y_j = $y_s - 0.5\int_A \left(z^2 + y^2\right)^2 y dA/I_z$;

y_s = coordinate of the shear centre with respect to centroid, positive when the shear centre is on the compression side of the centroid; and

y, z = coordinates of the elemental area with respect to centroid of the section.

y_j can be calculated by using the following approximation:

a) *Plain flanges*:

1) $y_j = 0.8 (2\beta_f - 1) h_y /2.0$ (when $\beta_f > 0.5$)
2) $y_j = 1.0 (2\beta_f - 1) h_y /2.0$ (when $\beta_f \leq 0.5$)

b) *Lipped flanges*:

1) $y_j = 0.8 (2\beta_f - 1) (1+ h_L/h) h_y/2$ (when $\beta_f > 0.5$)
2) $y_j = (2\beta_f - 1) (1+ h_L/h) h_y/2$ (when $\beta_f \leq 0.5$)

where

h_L = height of the lip,

h = overall height of the section,

h_y = distance between shear centre of the two flanges of the cross section, and

$\beta_f = I_{fc} /(I_{fc} + I_{ft})$ where I_{fc}, I_{ft} are the moment of inertia of the compression and tension flanges, respectively, about the minor axis of the entire section.

I_t = St. Venant's Torsion constant, given by:

$I_t = \sum b_i t_i^3 /3$ (for open section)

$= 4A_e^{\,2} / \sum (b/t)$ (for hollow section)

where

A_e = area enclosed by the section, and

b, t = breadth and thickness of the elements of the section, respectively.

I_w = The warping constant, given by:

$(1-\beta_f) \beta_f I_y h_y^2$ (for I-sections mono-symmetric about weak axis)= 0 (for angle, Tee, narrow rectangle section and approximately for hollow sections)

Table 40 Constants c_1, c_2, and c_3

(*Clause* E-1.2)

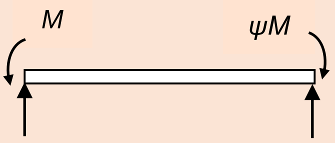
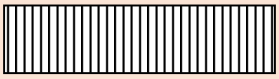
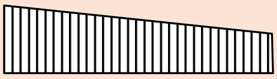
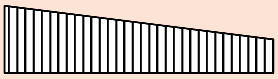
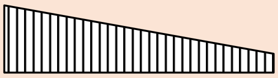
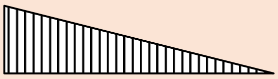
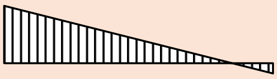
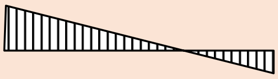
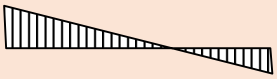
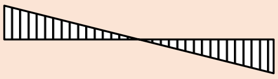
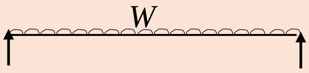
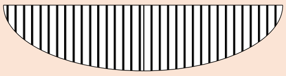
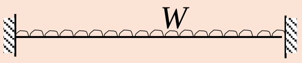
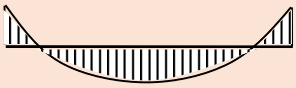
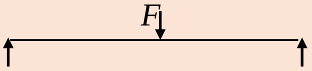
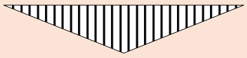
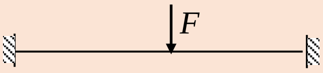
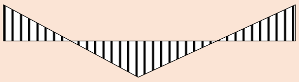
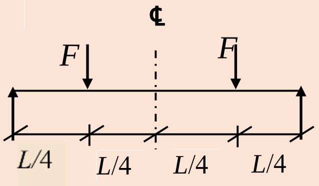
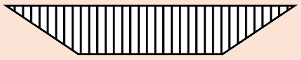
Loading and Support Conditions	Bending Moment Diagram	Value of *K*	Constants		
			c_1	c_2	c_3
(1)	(2)	(3)	(4)	(5)	(6)
	ψ = +1 	1.0 0.7 0.5	1.000 1.000 1.000	---	1.000 1.113 1.144
	ψ= + ¾ 	1.0 0.7 0.5	1.141 1.270 1.305	---	0.998 1.565 2.283
	ψ = + ½ 	1.0 0.7 0.5	1.323 1.473 1.514	---	0.992 1.556 2.271
	ψ = + ¼ 	1.0 0.7 0.5	1.563 1.739 1.788	---	0.977 1.531 2.235
	ψ = 0 	1.0 0.7 0.5	1.879 2.092 2.150	---	0.939 1.473 2.150
	ψ = - ¼ 	1.0 0.7 0.5	2.281 2.538 2.609	---	0.855 1.340 1.957
	ψ = - ½ 	1.0 0.7 0.5	2.704 3.009 3.093	---	0.676 1.059 1.546
	ψ = - ¾ 	1.0 0.7 0.5	2.927 3.009 3.093	---	0.366 0.575 0.837

Table 40 (*Concluded*)

Loading and Support Conditions	Bending Moment Diagram	Value of *K*	Constants		
			c_1	c_2	c_3
(1)	(2)	(3)	(4)	(5)	(6)
	ψ = - 1 	1.0 0.7 0.5	2.752 3.063 3.149	---	0.000 0.000 0.000
		1.0 0.5	1.132 0.972	0.459 0.304	0.525 0.980
		1.0 0.5	1.285 0.712	1.562 0.652	0.753 1.070
		1.0 0.5	1.365 1.070	0.553 0.432	1.730 3.050
		1.0 0.5	1.565 0.938	1.267 0.715	2.640 4.800
		1.0 0.5	1.046 1.010	0.430 0.410	1.120 1.890

ANNEX F

(*Clauses* 11.2.1.2, 15.6.4.2, 17.6.1, 18.10.4.1 *and* 18.11.2.1)

CONNECTIONS

F-1 GENERAL

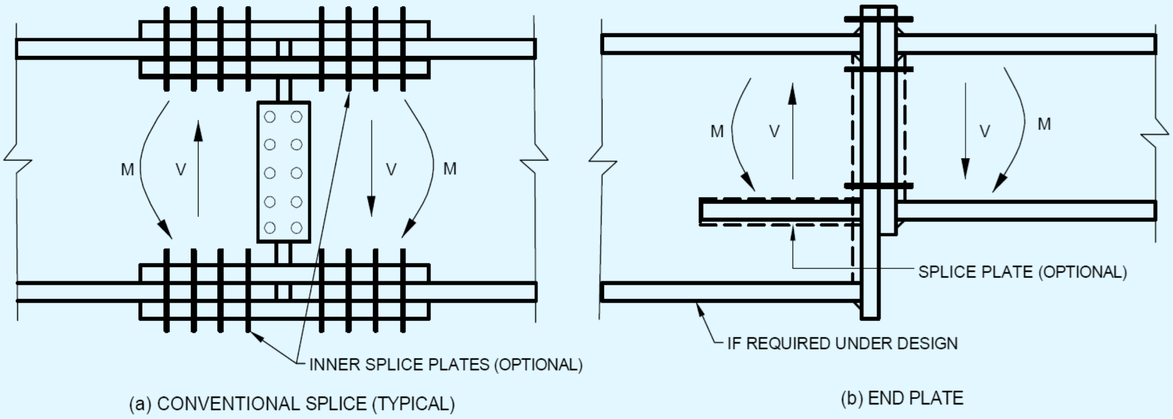
The requirement for the design of splice and beam to column connection as well as recommendation for their design shall be as given below.

F-2 BEAM SPLICES

F-2.1 For rolled section beam splices located away from the point of maximum moment, it may be assumed that the flange splice carries all the moment and the web splice carries the shear (*see* Fig. 30). However, in the case of a deep girder, the total moment may be divided between the flange and the web in accordance with the stress distribution. The web connection should then be designed to resist its share of moment and shear. Even web splice is designed to carry only shear force, the moment about the centroid of the bolt group on either side of the splice should be designed for moment due to eccentricity.

F-2.2 Flange joints should preferably not be located at points of maximum stress. Where splice plates are used, their area shall not be less than 5 percent in excess of the area of the flange element spliced; and their centre of gravity shall coincide, as nearly as possible with that of the element spliced. There shall be enough fasteners on each side of the splice to develop the load in the element spliced plus 5 percent but in no case should the strength developed be less than 50 percent of the effective strength of the material spliced. Wherever possible in welded construction, flange plates shall be joined by complete penetration butt welds. These butt welds shall develop the full strength of the plates. Whenever the flange width or thickness changes at the splice location, gradual transition shall be made in the width/thickness of the larger flange.

F-2.3 When beam splice is located at the point of inflection of a continuous beam, the flange splicing requirement given above may be relaxed appropriately.



(a) CONVENTIONAL SPLICE (TYPICAL)

(b) END PLATE

FIG. 30 BEAM SPLICES

F-3 COLUMN SPLICE

F-3.1 Where the ends of compression members are faced for bearing over the whole area, they shall be spliced to hold the connected parts aligned. The ends of compression members faced for bearing shall invariably be machined to ensure perfect contact of surfaces in bearing (*see* Fig. 31).

F-3.2 Where such members are not faced for complete bearing the splices shall be designed to transmit all the forces to which the members is subjected at the splice location.

F-3.3 Wherever possible, splices shall be proportioned and arranged so that centroidal axis of the splice coincides as nearly as possible with the centroidal axes of the members joined, in order to avoid eccentricity; but where eccentricity is present in the joint, the resulting stress considering eccentricity shall be provided for.

F-3.4 If a column flange is subjected to significant tension or if the faces are not prepared for bearing, or if full continuity is required without slip, only HSFG bolts shall be used.

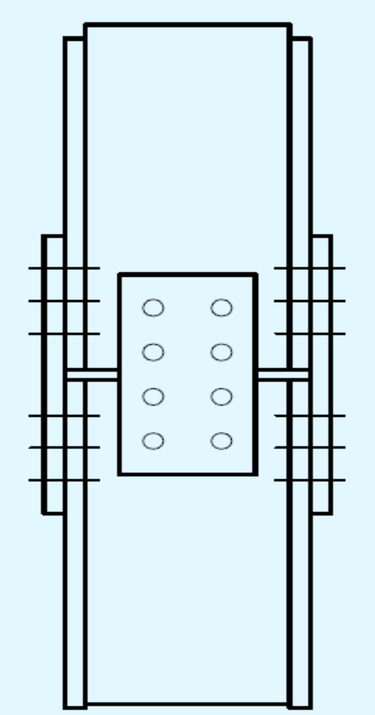


FIG. 31 COLUMN SPLICE
(TYPICAL)

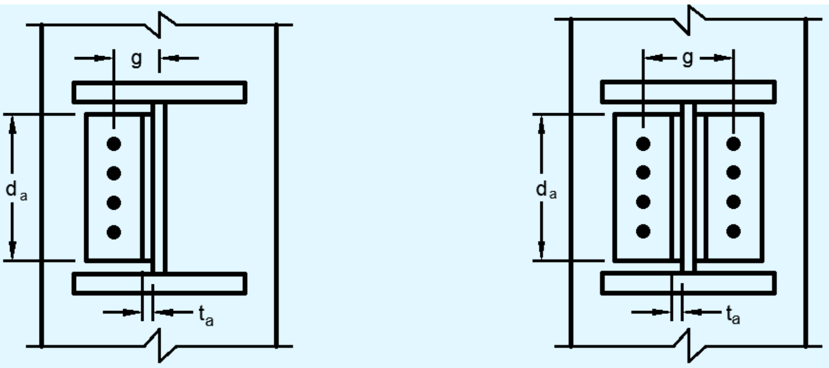
F-4 BEAM-TO-COLUMN CONNECTIONS

F-4.1 Simple Connections

Simple connections are assumed to transfer only shear at some nominal eccentricity and typically used in frames up to about five stories in height, where strength rather than stiffness govern the design. In such frames separate lateral load resisting system is to be provided in the form of bracings or shear walls. The connections shown in Fig. 32 (A), Fig. 32 (B), Fig. 32 (C) and Fig. 32 (D) can be assumed as simple connections in framed analysis and need to be checked only for the transfer of shear from beam to column.

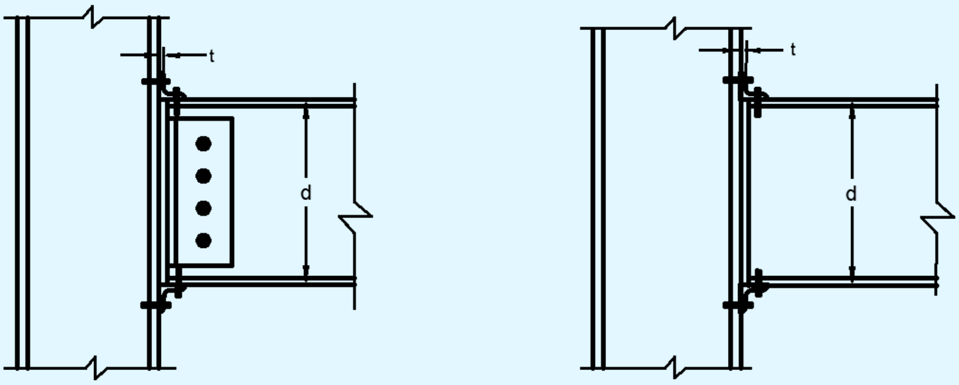
F-4.2 Rigid Connections

In high-rise and slender structures, stiffness requirements may warrant the use of rigid connections. Rigid connections transfer significant moments to the columns and are assumed to undergo negligible deformations at the joint. These are necessary in sway frames for stability and also contribute in resisting lateral loads. The connections shown in Fig. 32 (E), Fig. 32 (F), Fig. 32 (G) can be assumed as rigid connection in frame analysis and need to be checked for both shear and moment transfer from beam to the column. Fully welded connections can also be considered as rigid beam to column connections.



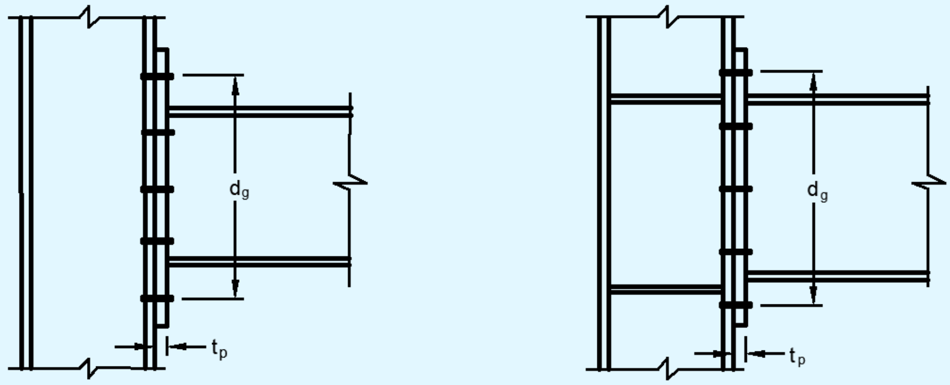
32 A SINGLE WEB ANGLE

32 B DOUBLE WEB ANGLE



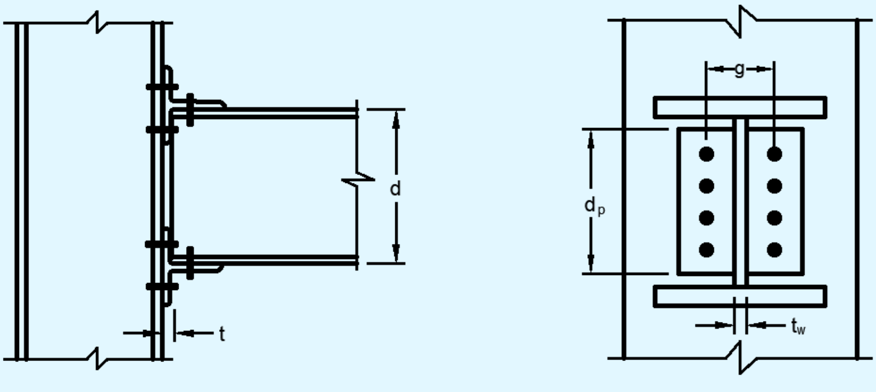
32 C TOP AND SEAT ANGLE WITH DOUBLE WEB ANGLE

32 D TOP AND SEAT ANGLE WITHOUT DOUBLE WEB ANGLE



32 E END PLATE WITHOUT COLUMN STIFFENERS

32 F END PLATE WITH COLUMN STIFFENERS



32 G T-STUB

32 H HEADER PLATE

FIG. 32 SIZE PARAMETER FOR VARIOUS TYPES OF CONNECTION

F-4.3 Semi-Rigid Connections

Semi-rigid connections fall between the two types mentioned above. The fact is that simple connections do have some degree of rotational rigidity as in the semi-rigid connections. Similarly, rigid connections do experience some degree of joint deformation and this can be utilized to reduce the joint design moments.

The moment-rotation relationship of the connections have to be determined based on experiments conducted for the specific design or based on the relationship derived from tests, presented in specialist literature. The simplest method of analysis will be to idealize the connection as an equivalent rotational spring with either a bilinear or non-linear moment-rotation characteristics. The classification proposed by Bjorhovde combined with the Frye-Morris model can be used with convenience to model semi-rigid connections, as given in the next section.

F-4.3.1 *Connection Classification*

Connections are classified according to their ultimate strength or in terms of their initial elastic stiffness and Bjorhovde's classification. It is based on the non-dimensional moment parameter ($m^1 = M_u / M_{pb}$) and the non-dimensional rotation parameter ($\theta^1 = \theta_r/\theta_p$), where θ_p is the plastic rotation. The Bjorhovde's classification is based on a reference length of the beam equal to 5 times the depth of the beam. The limits used for connection classification are shown in Table 41 and are graphically represented in Fig. 33.

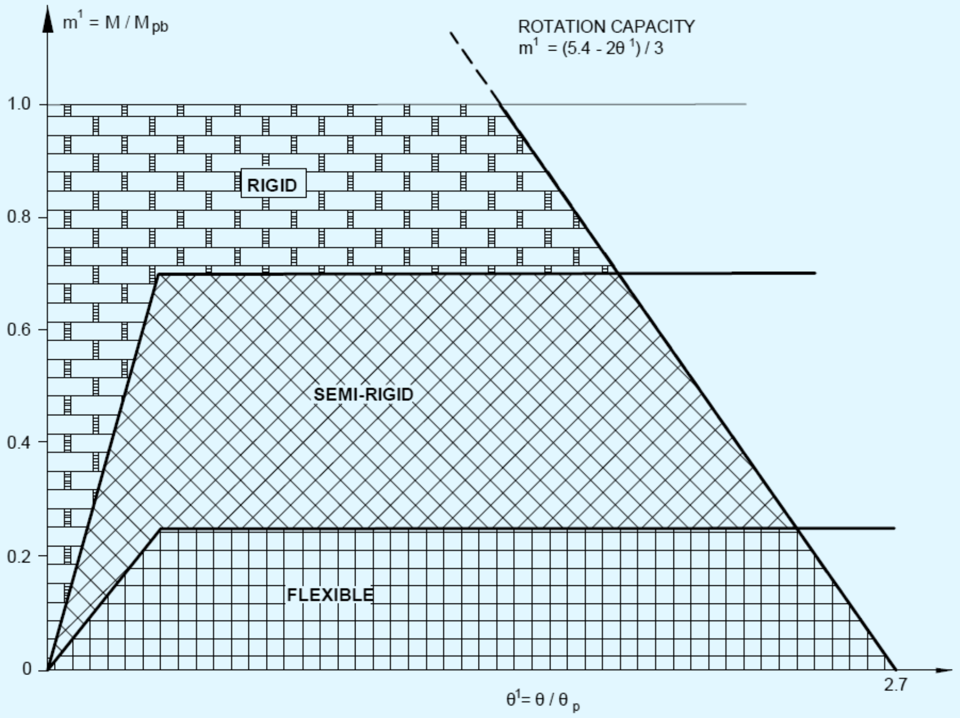


FIG. 33 CLASSIFICATION OF CONNECTIONS ACCORDING TO BJORHOVDE

F-4.3.2 *Connection Models*

Frye-Morris has derived the following polynomial model for the moment curvature relationship of semi-rigid connections:

$$\theta_r = C_1(KM)^1 + C_2\,(KM)^3 + C_3\,(KM)^5$$

where

M = moment at the joint, in kN.m;

K = standardization parameter which depend on the connection type and geometry; and

C_1, C_2, C_3 = curve fitting constants Table 42 shows the curve fitting constants and standardization constants for Frye-Morris Model [All size parameters in the table are in mm, (*see* Fig. 32)].

Table 41 Connection Classification Limits

(*Clause* F-4.3.1)

Sl No. (1)	Nature of the Connection (2)	In Terms of Strength (3)	In Terms of Stiffness (4)
i)	Rigid connection	$m^1 \geq 0.7$	$m^1 \geq 2.5\theta^1$
ii)	Semi-rigid connection	$0.7 > m^1 > 0.2$	$2.5\theta^1 > m^1 > 0.5\theta^1$
iii)	Flexible connection	$m^1 \leq 0.2$	$m^1 \leq 0.5\theta^1$

Table 42 Connection Constants in Frye-Morris Model

(*Clause* F-4.3.2)

Sl No. (1)	Type (2)	Connection Type (3)	Curve-Fitting Constants (4)	Standardization Constants (5)
i)	A	Single web angle connection	$C_1 = 1.91 \times 10^4$ $C_2 = 1.30 \times 10^{11}$ $C_3 = 2.70 \times 10^{17}$	$K = d_a^{-2.4} t_c^{-1.81} g^{0.15}$
ii)	B	Double web angle connection	$C_1 = 1.64 \times 10^3$ $C_2 = 1.03 \times 10^{14}$ $C_3 = 8.18 \times 10^{25}$	$K = d_a^{-2.4} t_c^{-1.81} g^{0.15}$
iii)	C	Top and seat angle connection with double web angle	$C_1 = 2.24 \times 10^{-1}$ $C_2 = 1.86 \times 10^4$ $C_3 = 3.23 \times 10^8$	$K = d^{-1.287} t_a^{-1.128} t_c^{-0.415}$ $l_a^{-0.694} (g - 0.5 d_b)^{1.35}$
iv)	D	Top and seat angle connection without double web angle	$C_1 = 1.63 \times 10^3$ $C_2 = 7.25 \times 10^{14}$ $C_3 = 3.31 \times 10^{23}$	$K = d^{-1.5} t_a^{-0.5} l_a^{-0.7} d_b^{-1.1}$
v)	E	End plate connection without column stiffeners	$C_1 = 1.78 \times 10^4$ $C_2 = -9.55 \times 10^{16}$ $C_3 = 5.54 \times 10^{29}$	$K = d_g^{-2.4} t_p^{-0.4} t_f^{-1.5}$
vi)	F	End plate connection with column stiffeners	$C_1 = 2.60 \times 10^2$ $C_2 = 5.37 \times 10^{11}$ $C_3 = 1.31 \times 10^{22}$	$K = d_g^{-2.4} t_p^{-0.6}$
vii)	G	T-stub connection	$C_1 = 4.05 \times 10^2$ $C_2 = 4.45 \times 10^{13}$ $C_3 = -2.03 \times 10^{23}$	$K = d^{-1.5} t_f^{-0.5} l_t^{-0.7} d_b^{-1.1}$

Table 42 (*Concluded*)

Sl No. (1)	Type (2)	Connection Type (3)	Curve-Fitting Constants (4)	Standardization Constants (5)
viii)	H	Header-plate connection	$C_1 = 3.87$ $C_2 = 2.71 \times 10^5$ $C_3 = 6.06 \times 10^{11}$	$K = t_p^{-1.6} g^{1.6} d_b^{-2.3} t_w^{-0.5}$

where

d = depth, in mm, of beam;

d_a = depth, in mm, of the angle;

d_b = diameter, in mm, of the bolt;

d_g = centre, in mm, to centre of the outermost bolt of the end plate connection;

g = gauge, in mm, distance of bolt line;

t_a = thickness, in mm, of the top angle;

t_c = thickness, in mm, of the web angle;

t_f = thickness, in mm, of flange T-stub connector;

t_w = thickness, in mm, of web of the beam in the connection;

t_p = thickness, in mm, of end plate, header plate;

l_a = length, in mm, of the angle; and

l_t = length, in mm of the T-stub connector.

NOTE — For preliminary analysis using a bilinear moment curvature relationship, the stiffness given in Table 43 may be assumed depending on the type of connection. The values are based on the secant stiffness at a rotation of 0.01 radian and typical dimension of connecting angle and other components as given in the table.

Table 43 Secant Stiffness

(*Table 42*)

SI No. (1)	Type of Connection (2)	Dimension mm (3)	Secant Stiffness kNm/Radian (4)
i)	Single web connection angle	$d_a = 250$, $t_a = 10$, $g = 35$	1 150
ii)	Double web-angle connection	$d_a = 250$, $t_a = 10$, $g = 77.5$	4 450
iii)	Top and seat angle connection without double web angle connection	d_a=300, t_a=10, l_a=140, d_b=20	2 730
iv)	Header plate	$d_p = 175$, $t_p = 10$, $g = 75$, $t_w = 7.5$	2 300

F-5 COLUMN BASES

F-5.1 Base Plates

Columns shall be provided with base plates capable of distributing the compressive forces in the compressed parts of the column over a bearing area such that the bearing pressure on the foundation does not exceed the design strength of the point. The design strength of the joint between the base plate and the foundation shall be determined taking account of the material properties and dimensions of both the grout and the concrete foundation.

F-5.2 Holding Down Bolts (Anchor Bolts)

F-5.2.1 Holding down bolts shall be provided if necessary to resist the effects of the design loads. They shall be designed to resist tension due to uplift forces and tension due to bending moments as appropriate.

F-5.2.2 When calculating the tension forces due to bending moments, the lever arm shall not be taken as more than the distance between the centroid of the bearing area on the compression side and the centroid of the bolt group on the tension side, taking the tolerances on the positions of the holding down bolts into account.

F-5.2.3 Holding down bolts shall either be anchored into the foundation by a hook or by a washer plate or by some other appropriate load distributing member embedded in the concrete.

F-5.2.4 If no special elements for resisting the shear force are provided, such as block or bar shear connectors, it shall be demonstrated that sufficient resistance to transfer the shear force between the column and the foundation is provided by one of the following:

a) Frictional resistance of the joint between the base plate and the foundation;

b) Shear resistance of the holding down bolts;

c) Shear resistance of the surrounding part of the foundation; and

d) Shear and bearing resistance of the shear key plates welded to the base plate and embedded in the pedestal/foundation.

ANNEX G

(*Foreword*)

PLATE GIRDERS WITH CORRUGATED WEB

G-1 FLEXURAL RESISTANCE

The overhang of the flange beyond the farthest face of the web at any section may be limited to that required by class 1, 2 and 3 sections, as given in Table 2. Contribution of web in flexural resistance is disregarded as given below.

The flexural design resistance is given by

$$M_d = Min\left\{\frac{b_c t_c f_{fc}}{\gamma_{m0}}\left(h_w + \frac{t_t + t_c}{2}\right); \frac{b_t t_t f_{ft}}{\gamma_{m0}}\left(h_w + \frac{t_t + t_c}{2}\right)\right\}$$

where

The dimensional symbols are shown in Fig. 34.

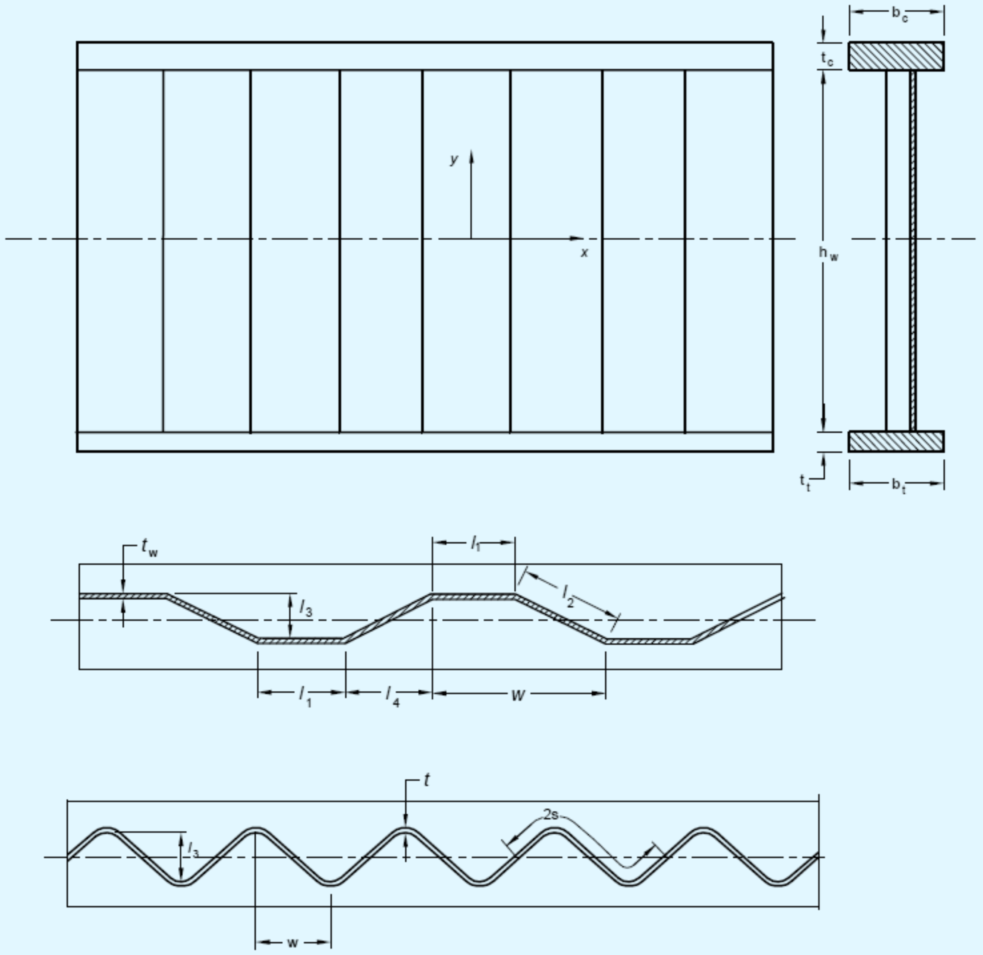


FIG. 34 ELEMENT DIMENSIONS OF PLATE GIRDER WITH CORRUGATED WEB

The design compressive stress, f_{fc}, is the minimum of yielding compressive stress after accounting for transverse (in-plane) bending of compression flange due to eccentric shear flow in the flange due to corrugated web as given below, or by lateral buckling of compression flange as given in **15.2.2**.

The yield strength after accounting for eccentric shear flow in the flanges is given by

$$f_{fc} = f_{yc}\sqrt{1 - \frac{4 M_{vc}\gamma_{m0}}{b_c^2 t_c f_{yc}}}\ ; \qquad f_{ft} = f_{yt}\sqrt{1 - \frac{M_{vt}\gamma_{m0}}{M_{Pf}}}$$

where

f_{yc}, f_{yt} = Yield strength of the material in the tension and compression flanges respectively

M_{Pf} = Ultimate design resistance of the flange under in in-plane bending

= $t\, b^3\, f_{yf}/4$ for plastic and compact flanges, $t\, b^3\, f_{yf}/6$ for semi compact flanges

M_{vc}, M_{vt} = in-plane transverse bending moment in the tension and compression flange, respectively due to eccentric shear force from the web as shown in Fig. 35, and is evaluated from

$$M_{vc} = \frac{V\, y_c b_c\, t_c\, l_1 l_3}{2I_z}; \qquad M_{vt} = \frac{V\, y_t b_t\, t_t\, l_1 l_3}{2I_z}$$

where

V = Shear force at the section of the girder;

I_z = Moment of inertia about the major axis of the section disregarding the corrugated web; and

y_c, y_t = Distance of the centroid of the compression and tension flange, respectively, from the neutral axis of the girder.

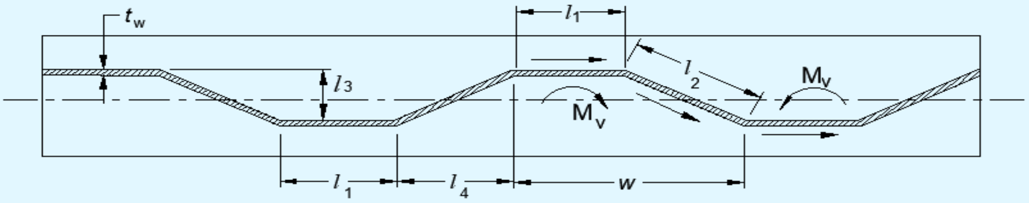


FIG. 35 IN-PLANE TRANSVERSE BENDING MOMENT IN FLANGES DUE TO ECCENTRIC SHEAR FLOW FROM WEB

G-2 SHEAR RESISTANCE

The design shear resistance of the web, V_d, is given by

$$V_d = V_n/\gamma_{m0}$$

where

$$V_n = h_w\, t_w\, \chi_v\, f_{yw}/\sqrt{3}$$

where

h_w, t_w, f_{yw} = depth, thickness and yield strength of the web;

χ_v = shear stress reduction factor to account for web buckling, and is the smallest of local buckling χ_{vl}, global buckling, χ_{vg}, or interaction buckling, χ_{vlg}, of the web under shear, evaluated as given below; and

χ_v = min (χ_{vl}, χ_{vg}, χ_{vlg}).

The shear stress reduction factor for local buckling of the web is evaluated as,

$\chi_{vl} = 1.0$ when $\lambda_{wl} \leq 0.8$,
$\chi_{vl} = [1 - 0.8(\lambda_{wl} - 0.8)]$ when $0.8 < \lambda_{wl} < 1.2$,
$\chi_{vl} = \frac{1}{\sqrt{3}\lambda_{wl}^2}$ when $\lambda_{wl} \geq 1.2$,

where

$$\lambda_{wl} = \sqrt{f_{yw}/(\sqrt{3}\tau_{cr,l})}$$

$$\tau_{cr,l} = \frac{k_v \pi^2 E}{12(1-\mu^2)\,(h_w/t_w)^2}$$

$$k_v = 4.0 + 5.35\left(\frac{c}{h_w}\right) \quad \text{when } (c/h_w) < 1.0$$

$$k_v = 5.35 + 4.0\left(\frac{c}{h_w}\right) \quad \text{when } (c/h_w) \geq 1.0$$

where

c is larger of l_1 and l_2 of corrugated web (*see* Fig. 35).

In case of sinusoidally corrugated webs $\tau_{cr,e}$ may be evaluated using:

$$\tau_{cr,l} = \left(5.35 + \frac{l_3\, s}{h_w t_w}\right)\frac{\pi^2 E}{12(1-\mu^2)(s/t_w)^2}$$

The shear stress reduction factor for global buckling of the web is evaluated as:

$$\chi_{vg} = \frac{1.5}{(0.5+\lambda_{wg}^2)} \leq 1.0$$

$$\lambda_{wg} = \sqrt{f_{\mathrm{yw}}/(\sqrt{3}\tau_{\mathrm{cr,g}})}$$

$$\tau_{cr,g} = \frac{32.4}{t_w h_w^2}\sqrt[4]{D_x D_z^3}$$

$$D_x = \frac{Et_w^3}{12(1-\mu^2)}\frac{w}{s} \text{ for sinusoidal corrugation}$$

$$D_x = \frac{Et_w^3}{12(1-\mu^2)}\frac{w}{(l_1+l_2)} \text{ for profiled corrugation}$$

$$D_z = \frac{EI_z}{w}$$

I_z = second moment of area of one corrugation of length w

The shear stress reduction factor for global buckling of the web is evaluated as:

$$\chi_{vlg} = \frac{\chi_{vl} \times \chi_{vg}}{\sqrt{{\chi_{vl}}^2 + {\chi_{vg}}^2}} \leq 1.0$$

The reduction in shear resistance of the web due to the moment at the section need not be considered, since its contribution to flexure is not considered.

G-3 RESISTANCE TO CONCENTRATED LOAD

The design for bearing resistance under concentrated load and reactions may be carried out as required in **15.7**.

ANNEX H

(*Clause* 24.16)

GENERAL RECOMMENDATIONS FOR STEELWORK TENDERS AND CONTRACTS

H-1 GENERAL

H-1.1 The recommendations given in this annex are in line with those generally adopted for steelwork construction and are meant for general information.

H-1.2 These recommendations do not form part of the requirements of the Section and compliance with these is not necessary for the purpose of complying with this Section.

H-1.3 The recommendations are unsuitable for inclusion as a block requirement in a contract, but in drawing up a contract the points mentioned should be given consideration.

H-2 EXCHANGE OF INFORMATION

Before the steelwork design is commenced, the building designer should be satisfied that the planning of the building, its dimensions and other principal factors meet the requirements of the building owner and comply with regulations of all authorities concerned. Collaboration of building designer and steelwork designer should begin at the outset of the project by joint consideration of the planning and of such questions as the stanchion spacing, materials to be used for the construction, and depth of basement.

H-3 INFORMATION REQUIRED BY THE STEELWORK DESIGNER

H-3.1 General

Site plans showing in plan and elevation of the proposed location and main dimensions of the building or structure;

a) Ground levels, existing and proposed;

b) Particulars of buildings or other constructions which may have to remain on the actual site of the new building or structure during the erection of the steelwork;

c) Particulars of adjacent buildings affecting, or affected by, the new work;

d) Stipulation regarding the erection sequence or time schedule;

e) Conditions affecting the position or continuity of members;

f) Limits of length and weight of steel members in transit and erection;

g) Drawings of the substructure, proposed or existing, showing:

    1) levels of stanchion foundations, if already determined;

    2) any details affecting the stanchion bases or anchor bolts;

    3) permissible bearing pressure on the foundation; and

    4) provisions for grouting.

NOTE — In the case of new work, the substructure should be designed in accordance with the relevant standards dealing with foundations and substructure.

h) The maximum wind velocity appropriate to the site (*see* Part C 'Structural Design/Section 1 Loads and Load Effects' of this NBCS); and

j) Environmental factors, such as proximity to sea coast, and corrosive atmosphere. Reference to bye-laws and regulations affecting the steelwork design and construction.

H-3.2 Further Information Relating to Buildings

a) Plans of the floors and roof with principal dimensions, elevations and cross sections showing heights between floor levels;

b) The occupancy of the floors and the positions of any special loads should be given;

c) The building drawings, which should be fully dimensioned, should preferably be to the scale of 1 to 100 and should show all stairs, fire escapes, lifts, etc, suspended ceilings, flues and ducts for heating and ventilating. Doors and windows should be shown, as the openings may be taken into account in the computations of dead load;

    1) Requirements should be given in respect of any maximum depth of beams or minimum head room; and

    2) Large-scale details should be given of any special features affecting the steelwork.

d) The inclusive weight per m^2 of walls, floors, roofs, suspended ceilings, stairs and partitions, or particulars of their construction and finish for the computation of dead load;

    1) The plans should indicate the floors, which are to be designed to carry partitions. Where the layout of partitions is not known, or a given layout is liable to alteration, these facts should be specially noted so that allowance may be made for partitions in any position (*see* Part C 'Structural Design/Section 1 Loads and Load Effects' of this NBCS).

e) The superimposed loads on the floors appropriate to the occupancy, as given in Part C 'Structural Design/Section 1 Loads and Load Effects' of this NBCS or as otherwise required;

f) Details of special loads from cranes, runways, tips, lifts, bunkers, tanks, plant and equipment; and

g) The grade of fire resistance appropriate to the occupancy as may be required.

H-4 INFORMATION REQUIRED BY TENDERER (IF NOT ALSO DESIGNER)

H-4.1 General

All information listed under H-3.1;

a) Climatic conditions at site-seasonal variations of temperature, humidity, wind velocity and direction;

b) Nature of soil. Results of the investigation of sub-soil at site of building or structure;

c) Accessibility of site and details of power supply;

d) Whether the steelwork contractor will be required to survey the site and set out or check the building or structure lines, foundations and levels;

e) Setting-out plan of foundations, stanchions and levels of bases;

f) Cross sections and elevations of the steel structure, as necessary, with large-scale details of special features;

g) Whether the connections are to be bolted, riveted or welded. Particular attention should be drawn to connections of a special nature, such as turned bolts, high strength friction grip bolts, long rivets and overhead welds;

h) Quality of steel, and provisions for identification;

j) Requirements in respect of protective paintings at works and on site, galvanizing or cement wash;

k) Approximate dates for commencement and completion of erection;

m) Details of any tests which have to be made during the course of erection or upon completion; and

n) Schedule of quantities. Where the tenderer is required to take off quantities, a list should be given of the principal items to be included in the schedule.

H-4.2 Additional Information Relating to Buildings

a) Schedule of stanchions giving sizes, lengths and typical details of brackets, joints, etc;

b) Plan of grillages showing sizes, lengths and levels of grillage beams and particulars of any stiffeners required;

c) Plans of floor beams showing sizes, lengths and levels eccentricities and end moments. The beam reactions and details of the type of connection required should be shown on the plans;

d) Plan of roof steelwork. For a flat roof, the plan should give particulars similar to those of a floor plan. Where the roof is pitched, details should be given of trusses, portals, purlins, bracing, etc;

e) The steelwork drawings should preferably be to a scale of 1 to 100 and should give identification marks against all members; and

f) Particulars of holes required for services, pipes, machinery fixings, etc Such holes should preferably be drilled at works.

H-4.3 Information Relating to Execution of Building Work

a) Supply of materials;

b) Weight of steelwork for payment;

c) Wastage of steel;

d) Insurance, freight and transport from shop to site;

e) Site facilities for erection;

f) Tools and plants;

g) Mode and terms of payment;

h) Schedules;

j) Force majeure (sections and provisions for liquidation and damages for delay in completion); and

k) Escalation sections.

H-5 DETAILING

In addition to the number of copies of the approved drawings or details required under the contract, dimensioned shop drawings or details should be submitted in duplicate to the engineer who should retain one copy and return the other to the steel supplier or fabricators with his comments, if any.

H-6 TIME SCHEDULE

As the dates on which subsequent trades can commence, depend on the progress of erection of the steel framing, the time schedule for the latter should be carefully drawn up and agreed to by the parties concerned at a joint meeting.

H-7 PROCEDURE ON SITE

The steelwork contractor should be responsible for the positioning and levelling of all steelwork. Any checking or approval of the setting out by the general contractor or the engineer should not relieve the steelwork contractor of his responsibilities in this respect.

H-8 INSPECTION

References may be made to the good practice [C-6A(44)] for general guidance.

H-8.1 Access to Contractor’s Works

The contractor should offer facilities for the inspection of the work at all stages.

H-8.2 Inspection of Fabrication

Unless otherwise, agreed, the inspection should be carried out at the place of fabrication. The contractor should be responsible for the accuracy of the work and for any error, which may be subsequently discovered.

H-8.3 Inspection on Site

To facilitate inspection, the contractor should during all working hours, have a foreman or properly accredited charge hand available on the site, together with a complete set of contract drawings and any further drawings and instructions which may have been issued from time to time.

H-9 MAINTENANCE

H-9.1 General

Where steelwork is to be encased in solid concrete, brickwork or masonry, the question of maintenance should not arise, but where steelwork is to be housed in hollow fire protection or is to be unprotected, particularly where the steelwork is exposed to a corroding agent, the question of painting or protective treatment of the steelwork should be given careful consideration at the construction stage, having regard to the special circumstances of the case.

H-9.2 Connections

Where connections are exposed to a corroding agent, they should be periodically inspected, and any corroded part should be thoroughly cleaned and painted.

Where bolted connections are not solidly encased and are subject to vibratory effects of machinery or plant, they should be periodically inspected and all bolts tightened.

LIST OF STANDARDS

The following list records those standards which are acceptable as 'good practice' and 'accepted standards' in the fulfilment of the requirements of this NBCS. The latest version of a standard shall be adopted at the time of enforcement of this NBCS. The standards listed may be used by the Authority as a guide in conformance with the requirements of the referred clauses in this NBCS.

In the following list, the number appearing in the first column within parentheses indicates the number of the reference in this Subsection of this NBCS.

Sl No.	*IS No.*	*Title*
(1)	IS 786 : 1967	Conversion factors and conversion tables (*first revision*)
(2)	IS 808 : 2021	Hot rolled steel beam, column, channel and angle sections — Dimensions and properties (*fourth revision*)
	IS 1852 : 1985	Specification for rolling and cutting tolerance for hot rolled steel products (*fourth revision)*
	IS 12779 : 1989	Rolling and cutting tolerances for hot rolled parallel flange beam and column sections — Specification
(3)	IS 8000	Geometrical product specifications (GPS) — Geometrical tolerancing
	(Part 1) : 2019	Tolerances of form, orientation, location and run-out (*second revision*)
	(Part 2) : 2024	Maximum material requirement (MMR), least material requirement (LMR) and reciprocity requirement (RPR) (*third revision*)
	(Part 3) : 2023	Profile tolerancing (*third revision*)
	(Part 4) : 1976	Practical examples of indications on drawings
	IS 8976 : 1978	Guide for preparation and arrangement of sets of drawings and parts list
	IS 962 : 1989	Code of practice for architectural and building drawings (*second revision*)
(4)	IS 962 : 1989	Code of practice for architectural and building drawings (*second revision*)
(5)	IS 813 (Part 1) : 2018/ ISO 2553 : 2013	Welding and allied processes: Part 1 Symbolic representation on drawings — Welded Joints (*second revision*)
(6)	IS 2062 (Part 1) : 2025	Structural steel: Part 1 Hot rolled medium and high tensile steel *(eighth revision*)
(7)	IS 1608	Metallic materials — Tensile testing:
	(Part 1) : 2022/ ISO 6892-1 : 2019	Method of test at room temperature *(fifth revision)*
	(Part 2) : 2020/ ISO 6892-2 : 2018	Method of test at elevated temperature (*fourth revision*)
(8)	IS 1161 : 2014	Steel tubes for structural purposes — Specification (*fifth revision*)
(9)	IS 814 : 2004	Covered electrodes for manual metal arc welding of carbon and carbon manganese steel — Specification (*sixth revision*)
(10)	IS 1395 : 1982	Specification for low and medium alloy steel covered electrodes for manual metal arc welding (*third revision*)
(11)	IS 7557 : 1982	Specification for steel wire (up to 20 mm) for the manufacture of cold-forged rivets (*first revision*)
(12)	IS 1148 : 2009	Steel rivet bars (medium and high tensile) for structural purposes (*fourth revision*)
(13)	IS 1929 : 1982	Specification for hot forged steel rivets for hot closing (12 mm to 36 mm diameter) (*first revision*)

Sl No.	*IS No.*	*Title*
	IS 2155 : 1982	Specification for cold forged solid steel rivets for hot closing (6 mm to 16mm diameter) (*first revision*)
(14)	IS 1363	Hexagon head bolts, screws and nuts of product grade C:
	(Part 1) : 2023/ ISO 4016 : 2022	Hexagon head bolts (size range M5 to M64) (*sixth revision*)
	(Part 2) : 2023/ ISO 4018 : 2022	Hexagon head screws (size range M5 to M64) (*sixth revision*)
	(Part 3) : 2018/ ISO 4034 : 2012	Hexagon nuts, Style 1 (size range M5 to M64) (*fifth revision*)
	IS 1364	Hexagon head bolts, screws and nuts of product grades A and B:
	(Part 1) : 2023/ ISO 4014 : 2022	Hexagon head bolts (size range M1.6 to M64) (*sixth revision*)
	(Part 2) : 2023/ ISO 4017 : 2022	Hexagon head screws (size range M1.6 to M64) (*sixth revision*)
	(Part 3) : 2018/ ISO 4032 : 2012	Hexagon nuts, Style 1 (size range M1.6 to M64) (*fifth revision*)
	(Part 4) : 2025/ ISO 4035 : 2023	Hexagon nuts , Style 0 (size range M1.6 to M64) (*fifth revision*)
	(Part 5) : 2002/ ISO 4036 : 1999	Hexagon thin nuts — Product grade B (unchamfered) (size range M1.6 to M10) (*fourth revision*)
	IS 1367	Technical supply conditions for threaded steel fasteners:
	(Part 1) : 2014/ ISO 8992 : 2005	General requirements for bolts, screws, studs and nuts (*fourth revision*)
	(Part 2) : 2002/ ISO 4759-1 : 2000	Tolerance for fasteners — Bolts, screws, studs and nuts — Product grades A, B and C (*third revision*)
	(Part 3) : 2017/ ISO 898-1 : 2013	Mechanical properties of fasteners made of carbon steel and bolts, screws and studs (*fifth revision*)
	(Part 5) : 2018/ ISO 898-5 : 2012	Mechanical properties of fasteners made of carbon steel and alloy steel — Set screws and similar threaded fasteners with specified hardness classes — Coarse thread and fine patch thread (*fourth* revision)
	(Part 6) : 2025/ ISO 898-2 : 2022	Mechanical properties of fasteners made of carbon steel and alloy steel — Nuts with specified property classes (*fifth revision*)
	(Part 7) : 1980	Mechanical properties and test methods for nuts without specified proof loads (*second revision*)
	(Part 8) : 20020/ ISO 2320 : 2015	Prevailing torque type steel nuts — functional properties (*fifth revision*)
	(Part 9)	Surface discontinuities:
	Sec 1 : 1993/ ISO 6157-1 : 1988	Bolts, screws and studs for general application (*third revision)*
	Sec 2 : 1993/ ISO 6167-3 : 1988	Bolts, screws and studs for special applications (*third revision*)

Sl No.	*IS No.*	*Title*
	(Part 10) : 2002/ ISO 6157-2 : 1995	Surface discontinuities — Nuts (*third revision*)
	(Part 11) : 2024/ ISO 4042 : 2022	Electroplated coating systems (*fifth revision*)
	(Part 12) : 1981	Phosphate coatings on threaded fasteners (*second revision*)
	(Part 13) : 2020/ ISO 10684 : 2004	Hot dip galvanized coatings on threaded fasteners (*third revision*)
	(Part 14)	Mechanical properties of corrosion-resistant stainless-steel fasteners:
	Sec 1 : 2023/ ISO 3506-1 : 2020	Bolts, screws and studs with specified grades and property classes (*fifth revision*)
	Sec 2 : 2023/ ISO 3506-2 : 2020	Nuts with specified grades and property classes (*fifth revision*)
	Sec 3 : 2018/ ISO 3506-3 : 2009	Set screws and similar fasteners not under tensile stress (*fourth revision*)
	(Part 16) : 2002/ ISO 8991 : 1986	Designation system for fasteners (*third revision*)
	(Part 17) : 2023/ ISO 3269 : 2019	Inspection, sampling and acceptance procedure (*fifth revision*)
	(Part 18) : 1996	Packaging (*third revision*)
	(Part 19) : 1997/ ISO 3800 : 1993	Axial load fatigue testing of bolts, screws and studs
	(Part 20) : 1996/ ISO 898-7 : 1992	Torsional test and minimum torques for bolts and screws with nominal diameters 1 mm to 10 mm
	IS 3640 : 1982	Specification for hexagon fit bolts (*first revision*)
	IS 3757 : 1985	Specification for high strength structural bolts (*second revision*)
	IS 5370 : 1969	Specification for plain washers with outside diameter ≈ 3 × inside diameter
	IS 5372 : 1975	Taper washer for channels (ISMC) (*first revision*)
	IS 5374 : 1975	Taper washers for I-beams (ISMB) (*first revision*)
	IS 5624 : 2021	Foundation bolts - Specification (*second revision*)
	IS 6610 : 1972	Specification for heavy washers for steel structures
	IS 6623 : 2004	High strength structural nuts — Specification (*second revision*)
	IS 6639 : 1972	Specification for hexagon bolts for steel structures
	IS 6649 : 1985	Specification for hardened and tempered washers for high strength structural bolts and nuts (*first revision*)
(15)	IS 4000 : 1992	High strength bolts in steel structures — Code of practice (*first revision*)
(16)	IS 1030 : 1998	Carbon steel castings for general engineering purposes (*fifth revision*)
(17)	IS 2708 : 1993	1.5 percent manganese steel castings for general engineering purpose (*third revision*)
(18)	IS 1278 : 1972	Specification for filler rods for gas welding (*second revision*)

Sl No.	*IS No.*	*Title*
(19)	IS 1387 : 1993	General requirements for the supply of metallurgical materials (*second revision*)
(20)	IS 15977 : 2013	Classification and acceptance test for bare solid wire electrodes and wire flux combination for submerged arc welding of structural steel — Specification
(21)	IS 6419 : 1996	Welding rods and bare electrodes for gas shielded arc welding of structural steels — Specification (*first revision*)
	IS 6560 : 2017/ ISO 21952 : 2012	Welding consumables — wire electrodes, wires, rods and deposits for gas shielded arc welding of creep resisting steels — Classification (*second revision*)
(22)	IS 513	Cold reduced carbon steel sheet and strip:
	(Part 1) : 2016	Cold forming and drawing purpose (*sixth revision*)
	(Part 2) : 2016	High tensile and multi-phase steel (*sixth revision*)
(23)	IS 1079 : 2017	Hot rolled carbon steel sheet, plate and strip - Specification (*seventh revision*)
(24)	IS 1367 (Part 3) : 2017/ISO 898-1 : 2013	Technical supply conditions for threaded steel fasteners: Part 3 Mechanical properties of fasteners made of carbon steel and bolts, screws and studs (*fifth revision*)
(25)	IS 1875 : 1992	Carbon steel billets, blooms, slabs and bars for forgings — Specification (*fifth revision*)
(26)	IS 1990 : 2009	Steel rivet and stay bars for boilers (*second revision*)
(27)	IS 2002 : 2024	Steel plates for pressure vessels for intermediate and high temperature service including boilers — Specification (*fourth revision*)
(28)	IS 3039 : 2024	Structural steel for ship construction — Specification (*third revision*)
(29)	IS 6240 : 2008	Hot rolled steel plate (up to 6 mm) sheet and strip for the manufacture of low pressure liquefiable gas cylinders (*fourth revision*)
(30)	IS 9295 : 2024	Steel tubes for idlers for belt conveyors — Specification (*second revision*)
(31)	IS 10748 : 2004	Hot rolled steel strip for welded tubes and pipes — Specification (*second revision*)
(32)	IS 11587 : 1986	Specification for structural weather resistant steels
(33)	IS 15103 : 2002	Fire resistant steel — Specification
(34)	IS 15962 : 2012	Structural steels for building and structures with improved seismic resistance
(35)	IS 801: 1975	Code of practice for use of cold-formed light gauge steel structural members in general building construction (*first revision*)
(36)	IS 808 : 2021	Hot-rolled steel beam, column, channel and angle sections — Dimensions and Properties (*fourth revision*)
(37)	IS 4326 : 2013	Earthquake resistance design and construction of buildings — Code of practice (*third revision*)
(38)	IS 1946 : Part 2 : 2025	Fixing Devices in Walls, Ceilings and Floors of Solid Construction: Part 2 Design of post-installed anchorage to concrete — Code of practice
(39)	IS 3757 : 1985	Specification for high strength structural bolts (*second revision*)
(40)	IS 1367	Technical supply conditions for threaded steel fasteners:
	(Part 1) : 2014/ ISO 8992 : 2005	General requirements for bolts, screws, studs and nuts (*fourth revision*)

Sl No.	*IS No.*	*Title*
	(Part 2) : 2002/ ISO 4759-1 : 2000	Tolerance for fasteners — Bolts, screws, studs and nuts – Product grades A, B and C (*third revision*)
	(Part 3) : 2017/ ISO 898-1 : 2013	Mechanical properties of fasteners made of carbon steel and bolts, screws and studs (*fifth revision*)
	(Part 5) : 2018/ ISO 898-5 : 2012	Mechanical properties of fasteners made of carbon steel and alloy steel — Set screws and similar threaded fasteners with specified hardness classes — Coarse thread and fine patch thread (*fourth* revision)
	(Part 6) : 2025/ ISO 898-2 : 2022	Mechanical properties of fasteners made of carbon steel and alloy steel — Nuts with specified property classes (*fifth revision*)
	(Part 7) : 1980	Mechanical properties and test methods for nuts without specified proof loads (*second revision*)
	(Part 8) : 20020/ ISO 2320 : 2015	Prevailing torque type steel nuts — Functional properties (*fifth revision*)
	(Part 9)	Surface discontinuities
	Sec 1 : 1993/ ISO 6157-1: 1988	Bolts, screws and studs for general application (*third revision*)
	Sec 2 : 1993/ ISO 6167-3 : 1988	Bolts, screws and studs for special applications (*third revision*)
	(Part 10) : 2002/ ISO 6157-2 : 1985	Surface discontinuities — Nuts (*third revision*)
	(Part 11) : 2024/ ISO 4042 : 2022	Electroplated coating systems (*fifth revision*)
	(Part 12) : 1981	Phosphate coatings on threaded fasteners (*second revision*)
	(Part 13) : 2020/ ISO 10684 : 2004	Hot dip galvanized coatings on threaded fasteners (*third revision*)
	(Part 14)	Mechanical properties of corrosion-resistant stainless-steel fasteners
	Sec 1 : 2023/ ISO 3506-1 : 2020	Bolts, screws and studs with specified grades and property classes (*fifth revision*)
	Sec 2 : 2023/ ISO 3506-2 : 2020	Nuts with specified grades and property classes (*fifth revision*)
	Sec 3 : 2018/ ISO 3506-3 : 2009	Set screws and similar fasteners not under tensile stress (*fourth revision*)
	(Part 16) : 2002/ ISO 8991 : 1986	Designation system for fasteners (*third revision*)
	(Part 17) : 2023/ ISO 3269 : 2019	Inspection, sampling and acceptance procedure (*fifth revision*)
	(Part 18) : 1996	Packaging (*third revision*)
	(Part 19) : 1997/ ISO 3800 : 1993	Axial load fatigue testing of bolts, screws and studs

Sl No.	*IS No.*	*Title*
	(Part 20) : 1996/ ISO 898-7 : 1992	Torsional test and minimum torques for bolts and screws with nominal diameters 1 mm to 10 mm
(41)	IS 816 : 1969	Code of practice for use of metal arc welding for general construction in mild steel (*first revision*)
	IS 9595:1996	Metal arc welding of carbon and carbon manganese steels — Recommendations (*first revision*)
(42)	IS 18168 : 2023	Earthquake resistant design and detailing of steel buildings — Code of practice
(43)	IS 9077 : 1979	Code of practice for corrosion protection of steel reinforcement in RB and RCC construction
	IS 9172 : 1979	Recommended design practice for corrosion prevention of steel structures
(44)	IS 7215 : 1974	Tolerances for fabrication of steel structures
(45)	IS 12843 : 1989	Tolerances for erection of steel structures
(46)	IS 9595 : 1996	Metal arc welding of carbon and carbon manganese steels-Recommendations (*first revision*)
(47)	IS 919	Geometrical product specifications (GPS) — ISO code system for tolerances on linear sizes:
	(Part 1) : 2014/ ISO 286-1 : 2010	Bases of tolerance, deviations and fits (*third revision*)
	(Part 2) : 2014/ ISO 286-2 : 2010	Tables of standard tolerance grades and limit deviations for holes and shafts (*second revision*)
(48)	IS 816 : 1969	Code of practice for use of metal arc welding for general construction in mild steel (*first revision*)
	IS 819 : 1957	Code of practice for resistance spot welding for light assemblies in mild steel
	IS 1024 : 2025	Use of welding in bridges and structures subject to dynamic loading — Code of practice (*third revision*)
	IS 1261 : 1959	Code of practice for seam welding in mild steel
	IS 1323 : 1982	Code of practice for oxy-acetylene welding for structural work in mild steels (*second revision*)
	IS 9595 : 1996	Metal arc welding of carbon and carbon manganese steels-Recommendations (*first revision*)
(49)	IS 817	Training of welders — Code of Practice
	(Part 1) : 1992	Manual metal arc welding (*second revision*)
	(Part 2) : 1996	Oxyfuel welding (*second revision*)
	IS 1393 : 1961	Code of practice for training and testing of oxy-acetylene welders
	IS 7307 (Part 1) : 1974	Approval tests for welding procedures: Part 1 Fusion welding of steel
	IS 7310 (Part 1) : 2019/ISO 9606-1 : 2012	Qualification testing of welders — Fusion welding: Part 1 Steels (*first revision*)
	IS 7318 (Part 1) : 1974	Approval tests for welders when welding procedure approval is not required: Part 1 Fusion welding of steel

Sl No.	*IS No.*	*Title*
(50)	IS 1477	Code of practice for painting of ferrous metals in buildings:
	(Part 1) : 1971	Pre-treatment (*first revision*)
	(Part 2) : 1971	Painting (*first revision*)
(51)	IS 7205 : 1974	Safety code for erection of structural steelwork
(52)	IS 456 : 2000	Plain and reinforced concrete — Code of practice (*fourth revision*)

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NATIONAL BUILDING CONSTRUCTION STANDARDS

PART C STRUCTURAL DESIGN

SECTION 6 STEEL AND COMPOSITE CONSTRUCTION

6B COMPOSITE CONSTRUCTION IN STRUCTURAL STEEL AND CONCRETE

BUREAU OF INDIAN STANDARDS

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FOREWORD

This NBCS (Part C/Subsection 6B) covers the composite construction consists of the use of prefabricated steel structural units like steel beams and steel open web joists (trusses) in combination with concrete elements and often with steel reinforcements.

The design and construction should ensure monolithic action between the structural steel and concrete components so that they act as a single structural unit.

The Section 6 'Steel' was first published in 1970 and was subsequently revised in 1983, 2005 and 2016 as a chapter of the National Building Code of India. In the second revision in 2005, the detailed design provisions were not included as IS 800 : 1984 'Code of practice for general construction in steel (*second revision*)'was under revision at that time. This Section, therefore, then referred to the 1984 version of IS 800 with the remarks that the latest version would prevail, as and when published. It, however, covered the philosophical aspects of limit state design which was being introduced in the revision of IS 800. IS 800 was subsequently revised and published as IS 800 : 2007 and hence, became the prevailing version for use under this Section. In the third revision of 2016, the Section 6 was brought in line with the revised version of IS 800 : 2007 and its amendment No. 1 and to take care of further improvements and incorporations required.

In the current revision, this publication has been renamed as National Building Construction Standards (NBCS).

In this revision of Section 6, the Section has been subdivided into the following subsections with the chapter on 'composite construction in structural steel and concrete' being introduced for the first time:

a) 6A Steel; and

b) 6B Composite construction in structural steel and concrete.

The provisions of this Subsection (Part C/Subsection 6B) are largely based on IS 11384 : 2022 'Composite construction in structural steel and concrete — Code of practice (*first revision*)'. The growing use of steel-concrete composites in building construction necessitated this new chapter in this NBCS.

The provisions of this Subsection conform to the limit state design philosophy, ensuring consistency with IS 456 : 2000 'Plain and reinforced concrete — Code of practice' for reinforced concrete and Part C/Sec 6A for structural steel. The Subsection includes comprehensive provisions for the design of key structural components such as beams, slabs, and columns in composite construction. It specifically addresses two types of composite columns — Concrete-encased steel columns, which may be either fully or partially encased, and concrete-filled steel columns — Both of which enhance load-bearing capacity and fire resistance. For composite slabs, the Subsection includes two types: profiled sheeting, which serves as formwork for reinforced concrete, and embossed profile sheeting, which functions as both formwork and tension reinforcement, with or without shear connectors. It also provides guidelines for the design and testing of shear connectors to ensure efficient load transfer. Serviceability limit states regulate deflection, vibration, and fire performance. Additionally, the subsection includes specifications for light gauge steel and lightweight concrete, broadening the scope of composite construction applications. This subsection is restricted to the design of steel-concrete composite components and systems used in buildings.

Though the common methods of designs have been covered in this NBCS, special systems of design and construction, not covered by this NBCS, may be permitted on production of satisfactory evidence regarding their design adequacy and safety based on specialist literature or by analysis, test, or both.

All requirements of Part C/Sec 6A in so far as they apply, shall be deemed to form a part of this subsection, except where otherwise laid down in this subsection.

All standards, whether given herein above or cross-referred to in the main text of this Section, are subject to revision. The parties to agreement based on this Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

As the regulation of land development and buildings is a State subject and is dealt by the States and local bodies such as urban local bodies within their jurisdiction through building regulatory documents like building regulations, building byelaws, and fire regulations, this document is voluntary in nature and is non-binding. The implementation depends on adoption by concerned parties or stipulations in a contract or by appropriate adoption by the concerned authorities.

For the purpose of deciding whether a particular requirement of this Subsection is complied with the final value, observed or calculated, expressing the result of a test or analysis shall be rounded off in accordance with IS 2 : 2022 'Rules for rounding off numerical values (*second revision*)'. The number of significant places retained in the rounded-off value should be the same as that of the specified value in this Subsection.

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Important Explanatory Note for Users of the NBCS

In any Part/Section of this NBCS, where reference is made to **‘good practice’** in relation to design, constructional procedures or other related information, and where reference is made to **‘accepted standard’** in relation to material specification, testing, or other related information, the Indian Standards listed at the end of the Part/Section shall be used as a guide to the interpretation.

At the time of publication, the editions indicated in the standards were valid. All standards are subject to revision and parties to agreements based on any Part/Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

In the list of standards given at the end of a Part/Section, the number appearing within parentheses in the first column indicates the number of the reference of the standard in the Part/Section. For example:

a) Good practices [C-6B(1)] refers to the Indian Standard(s) give at serial number (1) of the list of standards given at the end of this Part C/Subsection 6B, that is, IS 456 : 2000 ‘Plain and reinforced concrete — Code of practice (*fourth revision*)’ and IS 800 : 2007 ‘General construction in steel — Code of practice (*third revision*)’; and

b) Accepted standards [C-6B(4)] refers to the Indian Standards given at serial number (4) of the list of standards given at the end of this Part C/Subsection 6B, that is, IS 2062 (Part 1) : 2025 'Structural steel: Part 1 Hot rolled medium and high tensile steel (*eighth revision*)'.

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART C STRUCTURAL DESIGN

SECTION 6 STEEL AND COMPOSITE CONSTRUCTION

6B COMPOSITE CONSTRUCTION IN STRUCTURAL STEEL AND CONCRETE

1 SCOPE

1.1 This NBCS (Part C/Subsection 6B) deals with the design and construction of composite structures made up of structural steel and cast-in-situ/precast concrete, joined together to act integrally.

1.2 This Subsection is applicable to simply supported as well as continuous beams slabs and supporting column systems. The design provisions in this code are based on the limit states method of design.

2 -

NOTE — This clause is intentionally left blank.

3 TERMINOLOGY

For the purpose of this Subsection, the definitions given in as per good practices [C-6B(1)] and the following shall apply.

3.1 Accidental Load — The load is not normally expected in design life but has a major impact if it ever occurs, such as ramming of vehicles against columns or any other member of the frame like bracings, blast loading, etc.

3.2 Accompanying Load — Imposed load acting along with leading imposed load but causing lower action and/or deflections.

3.3 Action — The primary cause for stress or deformations in a structure, such as dead, imposed, wind, seismic, or temperature loads.

3.4 Built-up Section — A member fabricated by inter-connecting more than one element to form a compound section acting as a single member.

3.5 Camber — intentionally introduced pre-curving (generally upwards) in a system, member or any portion of a member with respect to its chord. These are generally introduced to compensate for deflections at a specific level of loads.

3.6 Composite Action — Integral action of primary supporting steel member and supported concrete deck with or without limited slip at their interface to ensure greater strength and rigidity. In composite columns, it is the integral action between steel and its encasement or infill concrete. The shear transfer is to be ensured through the use of mechanical devices known as shear connectors in composite beams and columns, as required (*see* Fig. 8).

3.7 Design Load/Factored Load — A load value obtained by multiplying the characteristic load with the partial safety factor for loads.

3.8 Design Service Life — The time period during which the structure or its components should satisfy the design objectives and functions.

3.9 Detail Category — Designation given to a particular detail to indicate the S-N curve to be used in fatigue assessment.

3.10 Differential Shrinkages — It is entirely due to shrinkage of concrete from the time composite action comes into effect. When the coefficient of thermal expansion varies significantly between steel and concrete (concrete with limestone or granite aggregate), it also includes the difference in thermal strain between the steel and concrete. Differential shrinkage may lead to an increase in stresses and is more pronounced in continuous beams.

3.11 Fatigue — Damage caused by repeated fluctuations of stress, leading to progressive cracking of a structural element.

3.12 Fatigue Limit State — The state of failure through fatigue damage due to repeated application of loads.

3.13 Fatigue Strength — Stress range that can be endured by a category of detail, depending upon the number of cycles.

3.14 Flexible Shear Connector — It resists shear forces by bending, tension or shearing in the root at the connection point of the steel member. It is subjected to plastic deformations as it reaches the ultimate strength, and the failure mode is ductile. It consists of studs, channels, etc (Fig. 8) welded to steel members to develop composite action with the concrete.

3.15 Initial Dead Load — The combination of weight of steel structure and the portion of the concrete deck that is supported by the steel structure alone before the development of full composite action with concrete reaching 75 percent of its 28 days strength.

3.16 Limit State — The load state beyond which the structure is incapable of performing its desired function.

3.17 Loads — Applied forces as per loads indicated in relevant standards (*see* Part C 'Structural Design/ Section 1 Loads and Load effects' of this NBCS) for dead, imposed, wind, snow loads, etc, and also for seismic loads that the structure is subjected to during its lifetime.

3.18 Partial Safety Factor for Loads — The factors multiplied by the loads or their combinations to obtain design loads while checking performance under various limit states.

3.19 m-k Factors — Physically, in a composite slab, 'm' is a broad measure of the mechanical interlock between the embossed profiled decking sheet and the reinforced cement concrete on top of the deck, and 'k' represents the frictional resistance between the two elements that is, steel and concrete (*see* Fig. 38).

3.20 Rigid Shear Connectors — These are shear hoops welded to bars, angles, horseshoes or tees welded to the flange of the fabricated steel units, as shown in Fig. 8(b) and Fig. 8 (c). They resist shear forces by concrete bearing on the vertical face and shearing. They exhibit negligible deformation under shear transfer (that is, brittle failure). These are not usually recommended for ultimate limit state design.

3.21 Service Limit — The loading state beyond which the structure or its components becomes incapable of performing its intended function due to excessive deformation, or deflection, or vibration.

3.22 Serviceability Loads — The loads on the structure against which the serviceability of the structure needs to be checked.

3.23 Shear Connectors — These are the mechanical attachments to steel members to transfer interface shear between steel and concrete to develop composite action and are composed of flexible shear connectors [Fig. 8 (a), Fig. 8 (c)], rigid shear connectors [Fig. 8 (b)], etc.

3.24 S-N Curve — Curve, defining the relationship between the numbers of stress cycles to failure Nsc at a constant stress range Sc, during fatigue loading on parts of a structure.

3.25 Strength Factors — The factors by which the specified strength is divided to obtain design strength; while assessing the safety under limit states of strength.

3.26 Stress Range — Algebraic difference between two extremes of stresses in a cycle of loading at a location in a member.

3.27 Superimposed Dead Load — The dead loads added subsequent to concrete hardening of concrete that is resisted by composite action.

3.28 Transient Load — The loads that are assumed to be varying over a short time interval like imposed load, loads with dynamic effect, temperature effects, wind loads on the structure, earthquake loads, accident loads, etc.

3.29 Ultimate Limit State — The state at which the structure fails and loses its integrity leading to its collapse.

4 SYMBOLS

For the purpose of this Subsection, the symbols (other than those used for load categorization) given in Annex A are applicable.

5 MATERIALS AND WORKMANSHIP

5.1 The main materials for composite construction are structural steel, reinforcing steel, and concrete. The materials and workmanship of structural steel shall generally comply with specifications laid down in as per good practice [C-6B(3)], and that of reinforced concrete shall comply with specifications laid down in as per good practice [C-6B(2)]. However, the general properties and specifications of materials for composite construction are detailed as given in **5.2** to **5.4**.

5.2 Structural Steel

All the structural steel used in general construction, coming under the purview of this NBCS, shall before fabrication conform to the accepted standard [C-6B(4)].

Structural steel other than those complying with the accepted standard [C-6B(4)] may also be used provided that the limiting stresses and other design provisions are suitably modified and the steel is also suitable for the type of fabrication adopted.

Steel that is not supported by mill test results may be used only in unimportant members and details, where their properties such as ductility and weldability would not affect the performance requirements of the members and the structure as a whole. However, such steels may be used in the structural system after confirming their quality is as per the accepted standard [C-6B(4)], by carrying out appropriate tests in accordance with the method specified in the accepted standard [C-6B(5)].

5.2.1 *Properties of Structural Steel*

The following physical properties shall be assumed for all grades of steel for design purposes:

Unit mass of steel = 7 850 kg/m^3

Young's modulus (modulus of elasticity) = 2.0×10^5 MPa

Shear modulus = 0.769×10^5 MPa

Poisson's ratio = 0.30

Coefficient of thermal expansion = 0.000 012/°C

The mechanical properties of steel like yield stress, ultimate stress and, elongation shall be as per values indicated in as per good practice [C-6B(3)].

5.2.2 *Specifications of Structural Steel*

Unless otherwise permitted herein, structural steel used shall, before fabrication, comply with the requirements of the accepted standards [C-6B(6)].

The use of structural steel not covered by the above standards may be permitted with the specific approval of the competent authority.

5.2.3 *Other Steels*

Except where permitted with the specific approval of the authority, steels for machined parts and for uses in features other than structural members or elements shall comply with the relevant accepted standards [C-6B(7)], as appropriate.

5.2.4 *Castings and Forgings*

Steel casting and forgings shall comply with the requirements of the Indian Standards the accepted standard [C-6B(8)] as appropriate.

5.2.5 *Fasteners*

Bolts, nuts, washers and rivets shall comply with the following or relevant accepted standard [C-6B(9)], as appropriate.

5.2.6 *Welding Consumables and Practices*

Welding consumables and practices shall comply with the following accepted standard [C-6B(10)], as appropriate.

5.2.7 *Wire Ropes and Cables*

These shall conform to the relevant accepted standard [C-6B(11)] except where the use of other types is specifically permitted by the authority.

5.3 Concrete

5.3.1 All structural reinforced concrete shall be of minimum grade M20 and shall be in accordance with material specification and workmanship as stipulated in as per good practice [C-6B(2)]. The strengths shall be specified in terms of the characteristic compressive strengths of cubes, f_{ck}, measured at 28 days. The design provisions in this Subsection are applicable for concrete strength between M20 to M75. Specialist literature shall be adopted in composite design, while using concrete strength outside this range.

5.3.2 Concrete grade shall be designated based on its characteristic strength. The three main categories of concrete strength grade are given below, and the recommended design properties of concrete are correlated to 28 day characteristic compressive strength unless specified otherwise. The mechanical properties of concrete, namely, tensile strength and modulus of elasticity, shall be determined as per good practice [C-6B(2)]. Additional data is given in Annex F.

a) *Ordinary Concrete* — Concrete grades up to M20 are included in this type. It could be prepared by a nominal mix proportioned by the weight of its main ingredients;

b) *Standard Concrete* — This type comprises of concrete grades from M25 to M55. It is made based on a design mix proportioned by the weight of its main ingredients, along with chemical admixtures to achieve certain target values; and

c) *High Strength Concrete* — Concrete grades from M60 to M80 are included in this type. Even though usage of high strength concrete is allowed in composite construction, capacity equations specified in this provision shall not be directly used in the design. Specialist literature and experimental results are required for using this concrete.

5.3.3 *Lightweight Concrete*

Lightweight concrete may be used in composite construction, and the design provisions in this NBCS shall be used within a strength range of M20 to M60. The mean tensile strength $f_{ctm,l}$ and modulus of elasticity $E_{cm,l}$ of lightweight concrete is to be calculated as modifications over the provisions in [C-6B(2)], as follows:

$$f_{\mathrm{ctm,l}} = \eta_{\mathrm{l}} f_{\mathrm{ctm}}$$

$$E_{\mathrm{cm,l}} = \eta_{\mathrm{E}} E_{\mathrm{cm}}$$

The factors η_{l} and η_{E} are determined using the following equation:

$$\eta_{\mathrm{l}} = 0.4 + \frac{0.6\,\rho}{2\,200}$$

$$\eta_{\mathrm{E}} = \left(\frac{\rho}{2\,200}\right)^2$$

Here, ρ is the upper limit of the oven-dry density of the relevant class of lightweight concrete, as given in Table 1.

Table 1 Density Classes and Corresponding Design Densities for Lightweight Concrete

(*Clause* 5.3.3)

Sl No.	**Density Class, ρ**		**1.0**	**1.2**	**1.4**	**1.6**	**1.8**	**2.0**
(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)
i)	Density range (kg/m^3)		801 to 1 000	1 001 to 1 200	1 201 to 1 400	1 401 to 1 600	1 601 to 1 800	1 801 to 2 000
ii)	Density (kg/m^3)	Plain concrete	1 050	1 250	1 450	1 650	1 850	2 050
		Reinforced concrete	1150	1 350	1 550	1 750	1 950	2 150

5.3.4 Design of concrete components of a composite structure against creep, shrinkage and temperature stress may be done as indicated in as per good practice [C-6B(2)] or as per specialist literature.

5.4 Reinforcement Steel

5.4.1 Reinforcement steel shall consist of hot rolled, thermo-mechanically treated, or heat-treated rods, de-coiled rods, or cold-worked steel of various grades as given in Table 2. The grade designations and strength properties are given in Table 3.

Table 2 Grades of Reinforcing Steel

(*Clause* 5.4.1)

Sl No.	**Types of Steel**	**Grade/Designation**	**Relevant Standard**
(1)	(2)	(3)	(4)
i)	Mild steel (MS)	Grade I	[C-6B(12)]
ii)	High yield strength deformed (HYSD)	Fe 415, Fe 415S, Fe 415D Fe 500, Fe 500S, Fe 500D, Fe 550, Fe 550D, Fe 600	[C-6B(13)]

5.4.2 The minimum strength of reinforcing steel as specified in as per good practice [C-6B(2)] is either the yield stress in case of mild steel or 0.2 percent proof strength in case of high yield strength steel and it is notionally taken as the characteristic strength of reinforcement f_{yk} .

5.4.3 The steel may be coated or galvanized to improve its corrosion resistance. The following corrosion resistive steel may be used as reinforcements:

a) *Galvanized Reinforcements* — The strength, elongation and bond properties are not adversely affected by galvanizing;

b) *Epoxy-coated Reinforcements* — These are reinforcements conforming to the accepted standard [C-6B(13)] coated by fusion bonding epoxy conforming to the accepted standard [C-6B(14)]. The bond of coated reinforcements is lowered by up to 20 percent compared to un-coated reinforcements. The lap length and anchorage length shall be increased by 25 percent while using these steel bars; and

Stainless Steel Reinforcements — Properties of stainless steel reinforcement shall not be inferior to carbon steel reinforcement of corresponding strength and class. These are reinforcements conforming to the accepted standard [C-6B(15)].

Table 3 Strength of Reinforcing Steel

(*Clause* 5.4.1)

Sl No.	Type of Steel	Grade/ Designation	Minimum Yield Stress/0.2 Percent Proof Stress,	Minimum Tensile Strength, as Percent of the Actual 0.2 Percent Proof Stress/Yield Stress But Not Less Than	Minimum Percent Elongation
(1)	(2)	(3)	(4)	(5)	(6)
i)	Mild steel	Grade - I	Bars up to and including 20 mm dia = 250 MPa	410 MPa	23.0
			Bar dia > 20 mm ≤ 50 mm = 240 MPa	410 MPa	23.0
ii)	High yield strength deformed steel (HYSD)	Fe 415	415 MPa	110 Percent (≥ 485 MPa)	14.5
		Fe 415D/S		112 Percent (≥ 500 MPa)	18.0
		Fe 500	500 MPa	108 Percent (≥ 545 MPa)	12.0
		Fe 500D/S		110 Percent (≥ 565 MPa)	16.0
		Fe 550	550 MPa	110 Percent (≥ 585 MPa)	10.0
		Fe 550 D		108 Percent (≥ 600 MPa)	14.5
		Fe 600	600 MPa	106 Percent (≥ 600 MPa)	10.0

NOTES

1 Elongation on a gauge length of $5.65\sqrt{A}$, where A is the cross-sectional area of the test piece, when tested in accordance with [C-6B(5)].

2 For Seismic Zone III, IV and V; HYSD steel bars having a minimum elongation of 14.5 percent and conforming to other requirements of [C-6B(13)] shall be used.

3 For Seismic Zone III, IV and V; Structural steel maximum yield strength shall not exceed the specified minimum value by more than 20 percent and conforming to other requirements of [C-6B(13)] shall be used.

6 STRUCTURAL ANALYSIS

This section is applicable to composite structures in which most of the members are composite. Where the structural behaviour is essentially that of reinforced or prestressed concrete, with only a few composite members, analysis provisions of as per good practice [C-6B(2)] or as per good practice [C-6B(16)] respectively, shall be used. Similarly, where the structural behaviour is essentially that of structural steel, with only a few composite members, analysis provisions of as per good practice [C-6B(3)] shall be used.

6.1 Modelling and Basic Assumptions

6.1.1 *Local Buckling of Plate Elements of Steel Section and Section Classification*

The types of elements that are encountered in steel sections are listed below:

a) Internal elements are elements attached along both longitudinal edges to other elements or to longitudinal stiffeners connected at suitable intervals to transverse stiffeners, for example, web of I-section and flanges and web of box section;

b) Outside elements or outstands are elements attached along only one of the longitudinal edges to an adjacent element, the other edge being free to displace out of plane for example, flange overhang of an I-section, the stem of T-section and legs of an angle section; and

c) Tapered elements may be treated as a flat elements having an average thickness as defined in the accepted standard [C-6B(17)].

6.1.2 The section strength at the ultimate limit state should be considered based on their ability to resist local buckling before full plastic strength is developed. In this respect, the structural steel sections may be classified as given in as per good practice [C-6B(3)]. Guidelines for sectional classification of composite sections with and without concrete encasements are given below:

a) *Composite Sections*

1) Steel compression elements (plates) in a composite section should be classified according to the least favourable class of steel elements in compression;

2) The class of a composite section depends on the direction of the bending moment at that section;

3) A steel compression element restrained by a reinforced concrete element through shear connectors may be placed in a more favourable class, after ensuring its improved local buckling resistance due to the above connection;

4) Plastic stress distribution over the cross section should be used for section classifications 1 and 2. In classification 3, the elastic stress distribution should be used taking into account the sequence of construction and the effects of creep and shrinkage;

5) For classification, design values of the strength of materials should be taken. Concrete in tension should be neglected. The stress distribution should be established for the gross cross-section of the steel web and the effective concrete flanges;

6) The tension capacity of steel reinforcements satisfying the ductility requirements specified in 5.4, only can be used in evaluating the strength in the hogging moment regions of the composite members. When the design resisting moment of the full or partial composite members is evaluated based on either simple rectangular stress block or parabolic stress block, the minimum area of steel reinforcement, A_{st}, used within the effective width of the concrete flange should satisfy the following:

$$A_{st} = A_c\, \alpha\, \frac{1}{\varepsilon^2}\frac{f_{ctm}}{f_{yk}}\sqrt{k_c}$$

where

ε = $\sqrt{250/f_y}$;

A_c = Effective area of the concrete flange;

f_y = Nominal value of yield strength of structural steel, in MPa;

f_{yk} = Characteristic yield strength of tension reinforcement, in MPa;

f_{ctm} = Mean tensile strength of concrete, in MPa (Annex F);

k_c = $\frac{1}{(1+d_s/(2\,z_0))} + 0.3 \le 1.0$;

α = 1.06 for compact section, 1.17 for plastic section;

d_s = thickness of concrete slab excluding haunch if any; and

z_0 = vertical distance between the centroid of the uncracked concrete slab and the centroid of the uncracked effective composite section using the modular ratio m for short-term loading.

7) The welded mesh should not be included in the effective section unless it has sufficient ductility before fracture when embedded in concrete; and

8) Account should be taken of the class of steel section at every stage of construction in the global elastic analysis.

b) *Composite Sections without Concrete Encasements*

1) A steel compression flange that is restrained from buckling by effective attachment to a concrete flange by shear connectors may be assumed to be in class 1 if the maximum spacing of the connectors is in accordance with **11.6.3**;

2) Other steel flanges and webs in compression in the composite beams should be classified on the basis of width to thickness ratios and susceptibility to local buckling of steel only unless they are also restrained by concrete as in columns. Accordingly, sections are categorized into three groups as indicated in as per good practice [C-6B(3)]; and

3) In beams, cross-sections with webs in Class 3 and flanges in Class 1 or 2 may be treated as an effective cross-section in Class 2 with an effective web in accordance with Fig. 1. The proportion of the web in compression should be replaced by a part of $20\varepsilon t_w$ adjacent to the compression flange, with another part of $20\varepsilon\, tw$ adjacent to the plastic neutral axis of the effective cross-section where ε = $\sqrt{250/f_y}$ and t_w is the thickness of the web.

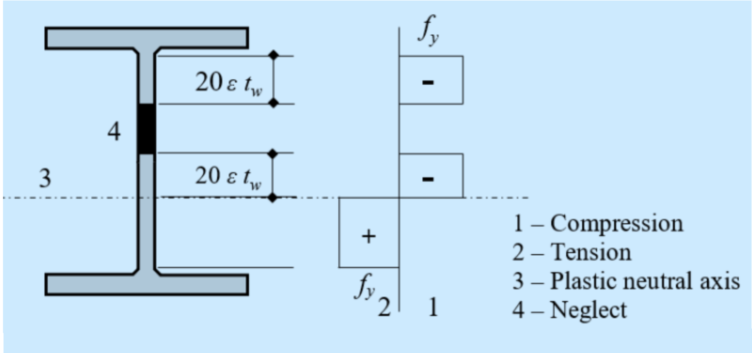


FIG. 1 EFFECTIVE CLASS 2 WEB IN BENDING

c) *Composite section with concrete encasements*

1) A steel outstand flange shall be classified as per Table 4; and

2) In partially concrete-encased I-section (Fig. 2), wherein the concrete is effectively attached to the web with stud or any reinforcement and covers on each side of the at least 80 percent of the flange overhang, the limiting overhang width of the flange to thickness ratio, b/t_f, for section classification may be taken as given in Table 4, where ε = $\sqrt{250/f_y}$.

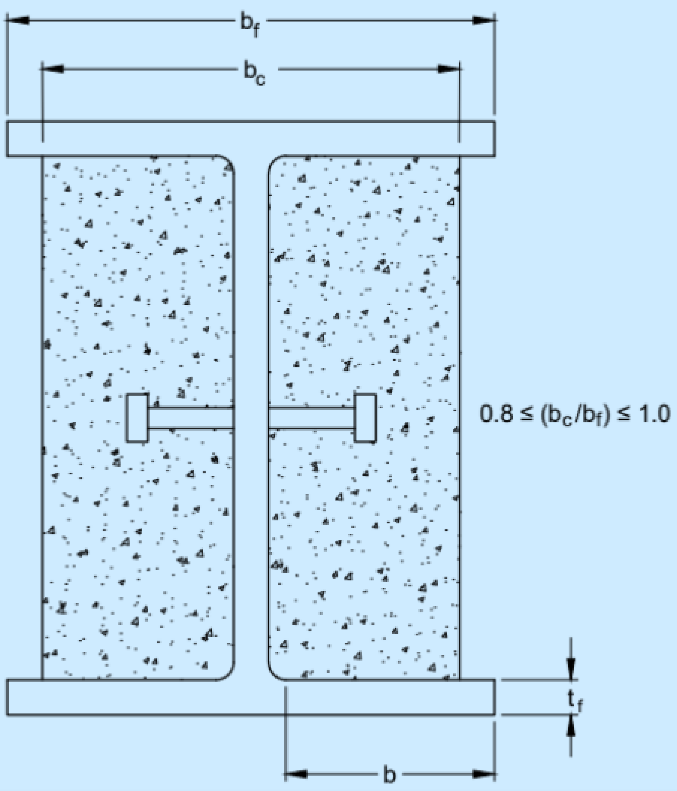


FIG. 2 PARTIALLY ENCASED I-SECTION

Table 4 Encased I Section Classification

[*Clause* 6.1.2(c)]

Sl No.	Section	Flange Overhang to Thickness Ratio (b/t_f)		
		Class 1 Plastic	Class 2 Compact	Class 3 Semi-compact
(1)	(2)	(3)	(4)	(5)
i)	Rolled section	9.4 ε	10.5 ε	15.7 ε
ii)	Welded section	8.4 ε	9.4 ε	13.6 ε

6.1.3 *Joints*

Joints in a composite structure may be modelled as:

a) Hinged, wherein the connection transfers only axial force and shear force, and negligible moment may be assumed to be transferred;

b) Rigid, wherein relative deformation between the members being joined is negligible due to the rigid nature of the joint, and the compatibility of deformation of the adjacent members at the joint may be assumed in the analysis; and

c) Semi-rigid, wherein the joint deformation under the force transferred across the joint should be modelled.

The effects of the deformation behaviour of the joints on the internal force resultants and deformations in the members and structure may be generally neglected. However, where such effects may be significant (such as in semi-rigid connections), they shall be considered as discussed in as per good practice [C-6B(3)].

6.1.4 *Foundation Support*

Normally the support from the foundation may be assumed as hinged or rigid, depending on the soil condition and foundation type. Effects of support deformation may be considered, where significant.

6.1.5 *Deformation of the Structure*

6.1.5.1 If under the external actions, the deformations are small, then the analysis can be done by studying the equilibrium of the undeformed structure. Such an analysis is referred to as first-order analysis or linear elastic analysis.

6.1.5.2 If under the external actions, the deformations are large enough to significantly affect or modify the structural behaviour, then the analysis should be performed considering the equilibrium of the structure under deformed configuration. Such an analysis is referred to as second-order analysis.

6.1.5.3 First-order analysis is adequate if the increase in the internal forces or moments due to actions on the deformation from the first-order analysis is less than 10 percent. This may be assumed to be satisfied if the ratio of the P_{cr}/P_d is greater than or equal to 10, where P_{cr} is the load corresponding to elastic instability of the member or structure as a whole and P_d, is the factored design compressive load. In evaluating the elastic critical load, P_{cr}, effect of cracking and creep of concrete, deformation of the joint shall be considered.

6.1.6 *Imperfections*

Effects of imperfections in the member (local imperfections) and imperfections in the overall geometry of the structure should be considered if they are significant. The first order analysis does not account for these, and hence the design method used should consider these effects. The second-order analysis should include the imperfections in the modelling, if the ratio of elastic critical load to the factored design loads, $P_{cr}/P_d < 4.0$. If the second-order analysis does not include the imperfection effects (when $P_{cr}/P_d \geq 4.0$), the design method used should consider the imperfection effects. If the second-order analysis includes imperfection modelling, then the design method shall not include the effects of imperfections.

6.1.7 *Shear Lag and Effective Width of Flanges*

The effectiveness of steel and concrete flanges is reduced due to shear deformation in their plane either through rigorous analysis or by using effective width of the concrete as given in section **8.3.3** and that of steel flanges as given in as per good practice [C-6B(3)].

6.1.8 *Creep, Shrinkage and Temperature*

The effect of creep of concrete on the internal forces can be accounted by using effective modulus of elasticity of concrete, as recommended in as per good practice [C-6B(2)], by considering the creep and the age of concrete at the time of loading. The shrinkage strain may be taken as recommended in as per good practice [C-6B(2)] or as per specialized literature.

When permanent loads are imposed in several stages, one mean value of time may be used for calculating creep coefficient. Such a mean value may also be used for evaluating prestressing deformations if the age of the relevant portion of the concrete at the time of prestressing is more than 14 days.

If a prefabricated and prestressed concrete slab is made composite with structural steel subsequently, the creep and shrinkage values only after the composite action becomes effective are to be taken.

The effects of creep, shrinkage and differential temperature, in terms of internal forces, moments and deformation in determinate structure and indeterminate structures, where compatibility is not enforced, are referred to as 'primary effects'. In indeterminate structures, wherein the compatibility of deformation is ensured in the analysis, the additional effects of enforcing compatibility are referred to as 'secondary effects'.

The effects of creep, shrinkage, and temperature are normally neglected in analysis for the ultimate limit state other than fatigue for composite members, in which steel sections used should meet either plastic or compact classification.

The characteristic values of indirect actions due to the controlled imposed deformations (for example jacking of supports) may be calculated using the characteristic or nominal values of material properties in prestressed indeterminate composite beams and slabs unless a more accurate method is followed.

6.1.9 *Cracking of Concrete*

The effect of cracking of concrete in tension zones, as obtained from elastic analysis of the uncracked concrete model, may be considered by using effective stiffness of cracked concrete as given in as per good practice [C-6B(2)].

6.1.10 *Sequence of Construction*

Depending upon the type of construction (propped/unpropped, prestressed, precast, etc) the model for different stages of loading may differ. For the resultant internal forces, stresses and deflection at service load considering the effects of the staged construction may be obtained by superposing the analysis results for different loads obtained from different appropriate models for the stage of construction.

The effect of the sequence of construction may be neglected in structures made of plastic and compact steel sections and the model corresponding to the final stage of construction may be utilized for the ultimate limit state, other than fatigue.

6.2 Methods of Global Analysis

Different methods of global analysis, as discussed in the following sections, are permitted. The design and member strength check methods are chosen to be consistent with assumptions in analysis and actual global/member behaviour. Linear elastic first order method is most commonly used, but the second order effects and member imperfection effects, etc. Have to be taken care of in the design and member check stages.

6.2.1 *Linear Elastic Analysis*

6.2.1.1 Effect of cracking of concrete in tension, creep, shrinkage, temperature, prestressing and sequence of construction should be considered in the linear elastic analysis, as discussed in **6.1** and **7**. Forces and moments from the linear elastic analysis may be used even when the design is based on the ultimate limit state. In the case of continuous structures with hogging moments over supports, evaluation of the effective section at supports may be necessary, as mentioned in **8.3.3**. Appropriate load combinations with corresponding load factors are to be used to find out the maximum design values of moments and shears.

The stability of a structure as a whole against overturning shall be ensured under the limit state as per provisions of as per good practice [C-6B(2)]. The foundation components of the structure shall also be safe against sliding under adverse conditions of the applied characteristic loads. The following factor of safety shall be ensured:

a) *Overturning* — The stability of a structure as a whole against overturning shall be ensured so that the restoring moment shall not be less than the sum of 1.2 times the maximum overturning moment due to the characteristic dead load and 1.4 times the maximum overturning moment due to the characteristic imposed loads. In cases where dead load provides the restoring moment, only 0.9 times the characteristic dead load as per good practice [C-6B(2)] shall be considered. Restoring moments due to imposed loads shall be ignored;

b) *Sliding* — The structure shall have a factor against sliding of not less than 1.4 under the most adverse combination of the applied characteristic forces. In this case also, only 0.9 times the characteristic dead load shall be taken into account if it assists in resisting sliding; and

c) *Instability* — Linear elastic instability analysis of member and the global system is possible, wherein first order assumptions and the resulting eigenvalue problem leads to eigenvalues as the instability load,

6.2.1.2 *Redistribution of moments from first order analysis*

Bending moments obtained from the linear elastic analysis of indeterminate slabs, beams and frames in composite structures in buildings may be redistributed to a limited extent as given below while ensuring the equilibrium is still satisfied:

a) concrete members are subjected primarily to flexure in accordance with as per good practice [C-6B(2)];

b) steel members satisfy the plastic section requirements of as per good practice [C-6B(3)];

c) composite members have partial or full shear connection as given in **11**;

d) redistributed internal forces and moments should satisfy equilibrium;

e) inelastic behaviour of the material, and local and lateral-torsional buckling should allow such a redistribution;

f) at least one end of the beam should be connected by a rigid or full-strength joint to the adjacent member; and

g) each span is of uniform depth.

Table 5 gives the maximum percentage reduction in the hogging bending moments obtained from linear elastic global analysis, in composite beams, unless it is verified that the plastic rotation capacity permits a higher value.

Table 5 Limits to Percentage Redistribution of Hogging Bending Moments Obtained from Linear Elastic Analysis

(*Clause* 6.2.1.2)

Sl No. (1)	Classification of the Cross-Section in the Hogging Moment Region (2)	Plastic (3)	Compact (4)	Semi-compact (5)	Slender (6)
i)	For un-cracked section analysis moment	40	30	20	10
ii)	For cracked section analysis moment	25	15	10	0

NOTES

1 For grades of steel having yield strength greater than 360 MPa, redistribution is applicable to beams with plastic or compact cross-sections. In the redistribution, the reduction in hogging moment should not exceed the values for compact sections given in Table 5, unless it is demonstrated that rotation capacity permits a higher value.

2 The limits in Table 5 for semi-compact and slender sections relate to bending moments to be resisted by composite members and moments to be resisted by bare steel section should not be redistributed.

6.2.2 *Non-linear Global Analysis*

The non-linear analysis may be performed as specified in as per good practice [C-6B(3)]. The non-linear behaviour of the shear connection shall be taken into account. Effects of deformed geometry of the structure, imperfections, joint and foundations, creep, shrinkage, temperature, stages of loading shall be taken into account as discussed in **6.1**.

6.2.3 *Rigid Plastic Analysis*

Rigid plastic global analysis may be used in composite structures to obtain ultimate limit state design values other than fatigue if the conditions given below are satisfied. Second-order effects, imperfections, creep, shrinkage, temperature effects, etc. need not be considered in the rigid plastic analysis. The effect of alternating plasticity due to variable loading need not be normally considered in buildings:

a) All the members and joints of the frame are either composite or structural steel;

b) Material and cross-section should satisfy requirements of plastic analysis as given in [C-6B(3)];

c) Joints are able to sustain the plastic resisting moments over a large plastic hinge rotation;

d) Critical plastic hinge location shall satisfy the following requirements:

   1) Cross-section of the structural steel section shall be symmetric about the plane of bending;
   2) restraints are provided to prevent lateral torsional buckling;
   3) lateral restraint is provided to the compression flange at all critical plastic hinge sections under any loading;
   4) The rotation capacity of the section, considering any axial compression at the section, should be adequate to permit the plastic hinge rotation to form the plastic collapse mechanism; and
   5) When rotation requirements are not calculated and ensured, all effective sections at potential plastic hinge locations should be of plastic classification;

e) The plastic hinge rotation capacity in composite sections may be assumed to be adequate where:

   1) the yield strength of structural steel does not exceed 450 MPa;
   2) the concrete slab is of normal density concrete, having a characteristic strength within the range of 25 MPa to 50 MPa;
   3) contribution of reinforced concrete encasement in compression is neglected in calculating design moment resistance;
   4) all effective steel sections at potential plastic hinge rotation should be plastic, and all the other sections should be plastic or compact;
   5) all beam connections to adjacent beams/columns should have adequate plastic rotation capacity or should have a design resisting moment of at least 1.2 times the design plastic resistance of the adjacent beam;
   6) structural steel compression flange at plastic hinge location should be laterally restrained;
   7) adjacent span lengths do not differ by more than 50 percent of the shorter span length;
   8) the end span length is not more than 115 percent of the adjacent span length;
   9) at plastic sections with the concrete slab is under compression, not more than 15 percent of the total depth of the section shall be under compression at the ultimate moment unless the plastic hinge at the section is the last to form (not requiring much plastic hinge rotation);
   10) plastic hinges shall not be located in composite columns unless plastic rotation capacity can be verified;
   11) the lateral support to the compression flange shall be located within half the depth of the steel section from the plastic hinge section; and
   12) sections away from plastic hinge regions should satisfy at least compact section requirements.

7 LIMIT STATE DESIGN

7.1 General

In the limit state design method, the structure shall be designed to withstand safely all loads likely to act on it throughout its life. The objective of the design is to arrive at a structure that will remain fit for use during its life with acceptable target reliability. In other words, the probability of a limit state being reached during its lifetime should be very low. The acceptable limit for the safety and serviceability requirements before failure occurs is called a limit state. In general, the structure shall be designed on the basis of the most critical limit state and shall be checked for other limit states.

For satisfactory functioning of a structure during its design life conditions, stipulations and directives laid down in [C-6B(1)] shall be adequately satisfied for all steel-concrete composite structures.

7.1.1 *Effect of Construction Sequence*

The linear elastic method is valid for the analysis of the structure after considering load history, sequence of concrete casting and development of composite strength. In the case of propped construction, most of the initial dead load is resisted through the beam-prop system and the steel beam remains basically unstressed at this stage. In the case of un-propped construction, the steel beams alone have to carry the initial dead load and construction loads. Consequently, stresses and deflections at this stage shall not exceed specified design limits. The necessary distinction has to be made in the analysis about the stage of loading and the effectiveness of the system resisting the load. In the ultimate limit state, however, this distinction is not necessary while checking for flexural resistance. For the design of steel components and concrete deck, stipulations of as per good practice [C-6B(1)] and this Subsection shall be applied.

7.1.2 The sequence of construction should be considered as an integral part of the design process, for example, when calculating the stresses under serviceability limit criteria. The sequence and method of construction need to be mentioned in the drawings. Additional information such as the position of construction joints, if any, may also be included in the drawings.

Where the composite section is loaded before the concrete has attained its 28 days characteristic cube strength, the elastic properties and limiting compressive strength of the concrete, and the nominal strengths of shear connectors should be based upon the cube strength of the concrete at the time of loading. Where a partially cast slab is assumed to act compositely, the shear connection should be designed for this condition as well as for the final condition. In calculating deflections, consideration should be given to the sequence of construction and, where appropriate, proper account should be taken of the pre-camber of steel section, the deflections of the steel section due to loads applied to it prior to the development of composite action and of partial composite action where deck slabs are cast in stages. In execution, the rate and sequence of concreting should be required to be such that partly matured concrete is not damaged as a result of limited composite action occurring from the deformation of the steel beams under subsequent concreting operations.

7.2 Limit States

A composite structure or part of it is considered unfit for use when it exceeds a particular state called the limit state, beyond which it infringes on one of the criteria governing its performance or use. The limit states can be classified into the following categories:

a) Ultimate limit state;
b) Serviceability limit state; and
c) Fatigue limit state.

7.2.1 *Ultimate Limit State*

It is the state when under the worst combination of factored loads the structure or its components either reach design strength or becomes unstable. Both stability and strength need to be checked under the ultimate limit state.

In steel-concrete composite structures used in buildings or general constructions, the significant ultimate limit states to be considered are as follows:

a) Collapse due to flexural, shear or bearing failure of one or more critical sections or components;
b) Collapse due to horizontal shear failure at the interface between the steel beam and the concrete slab or composite slab system involving concrete slab and embossed profiled sheets;
c) Collapse due to the vertical separation of the concrete/composite slab from the steel beams; and
d) Collapse due to shear failure between steel and concrete components of the composite column or due to buckling of both fully/partially concrete encased steel columns or concrete filled hollow sections used as columns.

7.2.2 *Serviceability Limit States*

It is the state at which any of the following conditions occur during the loads encountered under construction and service:

a) Stress in structural steel has reached the prescribed limit;

b) Stress in concrete has reached the prescribed limit;

c) Deflection of a structure or its component reaches the prescribed limit;

d) Concrete crack width reaches the prescribed limit;

e) Slip at the interface between steel and concrete exceeds the prescribed limit;

f) Vibration becomes excessive, especially at overhangs;

g) Excessive corrosion affecting the durability of the structure; and

h) Unacceptable effects due to fire.

7.2.3 *Fatigue Limit State*

It is the state at which stress range due to the application of imposed loads reaches the prescribed limit, corresponding to the number of load cycles and detail configuration.

7.3 Design Philosophy

For ensuring the design objectives, the design should be based on the characteristic values for material strengths (resistance) and applied loads (actions), which take into account the probability of variations in the material strengths and in the loads to be supported. The characteristic values should be based on statistical data, if available. Where such data is not available, they should be based on experiments. The design values are derived from the characteristic values through the use of partial safety factors, both for material strengths and for loads. In the absence of special considerations, these factors should have the values given in this section according to the material, the type of load and the limit state being considered. The reliability of the design is achieved by ensuring that:

$$\text{Design Action (Load)} \leq \text{Design Strength (Resistance)}$$

Design action refers to the external actions or load which act on the structure and the design resistance refers to the maximum resistance the structure and its components provides to resist the actions without causing failure of the structure and its components or causing hindrances to the smooth operation of the structure for which it is intended.

7.4 Design Actions (Loads)

7.4.1 *Actions* (*Loads*) *are Classified into Three Main Categories*:

a) *Permanent or dead loads* — Loads due to self-weight of structural and non-structural components, fittings, ancillaries, and fixed equipment etc. Dead loads shall be calculated on the basis of unit weights which shall be established taking into consideration the materials specified for construction. Alternatively, the dead loads may be calculated on the basis of nominal dimensions and unit weights of materials given in (*see* Part C 'Structural Design/Section 1 Loads and Load effects' of this NBCS);

b) *Variable or imposed loads* — Construction and service stage loads such as imposed loads (for example, crane loads, impact, etc.), wind loads, snow loads and other loads shall be assumed in accordance with (*see* Part C 'Structural Design/Section 1 Loads and Load effects' of this NBCS) and the earthquake forces shall be calculated in accordance with the same; and

c) *Accidental loads* — Accidental loads are actions or loads expected due to explosions and the impact of vehicles, etc. The characteristic values of accidental loads generally correspond to the value specified by relevant code, standard or client. Design for the accidental load is generally not required in every building unless it is required by the client or approving authority, in which case, general recommendations given in as per good practice [C-6B(3)] or specialist literature shall be followed.

7.4.2 Other than the actions due to the externally applied loads as given in **7.4.1**, if the effects of shrinkage, creep and temperature are liable to affect material safety and serviceability of the structure, these shall be accounted for in the design calculations (*see* Part C 'Structural Design/Section 1 Loads and Load effects' of this NBCS) .

7.4.3 *Load Combination*

The different combinations of loads considered shall be as given in (*see* Part C 'Structural Design/Section 1 Loads and Load effects' of this NBCS). For each combination, different partial safety factors for loads are assigned to different loads, γ_f to account for:

a) Possibility of unfavourable deviation of the load from the characteristic value;

b) Possibility of inaccurate assessment of the load;

c) Uncertainty in the assessment of effects of the load; and

d) Uncertainty in the assessment of the limit states being considered.

The loads or load effects shall be multiplied by the relevant γ_f factors, given in Table 6, to calculate the design loads or design load effects.

Table 6 Partial Safety Factor for Loads, γ_f for Limit States

(*Clause* 7.4.3 *and* 9.3.2.1)

Sl No.	**Combination**	**Limit State of Strength**					**Limit State of Serviceability**			
		DL	LL [2]		WL/EL	AL	DL	LL [2]		WL/EL
			Leading	Accompanying				Leading	Accompanying	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
i)	DL+LL+CL	1.5	1.5	1.05	–	–	1.0	1.0	1.0	–
ii)	DL+LL+CL+ WL/EL	1.2	1.2	1.05	0.6	–				
		1.2	1.2	0.53	1.2		1.0	0.8	0.8	0.8
iii)	DL+WL/EL	1.5 (0.9)[1]	–	–	1.5	–	1.0	–	–	1.0
iv)	DL+ER	1.2 (0.9)[1]	1.2	–	–	–	–	–	–	–
v)	DL+LL+AL	1.0	0.35	0.35	–	1.0	–	–	–	–

[1] This value is to be considered when the dead load contribution to stability against overturning is critical or the dead load causes a reduction in stress due to other loads.

[2] When the action of different imposed loads is simultaneously considered, the leading imposed load shall be considered to be the one causing the higher load effects in the member/section.

NOTE — The effects of actions (loads) in terms of stresses or stress resultants may be obtained from an appropriate method of analysis.

Abbreviations: DL= Dead Load, LL= Imposed Load, WL= Wind Load, CL= Crane Load (Vertical / horizontal), AL=Accidental Load, ER= Erection Load, EL= Earthquake Load.

7.5 Material Strength and Partial Safety Factor

The design strength, S_d of a structural component, is obtained as given below from nominal ultimate strength, S_u, and partial safety factors for material strength, γ_m.

$$S_d = S_u/\gamma_m$$

where the partial safety factor for materials, γ_m, (*see* Table 7), account for:

a) Possibility of unfavorable deviation of material strength from the characteristic value;

---

[1] This value is to be considered when the dead load contribution to stability against overturning is critical or the dead load causes a reduction in stress due to other loads.

[2] When the action of different imposed loads is simultaneously considered, the leading imposed load shall be considered to be the one causing the higher load effects in the member/section.

b) Possibility of unfavorable variation of member sizes;

c) Possibility of unfavorable reduction in member strength due to fabrication and tolerances; and

d) Uncertainty in the calculation of the strength of the members.

Table 7 Partial Safety Factor for Material γ_m

(*Clauses* 7.5, 8.3.5.1, 8.3.6.1 *and* 9.1.2)

Sl No. (1)	Material (2)	Item (3)	Partial Safety Factor γ_m (4)
i)	Structural steel, and steel sheeting	Resistance against yield stress, γ_{m0}	1.10
		Resistance of member to buckling, γ_{m0}	1.10
		Resistance against ultimate stress γ_{m1}	1.25
ii)	Reinforcement	Reinforcement resistance against yield stress,γ_k	1.15
iii)	Shear connectors	Yield stress, γ_{mv}	1.25
iv)	Connections	Bolts-friction type, γ_{mf}	1.25
		Bolts-bearing type, γ_{mb}	1.25
		Rivets, γ_{mr}	1.25
		Welds for shop fabrication, γ_{mw}	1.25
		Welds for site fabrication, γ_{mw}	1.50
v)	Concrete	For basic and seismic load combinations, γ_c	1.50

NOTE — The partial safety factor for resistance for all materials in case of accidental loads = 1.0

8 DESIGN FOR ULTIMATE LIMIT STATES

8.1 Composite Beams

Composite beams shall be checked for the following:

a) resistance to flexure;

b) resistance to lateral-torsional buckling;

c) resistance to web shear buckling;

d) resistance to longitudinal shear (between steel and concrete components).

8.1.1 *Assumptions*

Design for the limit state of collapse in flexure shall be based on the assumptions given below:

a) Plane sections normal to the neutral axis remain plane and normal after bending;

b) The maximum strain in concrete at the outermost compression fiber at collapse is taken as 0.003 5 in bending as per good practice [C-6B(2)];

c) The tensile strength of the concrete is ignored;

d) The stress-strain curve for the reinforcing steel shall be assumed to be the same as given in as per good practice [C-6B(2)];

e) The properties of structural steel shall be taken as given in as per good practice [C-6B(3)]; and

f) The stress-strain curve for concrete may be taken to be the same as given in as per good practice [C-6B(2)]. The corresponding parabolic stress block may be used to evaluate the design bending resistance of composite beams and slabs. The bending resistance of a composite beam for the value of concrete stress using an equivalent rectangular stress block, which simplifies the design resistance equation, may be used as an alternative method. Both methods and the design resistance equations are given in Annex B.

NOTE — Critical cross-sections include the following:

a) the sections where the bending moment is maximum;
b) the section at the faces of the support;
c) sections adjacent to concentrated force or reactions; and
d) locations where a sudden change of cross-section occurs; (ratio of greater to the lesser resisting moment at adjacent sections exceeds 1.2) (changes due to cracking of concrete not to be included).

8.1.2 *Ultimate Bending Resistance*

For determining the position of the plastic neutral axis and the ultimate moment of resistance of composite beams, the guidelines given in Annex B may be used.

8.1.2.1 *General*

Composite constructions of types: (a) Top flange of steel beam supporting the concrete slab (Fig. 3) and (b) composite slab resting on structural steel beam (Fig. 4) are included in this design philosophy. A typical composite beam arrangement is shown in Fig. 3, where cast in place or precast RC slab is directly resting on the steel beam. Fig. 4 depict a composite slab consisting of RC and profiled deck sheet with or without embossments) and supported on a structural steel beam, parallel and perpendicular to the steel beam, respectively. The neutral axis may be in the concrete slab, in the top flange of the steel section, or in the web of the steel section.

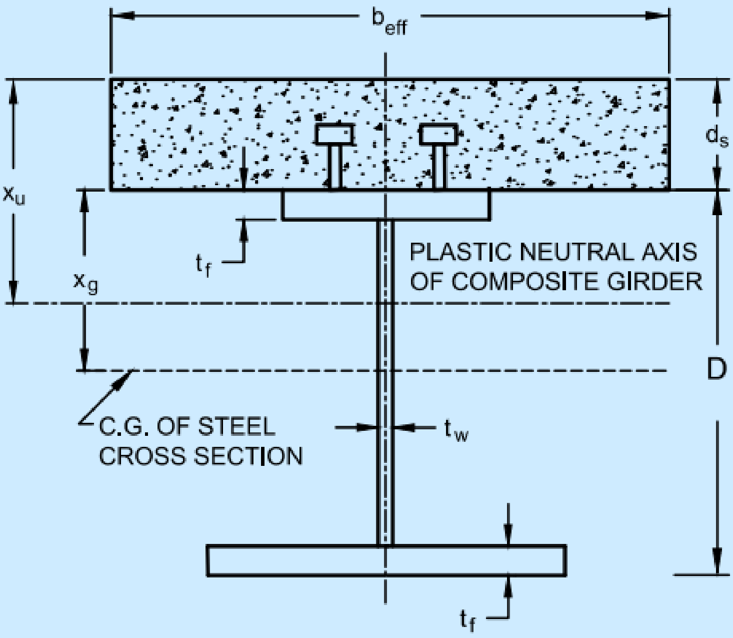
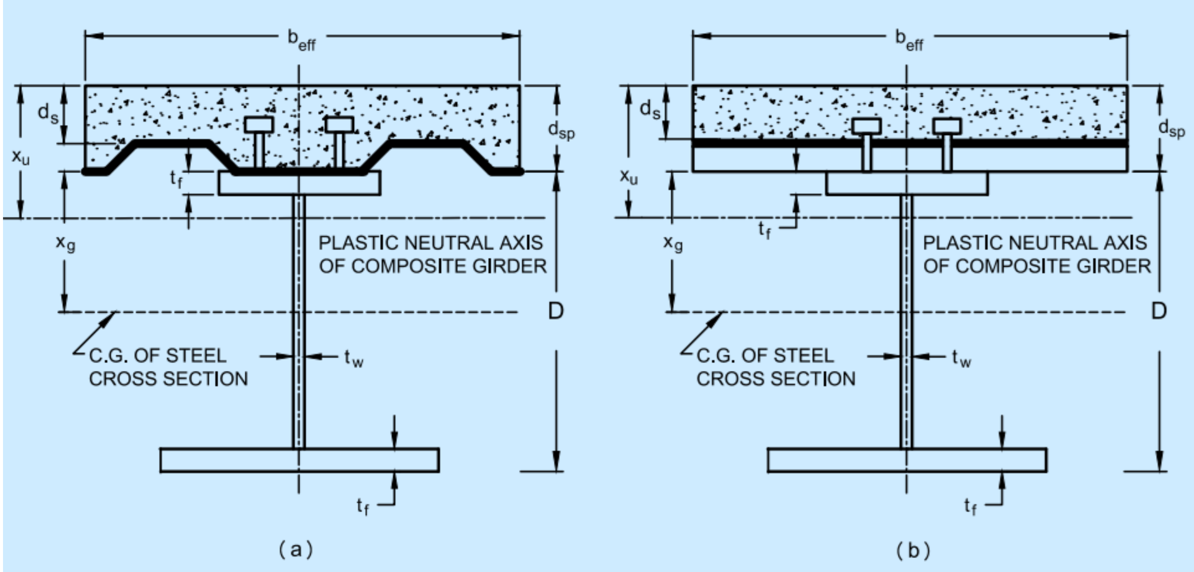


Fig. 3 Typical Composite Beams Without Profiled Decking Sheet



b_{eff}
d_s
d_{sp}
x_u
t_f
x_g
PLASTIC NEUTRAL AXIS OF COMPOSITE GIRDER
D
C.G. OF STEEL CROSS SECTION
t_w
(a)
(b)

Fig. 4 Typical Composite Beams with Profiled Decking Sheet (a) Ribs Parallel to Beams (b) Ribs Perpendicular to Beam

Bending moments and shears due to the application of factored loads may be analyzed in indeterminate structures by elastic theory assuming the concrete in the slab as un-cracked and unreinforced.

Hogging moments over internal supports as calculated above should be checked against section resistance assuming steel beam acting integrally with concrete (considering un-cracked and unreinforced). If the flexural tensile stress in concrete thus calculated exceeds the tensile strength of concrete, $f_{ctk,\,0.05}$ as in Annex F then a new analysis, neglecting concrete but including reinforcements over the effective width of the slab (*see* **8.3.3**) and over 15 percent of the span on each side of the support should be done to calculate the required design resistance, provided adjacent spans do not differ appreciably.

The redistribution of elastic analysis moment of indeterminate structure, as recommended in **6.2.1.2**, is allowed to arrive at the design moments in the case of plastic beams. Design for plastic analysis moments (as given in **6.2.3**) is permitted in the case of beams classified as plastic.

The bottom flange of the beam in the hogging moment zone should be adequately braced against lateral buckling. Otherwise, lateral buckling resistance has to be evaluated as recommended in **B-4**.

8.2 Precast Slab on Steel Beam

The use of precast slab, both full depth and partial depth, is allowed for composite construction as one of the components of composite beams. Precast slabs shall be erected and connected to the steel section so as to ensure composite action along with the steel beam.

8.2.1 *Full Depth Precast Slab*

Full-depth precast concrete deck panels may be used for new construction as well as for the replacement of deteriorated concrete decks on existing steel beams so as to obtain composite action. This shall be ensured by proper shear connection during the erection of these precast panels. The typical requirements for these types of beams are as given below:

a) Panels shall either span the full width of the concreting deck or shall be in lengths that span between two or more parallel beams. The minimum thickness of the slab shall be 150 mm;

b) The panels shall be connected to the beams using shear connectors in pockets, which consist of mechanical connectors, such as shear studs encapsulated in non-shrinking grouted pockets. These connections cause the panels to develop composite action with the beams; and

c) The contact between the precas t panels at their longitudinal edge should ensure transfer of compression between the panels, necessary for composite action.

8.2.2 *Partial Depth Precast Slab*

Partial depth precast concrete deck panels are generally thin RCC/prestressed concrete panels that span between beams and also serve as forms/shuttering for the cast-in-place concrete deck. The typical geometrical parameters that govern the use of these panels as a composite unit for the floor system are as given below:

a) The minimum thickness of the precast panels shall be 75 mm;

b) As a composite floor system, the cast in-situ concrete and the partial-depth panels together create the total thickness of the slab, with the panel reinforcing steel serving as the positive moment reinforcement in the bending direction of the combined slab;

c) Dimensions of the precast panels shall be chosen from consideration of easy handling, ease of lifting by cranes and for catering to the construction loads, including load of wet cast in-situ concrete;

d) Partial-depth panels must be capable of developing sufficient composite action with the cast *in-situ* concrete to be an effective floor system;

e) To ensure full bond between the cast *in-situ* concrete and precast panels, it is recommended that the top surface of the precast panel is intentionally roughened while casting it and is cleaned by removing the laitance or other contaminants on the surface and other measures may be taken, before the placement of the cast *in-situ* concrete so as to ensure a good bond between precast and cast in place concrete; and

f) After the precast panels are in place, the top layer of the reinforcing steel shall be placed over it, and the cast-in-situ concrete shall be placed on top of the panels.

8.2.3 *General Design Principles*

The design of precast slabs is based on the following principles:

a) The precast slab together with any *in-situ* concrete (for partial depth slab) should be designed as continuous in both the longitudinal and the transverse direction;

b) The joints between slabs should be designed to transmit membrane forces as well as bending moment and shear forces;

c) The effective width of precast slab in the composite beam action shall be calculated as per **8.3.3**;

d) The design principles of composite beams involving either full depth or partial depth precast slabs are similar to standard composite decks using cast *in-situ* reinforced concrete;

e) Vertical shear check of the composite beam shall be done as per **8.3.6**; and

f) For serviceability limit states, guidelines given in **7.2.2** and **9** shall be followed.

8.2.4 *Joints between Steel Beam and Precast Concrete Slab*

a) Where precast slabs are supported on steel beams without bedding, the influence of the vertical tolerances of the bearing surfaces shall be considered; and

b) The shear transfer between steel flange and precast concrete through mechanical shear connector shall be designed as per **11** with the following precautions:

    1) If shear connectors are welded to the steel beam projecting into the recesses within the slabs or joints between slabs, which are filled with concrete after erection, the detailing and the properties of the concrete should be such that it can be cast properly.

    2) The minimum infill around the shear connectors should be at least 25 mm.

    3) If shear connectors are arranged in groups, sufficient reinforcement should be provided near each group to prevent premature local failure in either the precast or the *in-situ* concrete.

    4) Special provision for protection against corrosion shall be adopted, wherein the steel flange under

precast slabs without bedding should have the same corrosion protection as the rest of the steelwork in addition to the top coating provided after erection.

5) Bedding with the purpose of protecting against corrosion may be designed to be non-load bearing.

8.2.5 *Joints between Precast members*

The critical sections of members close to joints should be designed to resist the most adverse combination of shear, axial force and bending caused by the ultimate vertical and horizontal forces. When the design of the precast members is based on the assumption that the joint between them is not capable of transmitting bending moment (*see* **8.3.4**), suitable precautions should be taken to ensure that if any crack developed is not excessive, and reduce the shear or axial force resistance of the member and should not be aesthetically or functionally objectionable.

Where space is left between two or more precast units, to be filled later with *in-situ* concrete or non-shrink grout, the gap should be large enough for easy placement and adequate compaction of the filling material to fill the gap completely.

8.2.6 *Structural Connection at Joints*

When designing and detailing the connections across joints between precast members, the overall stability of the structure, including its stability during construction, shall be considered. A typical joint connection is shown in Fig. 5.

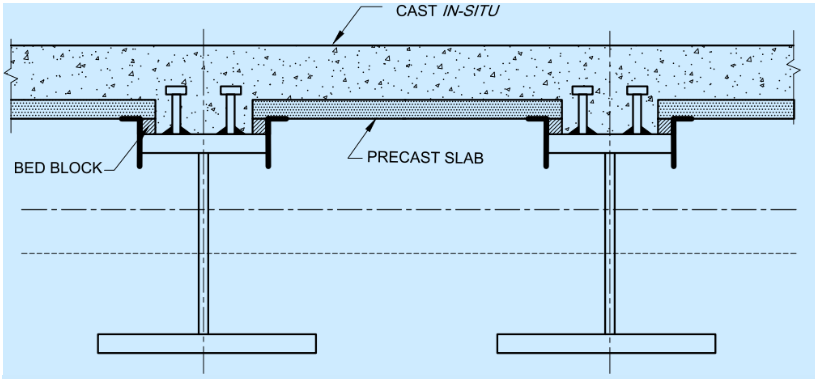


FIG. 5 TYPICAL JOINT CONNECTION FOR PARTIAL DEPTH PRECAST SLAB

8.3 Design Method

Connections should, where possible, be designed in accordance with the generally accepted methods applicable to reinforced concrete or structural steel.

8.3.1 *General Considerations in Design Details*

In addition to ultimate resistance requirements, the following should be considered:

a) *Protection* — Connections should be designed so that the standard of protection against weather and corrosion required for the rest of the structure is sufficiently maintained;

b) *Appearance* — Where connections are to be exposed, they should be designed to achieve and maintain the quality of appearance required for the rest of the structure; and

c) *Manufacture, assembly, and erection* — Methods of manufacture and erection should be considered during design. Care should be taken during erection and the following precautions are mandatory:

   1) Where projecting bars or sections are required, they should be kept to a minimum and made as simple as possible. The lengths of such projections should be not more than necessary;

   2) Fixing devices should be located in concrete sections of adequate strength;

   3) The practicability of both casting and assembly should be considered; and

4) Most connections require the introduction of suitable jointing material. Sufficient space should be allowed in the design for such material to ensure that the proper filling of the joint is possible.

8.3.2 *Reinforcement Continuity at Joint*

Where continuity of reinforcement is required through the connection, the joining method used should be such that the assumptions made in analyzing the structure and critical sections are realized. The standard methods applicable for achieving continuity of reinforcements are lapping, butt welding of bars and grout couplers.

8.3.3 *Effective Width of Concrete Slab*

a) For resistance calculation, the width of the slab, which is effective as the compression flange of the composite beam on each side of the steel beam, b_{eff}, shall be as per the equation given below:

$$b_{\text{eff}} = b_{\text{o}} + (b_{\text{e1}} + b_{\text{e2}}) = b_{\text{o}} + \frac{L_{\text{e}}}{4} \leq b_{\text{o}} + (b_1 + b_2)$$

where

b_{o} = centre to centre between the outer row of shear connectors;

$b_{\text{e1}}, b_{\text{e2}}$ = are the value of the effective width of the concrete flange on each side of the web and taken as $L_{\text{e}}/8$ but not greater than the geometric width b_1 and b_2, respectively as shown in Fig. 6;

$L_{\text{e}}/8 \leq b_1$ and b_2 (*respectively*);

L_{e} = the effective equivalent span length of the corresponding composite beam;

centre-to-centre distance between the supports for simply supported beam; and

as shown in Fig. 7 in a continuously supported beam.

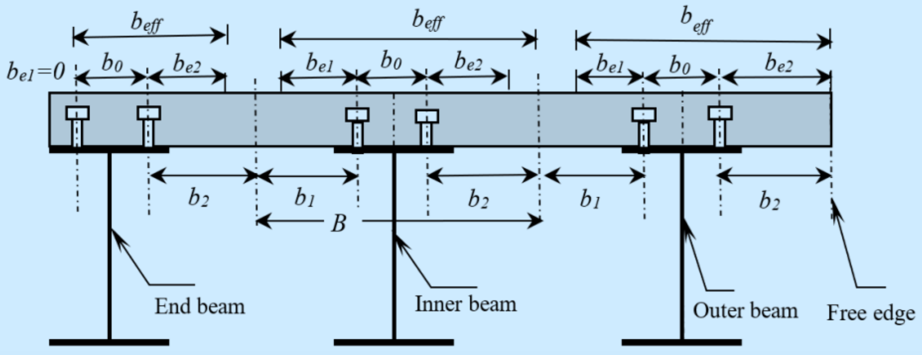


FIG. 6 EFFECTIVE WIDTHS FOR CONCRETE FLANGE OF COMPOSITE BEAMS

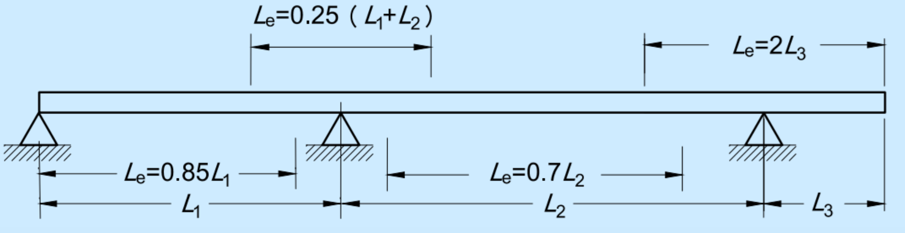


FIG. 7 EQUIVALENT SPANS FOR BEAM CONTINUITY

Reinforcements placed parallel to the steel beam within the effective width of the concrete slab should be considered for hogging moment resistance calculation of the composite beam at the continuous support.

b) The effective width at an end beam may be determined as:

$$b_{\text{eff}} = b_0 + \beta_{e1}\, b_{\text{e1}} + \beta_{e2}\, b_{\text{e2}}$$

where

β_{e1} = $0.55 + 0.025\,(L_{\text{e}}/b_{\text{e1}}) \leq 1.0$

β_{e2} = $0.55 + 0.025\,(L_{\text{e}}/b_{\text{e2}}) \leq 1.0$

L_{e} = Equivalent effective end span; and

b_{e1} = 0 as shown in Fig. 6.

8.3.4 *Effective Cross Section for Strength Calculation*

In calculating the strength of the cross section of the composite beams, the following should be considered:

a) For Sagging Moment — Concrete in the effective width and structural steel beam to be included but not the steel reinforcements in the effective width of concrete; and

b) For Hogging Moment — Concrete to be neglected but longitudinal steel reinforcement along the beam length within the effective width of the concrete in tension and structural steel beam to be included.

8.3.5 *Design of Structure for Bending Moment*

8.3.5.1 The factored design flexural strength, Md, in a beam and the external action, M, shall satisfy

$$M \leq M_d$$

where

M_{d} = $M_{\text{n}}/\gamma_{\text{m0}}$ = design flexural resistance calculated as given below;

γ_{m0} = partial safety factor against flexural failure (Table 7); and

M_{n} = nominal ultimate flexural resistance.

8.3.5.2 Considering local buckling, sections are to be analyzed as plastic, compact or semi-compact with the following additional consideration:

a) Load history and development in composite action are to be taken into consideration with appropriate values of the modular ratio, *m* at each stage, and stresses and deflections are to be the summation of values over successive stages;

b) Determination of bending resistance for a beam before composite action has set in or during the construction stage shall be done as per good practice [C-6B(3)];

c) The structural steel reinforcement and concrete fully interact with full shear transfer between the concrete and structural steel under composite action;

d) The effective width of concrete in composite action may be as mentioned in **8.3.3**;

e) For calculating the bending resistance of plastic, compact and semi-compact composite beams, the procedure presented in Annex B may be followed; and

f) The partial shear connection may be used in plastic and compact sections either for attaining economy without losing much in the moment capacity of the composite section or under conditions where the number of shear connectors required for full shear interactions cannot be provided. Requirements on the method of evaluating the bending resistance of partial shear connection are presented in **B-1.2**.

The bending moment and shear force distribution in continuous beams for secondary, as well as primary moment resistant frames/beams have to be determined by structural analysis.

8.3.5.3 *Design of structure for effect of lateral buckling on moment resistance*

Lateral buckling may govern the design under the following conditions:

a) At the construction stage, in the top flange closer to mid-span in both simply supported and continuous beams; and

b) At the construction and composite stage, in the bottom flange closer to support in continuous beams.

At the construction stage, the effect of lateral buckling on the bottom flange in a continuous beam shall be taken care of by considering cantilever action up to the point of inflection from the support.

If required, suitable horizontal bracings or members may be provided at the bottom flange to reduce the effective length of the compression flange near support. For beams that are provided with such bracings or members giving effective lateral restraint to the compression flange at intervals along the span, the effective lateral restraint shall be capable of resisting a force equal to 2.5 percent of the maximum force in the compression flange taken as divided equally between the numbers of points at which the restraint in bracing members occur. In beams supporting composite slabs, wherein the sheeting is welded to the top flange before concreting is done, the lateral restraint of the deck sheet may be considered.

The effective laterally unsupported length of compression flange of steel sections in sagging and hogging moment regions may be taken as given in as per good practice [C-6B(3)]. In sagging moment segments of composite beams, the concrete slab may be assumed to provide lateral support, provided an adequate shear connection between the slab and the beam is provided. In the hogging moment regions of composite beams, the effective length considering the rotational restraint provided by the slab to the top tension flange may be taken into account as given in **B-2**.

8.3.5.4 *Simplified design of continuous beams in buildings without lateral bracings*

Continuous composite beams (or composite beams within a frame) with plastic, compact, or semi-compact sections may be designed without any additional lateral bracings to the compression flange when the following conditions are satisfied:

a) The concrete slab on top should be adequately attached with shear connectors to the structural steel section and to at least one another parallel member top flange to facilitate inverted U-frame action that rotationally restrains bottom flange lateral buckling at hogging moment sections;

b) Adjacent span lengths of continuous beams should not differ by more than 20 percent of the shorter span length. Cantilever span length should not exceed 15 percent of the adjacent span length;

c) The loading on each span should be uniformly distributed, with the permanent design loads exceeding 40 percent of the total design load;

d) At each support of steel member, the bottom flange should be laterally restrained with a web bearing stiffener at that location; and

e) The maximum depth of steel beam sections should not exceed the value given in Table 8.

Table 8 Maximum Depth of Steel Beams in Composite Construction (In mm)

[*Clause* 8.3.5.4 (e)]

Sl No.	Type of Member	Nominal Yield Strength Limit of Structural Steel (MPa)							
		250		300		350		> 400	
		Un-cased	En-cased	Un-cased	En-cased	Un-cased	En-cased	Un-cased	En-cased
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
i)	I Section	800	1 000	700	900	650	850	500	650
ii)	Parallel flange	600	800	550	750	400	600	270	430

8.3.6 *Design of Structural Steel Web against Vertical Shear Force*

8.3.6.1 The factored design shear force, V_d, in a composite beam due to external action, V, shall satisfy:

$$V \leq V_d$$

where

Vd = design shear resistance calculated as given below.

$$V_d = V_n/\gamma_{m0}$$

γ_{m0}= partial safety factor as mentioned in Table 7.

V_n = nominal ultimate shear resistance.

The vertical shear force is assumed to be resisted by the web of the steel section only unless the value for contribution from the reinforced concrete part of the beam has been established. The nominal shear resistance, Vn may be governed by plastic shear resistance or strength of the web or governed by shear buckling as given below:

a) *Plastic Shear Resistance*

The nominal plastic shear resistance of composite beams under pure shear shall be calculated as indicated in as per good practice [C-6B(3)], disregarding the contribution of the concrete slab. The shear resistance for I-sections, channels both for major axis bending and minor axis bending as well as for rectangular and circular hollow sections of uniform thickness shall be as per good practice [C-6B(3)].

b) *Shear Buckling Resistance*

Resistance to shear buckling shall be verified as specified in as per good practice [C-6B(3)]. The nominal shear resistance, Vn, of webs with or without intermediate stiffeners as governed by buckling may be evaluated as detailed in as per good practice [C-6B(3)] either using the simple post-critical method or tension field method. The contribution of encasing concrete to shear resistance may be considered and that of shear reinforcement can be considered provided they consist of closed-loop stirrups. The total shear may be shared between the structural steel section and encasing concrete in the ratio of their contribution to plastic moment capacity.

8.3.6.2 *Reduction in bending resistance under high shear force*

If V is less than 0.6Vd, reduction in the plastic bending resistance of the section need not be considered. When $V > 0.6V$d, the bending resistance is reduced as the contribution of the web to bending gets diminished. The reduced bending resistances of the following sections are given below:

a) *Plastic or compact section*

$$M_{dv} = M_d - \beta(M_d - M_{fd}) \leq (1.2\, z_e f_y)/\gamma_{m0}$$

where

β = $(2V/V_d - 1)^2$

M_d = plastic design moment of the whole section disregarding high shear force effect considering web buckling effects

V = factored applied shear force.

V_d = design shear resistance as governed by web yielding or web buckling

M_{fd} = Plastic design resistance of the area of the cross section excluding the shear area, considering partial safety factor γ_{m0}

b) *Semi-compact Section*

$$M_{\mathrm{dv}} = Z_{\mathrm{e}} f_{\mathrm{y}} / \gamma_{\mathrm{mo}}$$

where

Z_e = elastic section modulus of the whole section.

8.3.7 *Hybrid Sections*

Use of hybrid steel sections consisting of different grade steel elements is permitted. The plastic and compact section design strength is obtained by using the appropriate value of yield stress in the different elements of the hybrid section. The design strength of the semi-compact section is evaluated with necessary adjustment (reduction) in stresses of the flange element in the cross-section with higher yield stress by the reduction factor, R_h. The R_h may be determined using the procedure as presented in **B-3** of Annex B.

8.3.8 *Partially Encased Sections*

This section is applicable for partially encased composite plastic or compact beams, provided the web depth to thickness ratio, d/t_w, is less than or equal to 117ε.

The full shear connection between the structural steel section and concrete encasing the web shall be ensured. The steel reinforcement in the compression zone and concrete in the tension zone may be disregarded.

The partial shear connection may be used in the partially encased composite section, provided the requirements of **8.3.5.2** are satisfied.

9 DESIGN FOR SERVICEABILITY LIMIT STATES

9.1 General

9.1.1 Serviceability limit states are related to the criteria governing normal use. Serviceability limit state is the limit state beyond which the serviceability criteria specified below are no longer met:

a) Stress and deflection limit;

b) Vibration limit;

c) Durability consideration; and

d) Fire resistance

9.1.2 Linear elastic analysis is used for finding out design moments and stresses under various load combinations and load factors, as mentioned in Table 7, for serviceability limit states. Concrete is assumed as unreinforced and un-cracked for the analysis.

9.1.3 *Method of Construction*

The stress and strain at serviceability limit state depend on whether the steel beam is propped or un-propped during construction, as given below:

a) *Un-propped construction* — In un-propped construction, the steel beam has to carry the construction load, including shuttering, wet concrete and its own weight until the concrete hardens;

b) *Propped construction* — In propped construction, both the dead and imposed load are resisted by the composite section. When props are used, they should be kept in place until the *in-situ* concrete has attained a strength equal to approximately twice the stress to which the concrete may be subjected to upon removal of props; and

c) *Non-composite construction* — In non-composite construction, the concrete slab is designed according to [C-6B(2)] and the steel deck sheet act just as a permanent shuttering.

The difference in the method (a) and (b) of construction does not, however, affect the ultimate limit load, wherein the total load, including the transient loads, shall be resisted by the composite section.

9.2 Negative Moments

Negative moments over intermediate supports may be adjusted as mentioned in **8.1.2.1**.

9.3 Stresses and Deflections

For calculating stresses at service load and deflection, the value of the modular ratio, *m* shall be taken as,

$m = \frac{E_s}{E_{cm}} \geq 7.5$ For short-term effect or loading.

$m = \frac{E_s}{K_c E_{cm}} \geq 15.0$ For permanent or long-term loads.

where

K_c = Creep factor, 0.5

E_s = Modulus of elasticity for steel = 2.0×10^5 N/mm^2;

E_{cm} = Modulus of elasticity of cast *in-situ* concrete as per Annex F;

f_{ck} = characteristic cube compressive strength of concrete in N/mm^2; and

E_{ci} = Modulus of elasticity of cast *in-situ* concrete at *i* days ($i < 28$ days).

The equivalent area of concrete slab at any stage shall be determined by dividing the effective width of the concrete slab by the modular ratio as given below.

$$m = \frac{E_s}{E_{ci}}$$

Final stresses and deflection are to be worked out separately at each stage of load history with relevant modular ratios and section modulus as discussed above and then added together.

9.3.1 *Limiting Stresses for Serviceability*

Limiting stresses for different stages of construction are as indicated below:

a) Concrete — The limiting compressive stress in concrete should not exceed one-third of the characteristic strength of concrete;

b) Reinforcement Steel — The limiting tensile stress in steel reinforcement should not exceed f_{yk}/γ_k; and

c) Structural Steel — The limiting stress in steel beam considering the different stages of construction should not exceed f_y/γ_{mo}.

Where bearing stress is combined with tensile or compressive stress, bending and shear stresses under the most unfavourable conditions of loading, the equivalent stress obtained from the following equation shall not exceed $0.9f_y$:

$$f_{ec} = \sqrt{f_{bc}{}^2 + f_p{}^2 + f_{bc}.f_p + 3\tau_b{}^2}$$

and

$$f_{et} = \sqrt{f_{bt}{}^2 + f_p{}^2 + f_{bt}.f_p + 3\tau_b{}^2}$$

where

f_{ec} and f_{et} = equivalent compressive and tensile stress in steel section;

f_{bc} and f_{bt} = actual compressive and tensile stress in steel section;

f_p = actual bearing stress in steel section; and

τ_b = actual shear stress in steel section.

The value of bending stresses f_{bc} about each axis, to be used in the above formula, shall be individually lesser than the values of the maximum allowable stresses in bending about the corresponding axis.

9.3.2 *Limiting Deflection and Camber*

9.3.2.1 *Deflection limit*

The deflection under serviceability loads of a building or a building component should not impair the strength of the structure or components or cause damage to finishing. Deflections are to be checked for the most adverse but realistic combination of service loads and their arrangements by elastic analysis using a load factor given Table 6. The deflection of a member shall be calculated without considering the impact factor or dynamic effect of the loads on deflection. As per good practice [C-6B(3)] gives recommended limits of deflections for certain structural members and systems. Circumstances may arise where greater or lesser values would be more appropriate depending upon the nature of the material in element to be supported (vulnerable to cracking or not) and intended use of the structure, as required by the client.

9.3.2.2 *Provision of camber*

Where the deflection due to the combination of dead load and imposed load is likely to be excessive, consideration should be given to pre-camber the steel beams. The values of desired camber shall be specified in the design drawing. Generally, for spans greater than 25 m, camber approximately equal to the deflection due to dead loads plus half the imposed load may be used.

9.4 Vibration

Suitable provisions in the design shall be made for the dynamic effects of imposed loads, impact loads and vibration due to machinery operating loads. In severe cases, the possibility of resonance, fatigue or unacceptable vibrations shall be investigated. Unusually flexible structures (generally the height to the effective width of lateral load resistance system exceeding 5 : 1) shall be investigated for lateral vibration under dynamic wind loads as per(*see* Part C 'Structural Design/Section 1 Loads and Load effects' of this NBCS). Structures subjected to a large number of cycles of loading shall be designed against fatigue failure in accordance with as per good practice [C-6B(3)]. The floor vibration effect shall be considered using specialist literature.

9.5 Durability

9.5.1 Several factors that affect the durability of the buildings under conditions relevant to their intended life are listed below:

a) The environment;

b) The degree of exposure;

c) The shape of the member and the structural detail;

d) The protective measure; and

e) Ease of maintenance.

The durability of the structural steel component of a composite section shall be ensured by recommendations as given in as per good practice [C-6B(3)]. Specialist literature may be referred to for more detailed additional information in design for durability. For concrete, the durability shall be ensured by following the recommendations as given in as per good practice [C-6B(2)].

9.5.2 *Profiled Steel Sheeting for Composite Slabs*

The durability criteria for profiled steel sheets of composite deck slab shall be met by the following procedures:

a) The exposed surfaces of the steel sheeting shall be adequately protected to resist particular atmospheric conditions; and

b) A zinc coating of a total mass 275 g/m^2 (including both sides) is sufficient for internal floors in a non-aggressive environment, but the specification may be varied depending on service conditions.

9.6 Fire Resistance

Fire resistance of a steel component of a composite member is a function of its mass, its geometry, and the actions to which it is subjected, its structural support conditions, fire protection measures adopted and the fire to which it is exposed. Design provisions to the resistance of fire for concrete shall be as per guidelines given in as per good practice [C-6B(2)]. For the design of structural steel components for fire resistance, as per good practice [C-6B(3)] shall be referred. Specialist literature may be referred to for more detailed information on the design for fire resistance of steel/composite structures. The aspect of fire resistance is given in **15**.

9.7 Control of Cracking in Concrete and Crack Width Calculation

Minimum reinforcements in terms of diameter and spacing required for crack control at the top of concrete as per good practice [C-6B(2)] are to be provided in composite beams at the zone of the negative moment to prevent cracks adversely affecting the appearance and durability of the structure. Crack width calculation as well as limiting crack width as given in as per good practice [C-6B(2)] may be followed, subject to the discretion of engineers. The crack width in concrete shall be restricted to values as indicated in as per good practice [C-6B(2)].

10 DESIGN FOR FATIGUE LIMIT

This section applies to the design of structures and structural elements subject to loading which could lead to fatigue failure. The following effects are not considered in the section:

a) Corrosion fatigue;

b) Low cycle (high stress) fatigue;

c) Thermal fatigue;

d) Stress corrosion cracking;

e) Effects of high temperature (> 150 °C); and

f) Effects of low temperature (< below transition temperature).

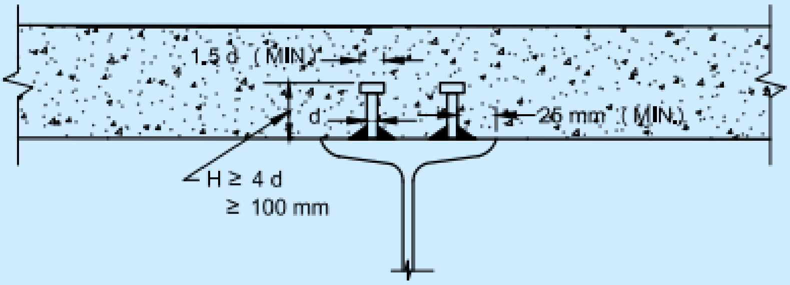
The fatigue design of various components of composite structures like members, welded joints, bolts, shear lugs etc. shall be carried out as per the specifications laid down in as per good practice [C-6B(3)]. Fatigue provisions in the design of shear connectors are discussed in **11.3**.

11 SHEAR CONNECTORS

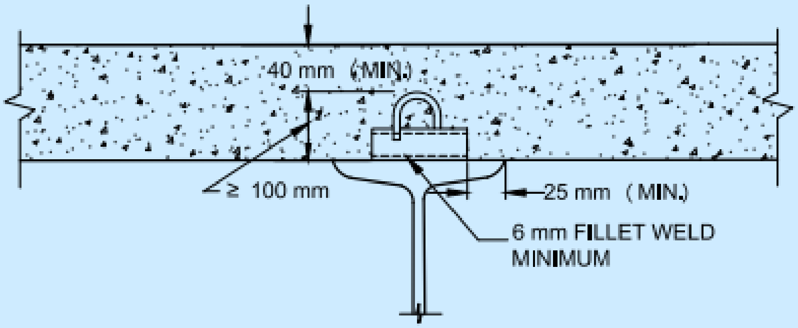
The shear connectors shall fulfill the dual purpose of transferring shear force between concrete and structural steel as well as anchoring the two components relative to each other with minimum slip to ensure full or partial composite action as per the design requirement. The dimensional details of shear shall be as given in Fig. 8.

11.1 Longitudinal Shear in Beams and Slabs

Longitudinal shear load on shear connectors in a composite section, irrespective of boundary conditions of the members, is to be calculated for service and fatigue limit states on the basis of elastic theory. Appropriate sectional properties based on effective widths and modular ratios as per the load history and development of composite action shall be considered for the design of the section for resistance against longitudinal shear between steel and concrete.



(a) STUD CONNECTOR



(b) ANGLE / CHANNEL CONNECTOR - TRANSVERSE SECTION

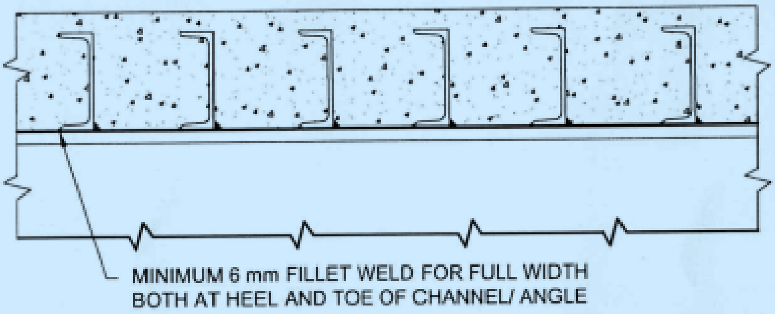

MINIMUM 6 mm FILLET WELD FOR FULL WIDTH
BOTH AT HEEL AND TOE OF CHANNEL/ ANGLE

FIG. 8 DETAILS OF SHEAR CONNECTORS

NOTES

1 The diameter of the stud connector welded to the flange plate shall not exceed two and half times the flange plate thickness.

2 The height of the stud connectors shall not be less than four times their diameter nor 100 mm.

3 The diameter of the head of the stud shall not be less than one and a half times the diameter of the stud and the depth shall not be less than 0.4 d.

4 The size of the fillet weld joining other types of connectors to the flange plate shall not exceed half the thickness of the flange plate.

5 Channel and angle connectors shall have at least 6 mm fillet welds placed along the heel and toe of the channels/angles. The clear distance between the edge of the flange and the edge of the shear connectors shall not be less than 25 mm.

6 The overall height of a connector, including any hoop, which is an integral part of the connector, shall be at least 100 mm with a clear cover of 25 mm.

11.2 Design Strength of Shear Connectors

Shear connectors shall be checked for adequacy against failure in both ultimate limit states and fatigue limit states. The strength of shear connectors against failure under ultimate limit states and fatigue limit states shall be considered as per 11.2.1, 11.2.2 and 11.3, respectively.

11.2.1 *Design Strength of Shear Connectors*

Design static strengths of flexible shear connectors, mainly stud connectors and channel connectors can be determined by the following equations:

a) *Stud connectors*

The design resistance, Q_d of stud shears connectors shall be as given below:

$$Q_\mathrm{d} = \frac{0.8 f_{us}.\pi.d^2/4}{\gamma_\mathrm{mv}} \leq \frac{0.29\ \alpha\ d^2\sqrt{0.8\ f_\mathrm{ck}.E_\mathrm{cm}}}{\gamma_\mathrm{mv}}$$

where

$$\alpha = 0.2\left\{\frac{h_\mathrm{s}}{d}+1\right\} \text{ for } 3 \leq \frac{h_\mathrm{s}}{d} \leq 4 \text{ and } \alpha = 1.0 \quad \text{for } \frac{h_\mathrm{s}}{d} > 4;$$

Q_d = design strength of stud in, Newton (N);

γ_{mv} = partial safety factor for stud connector = 1.25;

d = diameter of the shank of the stud, in mm (16 mm ≤ d ≤ 25 mm);

f_us = ultimate tensile strength of the stud material $\leq$ 500 N/mm^2;

f_ck = Characteristic compressive strength of concrete of density not less than 1750 kg/m^3;

h_s = nominal height of stud in mm; and

E_{cm} = Secant modulus of elasticity of concrete (*see* Annex F).

b) *Channel Connectors*

Assuming that the web of the channel is placed vertical and the shear applied is nominally perpendicular to the web, the design resistance of a channel connector shall be determined as given below:

$$Q_d = \frac{\left[20b(h)^{3/4}\right](0.8f_\mathrm{ck})^{1/3}}{\gamma_{mv}}$$

where

Q_d = Design strength of channel in Newton (N);

h = height of the channel in mm;

b = length of the channel in mm;

f_ck = Characteristic compressive strength of concrete in MPa; and

γ_{mv} = factor for channel shear connector = 1.25.

While using the channel shear connectors, the following recommendations need to be followed:

a) The height h of the channel should not exceed 20 times the channel web thickness or 150 mm, whichever is less;

b) The width b of the channel should not exceed 300 mm;

c) The underside of the top flange of the channel should not be less than 30 mm clear above the bottom reinforcement; and

d) The size of the fillet weld connecting the channel to the flange plate should not exceed half the flange plate thickness.

11.2.2 The design strengths of some standard shear connectors are given in Table 9. The following points have to be considered while using Table 9:

a) $f$ck is the specified characteristic cube strength at 28 days;

b) Connector strengths for concrete of intermediate grade may be obtained by linear interpolation;

c) For channels of lengths different from those quoted above, the capacities are proportional to the lengths greater than 150 mm;

d) For rolled angle and tee shear connectors, the values given for channel connectors are applicable, provided the height is at least equal to that of the channel;

e) For stud connectors of overall height greater than 100 mm, the design static strength should be taken as the values given in Table 9 for 100 mm high connectors;

f) The above provisions of stud connectors are not applicable to composite slab using a profiled deck. The strength of the shear connector in such cases is given in **11.2.3**;

g) The number of shear connectors given by the above Table 9 shall be distributed in the zone between the maximum and the zero moment sections. The number of connectors has to meet both ultimate strength consideration as well as fatigue consideration; and

h) In order to avoid undesirable slip, the maximum interface shear per unit length due to superimposed dead load and imposed load under service conditions at any point in the beam should satisfy **11.3.1**.

Table 9 Ultimate Static Design Strengths of Shear Connectors (*Q*n for Different Concrete Strengths)

(*Clause* 11.2.2 *and* 11.3.1)

Sl No.	Type of Connector	Material	Size		Ultimate Static Strength in kN per connector			
			Nominal diameter mm	Nominal height mm	For concrete strengths, f_{ck} MPa			
					25	30	40	50
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
i)	Stud connectors	Material with a characteristic yield strength of 385 MPa, minimum elongation of 18 percent and a characteristic tensile strength of 495 MPa	25	100	112	125	149	156
			22	100	87	97	115	120
			20	100	72	80	90	100
			20	75	63	71	84	97
			19	100	65	72	86	90
			19	75	64	72	85	90
			16	75	46	51	61	64
			12	65	26	29	34	36
ii)	Channels 150 mm long (min)	As per [C-6B(4)] (E250 A/BR)	ISMC 125		244	259	285	307
			ISMC 100		206	219	241	260
			ISMC 75		166	176	194	209

11.2.3 *Design Resistance of Studs Used with Profiled Steel Sheeting*

11.2.3.1 *Sheeting with ribs parallel to the supporting beams*

The studs are located within a region of concrete that has the shape of a haunch (Fig. 9). When the sheeting is continuous across the beam, the width of the haunch b_0 is equal to the width of the trough, as given in Fig. 10. Where the sheeting is not continuous, b_0 is as given in Fig. 9. The depth of the haunch should be taken as d_p, the overall depth of the sheeting excluding embossments.

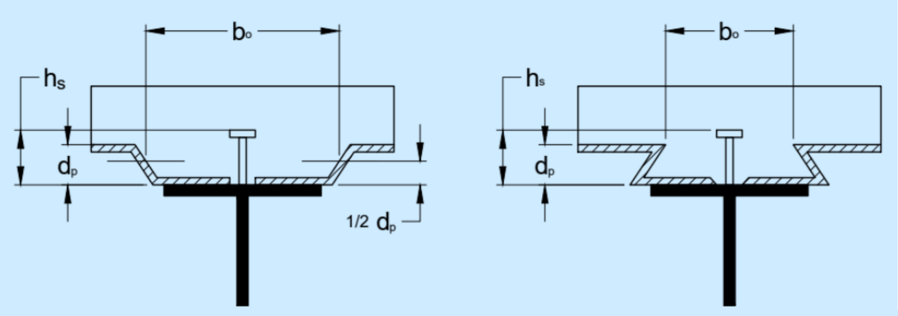


FIG. 9 BEAM WITH PROFILED DECKING SHEET RIBS PARALLEL TO THE BEAM

The design resistance of the shear connector should be taken as the resistance in a solid slab, multiplied by the reduction factor k_p given by the following expression:

$$k_{\mathrm{p}} = 0.6\frac{b_0}{d_{\mathrm{p}}}\left(\frac{h_{\mathrm{s}}}{d_{\mathrm{p}}} - 1\right) \leq 1.0$$

Where h_s is the overall height of the stud, but not greater than d_p+75 mm.

Where the sheeting is not continuous across the beam, as shown in Fig. 9, the side of the haunch and its reinforcement shoud be taken as the depth of the profile d_p excluding the embossments.

11.2.3.2 *Sheeting with ribs transverse to the supporting beams*

Provided that the conditions given in **11.2.2** are satisfied, the design shear resistance should be taken as the resistance in a solid slab, calculated as given by **11.2.1** (except that f_{us} should not be taken as greater than 450 N/mm^2) multiplied by the reduction factor k_t given by:

$$k_{\mathrm{t}} = \frac{0.7}{\sqrt{n_{\mathrm{r}}}}\frac{b_0}{d_{\mathrm{p}}}\left(\frac{h_{\mathrm{s}}}{d_{\mathrm{p}}} - 1\right) \leq 1.0$$

where

n_r is the number of stud connectors in one rib at the beam intersection, not to exceed two in calculation of the reduction factor k_t and of the longitudinal shear resistance of the connection.

The factor k_t should not be taken greater than the appropriate value k_{tmax} given in Table 10. The values for k_t are applicable provided that: the studs are placed in ribs with a height d_p not greater than 85 mm and a width b_0 not less than d_p and for through deck welding, the diameter of the studs is not greater than 20 mm, or for holes provided in the sheeting, the diameter of the studs is not greater than 22 mm.

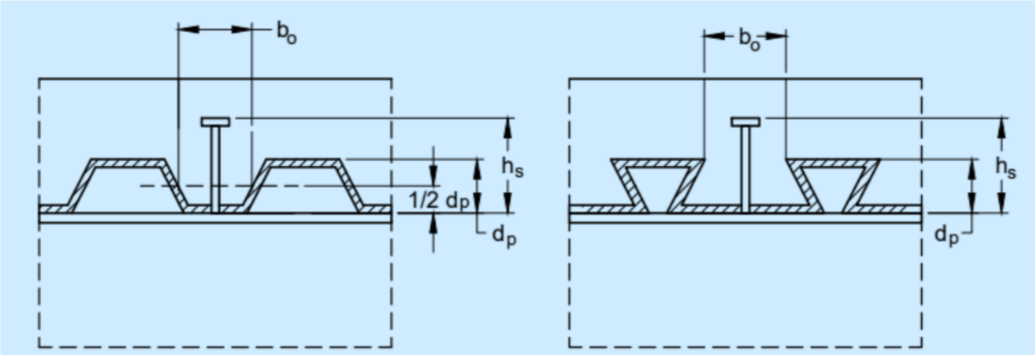


FIG.10 BEAM WITH PROFILED DECKING SHEET RIBS TRANSVERSE TO THE BEAM

Table 10 Upper Limits $K_{t,\max}$ for the Reduction Factor K_T

(*Clause* 11.2.3.2)

Sl No.	Number of Stud Connectors per Rib	Thickness t of Sheet (mm)	Studs 20 mm in Diameter and Welded Through Profiled Steel Sheeting	Profiled Sheeting with Holes and Studs 19 mm or 22 mm in Diameter
(1)	(2)	(3)	(4)	(5)
i)	n_r=1	≤1.0	0.85	0.75
		>1.0	1.0	0.75
ii)	n_r =2	≤1.0	0.70	0.60
		>1.0	0.8	0.60

11.3 Fatigue Strength of Shear Connectors

The fatigue shear stress range (fatigue Strength) of the shear connector shall be obtained from [C-6B(3)], corresponding to the design load life cycle, N_{SC}.

The strength shall be determined as given below:

$$\tau_f = \tau_{fn}\sqrt[5]{5\times10^6/N_{SC}}$$

τ_{fn} = design normal and shear fatigue stress range respectively of the detail for 5 × 10^6 cycles as given in [C-6B(3)].

τ_{fn} = 67 N/mm^2 for stud connector as per good practice [C-6B(3)].

τ_{fn} = 59 N/mm^2 for channel connector as per good practice [C-6B(3)] [provided that the thickness of the top flange of steel beam is greater than or equal to 12 mm and the edge distance from the end of weld to the edge of the top flange is 10 mm].

The design fatigue strengths of some standard shear connectors are presented in Table 11.

Table 11 Fatigue Strengths Qr (in kN)

(*Clause* 11.3)

Sl No.	Type of Connectors (Headed Stud – Diameter)	Connector Material	N = Nos. of Cycles in Millions				
			0.1	0.5	2	10	100
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	Headed studs φ 25	f_{ys} = 385 MPa f_{us} = 495 MPa Elongation = 18 percent	72	52	40	29	18
ii)	Headed studs φ 22		56	40	31	22	14
iii)	Headed studs φ 20		46	33	25	18	12
iv)	Headed studs φ 16		29	21	16	12	7
v)	Channel 150 long for a nominal weld of 8 mm	[C-6B(4)]	108	79	60	43	27

NOTE — For intermediate stress cycles the values may be interpolated from log scales (that is, the above equation). Other connectors, if used, should have their capacities established through tests.

11.3.1 *Spacing of Shear Connectors*

The design shear action per unit length of the steel concrete interface, V_L, is given by:

$$V_L = \sum \left[\frac{VA_{ec}y}{I}\right]_{DL,IL}$$

where

V_L = Longitudinal shear per unit length;

V = The factored vertical shear forces due to dead load and imposed load (including impact if any) separately at each state of load history;

A_{ec} = The transformed compressive area of concrete above the plastic neutral axis of the composite section with the appropriate modular ratio depending on the nature of load (short term that is, imposed load, or long term, that is, dead load);

y = C.G. distance of transformed concrete area from the plastic neutral axis;

I = Moment of Inertia of the composite section using an appropriate modular ratio; and

DL, IL = Different load history conditions, that is, sustained load or composite action dead load, transient load, or composite action imposed load. These loads are to be considered with appropriate load factors at this stage.

Maximum spacing of shear connectors, S_{L1} is given as

$$S_{L1} = \frac{\sum Q_n}{V_L}$$

Q_n is the ultimate static strength of one shear connector (Table 9) and the summation is over the number of shear studs in one section.

The maximum longitudinal force at the interface due to bending moment shall also be calculated over the shear span, *L,* equal to the distance from zero moment to maximum moment section and is given by the following equations:

$$H_1 = A_{sl} f_y \times 10^{-3} / \gamma_{m0}$$

$$H_2 = 0.36 f_{ck} A_{ec} \times 10^{-3}$$

where

H_1, H_2 = Longitudinal interface shear force due to bending (kN);

A_{sl} = Area of tensile steel (mm^2) in the longitudinal direction;

A_{ec} = Effective area of concrete:

$b_{eff}.x_u$ (for neutral axis within the slab); and

$b_{eff}.\ d_s$ (for the neutral axis in the steel section)

Sufficient connectors should be provided to resist the longitudinal force *H*, the maximum compressive force action in the composite beam slab interface, which is the smaller of H_1 and H_2.

The maximum spacing of shear connectors, S_{L2}, is given as:

$$S_{L2} = \frac{\sum Q_n}{H} . L$$

11.3.2 *Fatigue Strength of Shear Connectors*

$$V_r = \Sigma \left[\frac{V_R . A_{ec} . y}{I}\right]_{LL}$$

where

V_R = The shear range in which is the difference between the maximum and minimum vertical shear envelop due to imposed load and impact; and

H = is imposed load with impact.

V, Aec, y and I are as explained above

Spacing of shear connectors from fatigue consideration is given as:

$$S_R = \frac{\Sigma Q_r}{V_r}$$

Q_r is the design fatigue strength of one shear connector, which is to be taken from as per good practice [C-6B(3)] Table 10.

For full shear connection, the lowest spacing of S_{L1}, S_{L2}, and S_R is to be provided as the actual spacing of the shear connectors.

11.4 Partial Shear Connection

11.4.1 Partial shear connection may be used either for attaining economy without losing much in the moment capacity of the composite section or where the number of shear connectors required for full shear cannot be provided without compromising minimum spacing provisions.

Partial shear connections may be used in plastic and compact sections. The number of connectors n_p shall then be determined by a partial shear connection theory, taking into account the deformation capacity of the shear connector.

$$S_c \text{ degree of shear connection} = \frac{n_p}{n_f}$$

n_p = Number of shear connectors provided for partial shear connection;

n_f = Number of shear connectors required for full shear connection;

M_R = Required reduced bending resistance of the section;

M_d = The fully plastic moment of resistance of the composite section; and

M_{ps} = Plastic moment of resistance of steel section alone.

$$n_p = \frac{M_R - M_{ps}}{M_d - M_{ps}} n_f$$

11.4.2 *Limitation on the Use of Partial Shear Connection in Beams for Buildings*

Headed studs with an overall length after welding not less than 4 times its diameter and with shank diameter not less than 16 mm and neither greater than 25 mm may be considered as ductile with the following limits for the degree of shear connection, S_c:

a) For steel sections with equal flanges:

$$L_e \leq 25: S_c \geq \; 1 - 1.42\varepsilon^2\,(0.75 - 0.03L_e);\, S_c \geq 0.4$$

$$L_e > 25: S_c = 1.0$$

b) For steel sections having a bottom flange with an area of three times the area of top flange:

$$L_e \leq 20: S_c \geq 1 - 1.42\varepsilon^2\,(0.30 - 0.015L_e);\;\; S_c \geq 0.4$$

$$L_e > 20: S_c = 1.0$$

where

$\epsilon = \sqrt{250/f_y}$, L_e is the distance between points of zero bending moment in the sagging bending range in metres. For typical continuous beams, L_e may be assumed as shown in Fig. 6 and Fig. 7.

c) For steel sections having a bottom flange with an area exceeding the area of the top flange but less than three times that area, the limit for S_c may be determined from expressions in (a) and (b) above by linear interpolation.

11.5 Precautions against Separation of Steel Beam from Concrete

a) Where a concrete haunch is used, between the steel flange and the soffit of the slab, top of stud and top flange of channel shear connectors shall extend up to at least 40 mm above the transverse reinforcements in the haunches, provided the reinforcements are sufficient to transfer longitudinal shear; and

b) Where shear connectors are placed adjacent to the longitudinal edge of the slab, transverse reinforcement provided in accordance with **11.7** shall be fully anchored in the concrete between the edge of the slab and the adjacent row of connectors.

11.6 Detail of Haunches in Reinforced Concrete

11.6.1 Figure 11 indicates the dimension of haunches as applicable for slabs with haunches resting on steel beam. The edge of haunches shall be located outside a line drawn at 45 degrees from the outside edge of the base of the connector, as shown in Fig. 11.

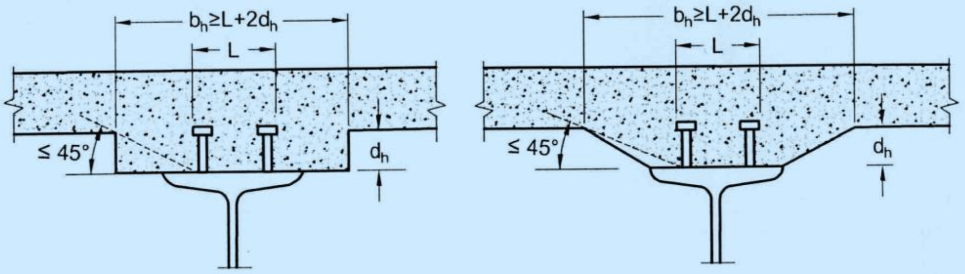


FIG. 11 DIMENSION OF HAUNCHES

11.6.2 *Clear Cover to Shear Connectors*

The clear depth of concrete cover over the top of the shear connectors shall not be less than 25 mm. The horizontal clear concrete cover to any shear connector shall not be less than 50 mm as shown in Fig.12.

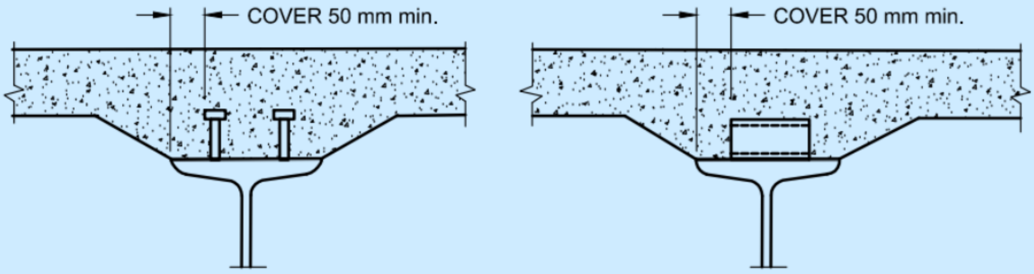


FIG. 12 CLEAR COVER TO SHEAR CONNECTORS

11.6.3 *Spacing of Shear Connectors*

Where the compression flange of steel beam, in spite of being semi-compact is assumed to be compact or plastic based on the restraint provided by shear connectors, the centre-to-centre spacing of the shear connectors in the direction of the compression should satisfy the following:

a) Where the slab is in contact over the full length (for example, solid slab)

$$S_{\mathrm{L}} < 21 \cdot t_{\mathrm{f}} \, . \, \varepsilon$$

b) Where the slab is not in contact over the full length (for example, slab with ribs transverse to the beam):

$$S_{\mathrm{L}} < 14 \cdot t_{\mathrm{f}} \, . \, \varepsilon$$

where

$\varepsilon = \sqrt{250/f_{\mathrm{y}}}$

t_{f} = thickness of the flange;

f_{y} = nominal yield strength of the flange in N/mm^2; and

S_{L} = maximum spacing of the shear connector.

In addition, the clear distance from the edge of the compression flange to the nearest line of shear connectors should not be greater than $9t_{\mathrm{f}} \ \varepsilon$ or 50 mm, whichever is less.

In all cases, a shear connector shall be provided throughout the length of the beam and may be uniformly spaced between critical cross sections. The maximum longitudinal spacing of the shear connectors shall be limited to the lesser of 600 mm or 3 times the total slab thickness or four times the height of the connector (including any hoop which is an integral part of the connector), whichever is least.

Minimum spacing should be such as to allow proper concrete flow and compaction around the connectors. In stud connectors, the minimum spacing should not be less than 75 mm.

11.7 Transverse Shear Check (Requirement of Bottom Steel in Concrete Slab)

Planes, which are critical for longitudinal shear failure in the process of transfer of longitudinal shear from the beam to the slab are of four main types as shown in Fig. 13. The shear force Q in kN/m of beam is given by:

$$Q = \frac{N_{\mathrm{r}} \, Q_{\mathrm{u}}}{S_{\mathrm{L}}}$$

where

N_{r} = Number of shear connection at a section;

Q_{u} = Design strength one shear connector; and

S_{L} = Longitudinal spacing of connector in meter.

The shear force transferred per metre length from steel beam to concrete slab above, V_{L} shall satisfy both the following conditions:

a) $V_{\mathrm{L}} \leq 0.623 \, L\sqrt{f_{\mathrm{ck}}}$; or

b) $V_{\mathrm{L}} \leq 0.232 \, L\sqrt{f_{\mathrm{ck}}} + 0.1. A_{\mathrm{st}}. f_{\mathrm{yk}}. n$

where

V_{L} = Longitudinal shear force per unit length calculated for the ultimate limit state;

f_{ck} = Characteristic strength of concrete, in MPa;

f_{yk} = Yield stress of transverse reinforcement, in MPa;

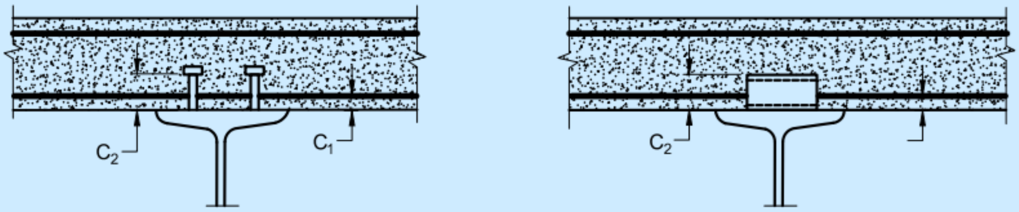
L = Length (in mm) of possible shear planes; for two rows of shear studs as shown in Fig.15, $L = 2\,h_s + b_0$;

n = Number of times each lower transverse reinforcing bar is intersected by a shear surface (that is, the number of rows of shear the connector at one section of the beam). Generally, for T-beam n = 2 and for L-beam n = 1; and

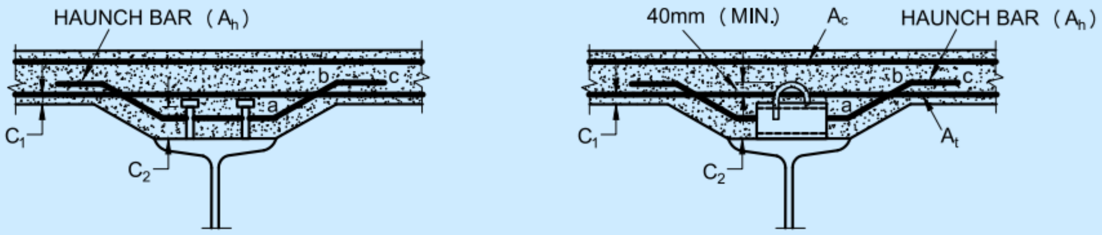
A_{st} = Sectional areas (in cm^2) of transverse reinforcements per meter run of the beam. The amount of transverse steel (cm^2/m) in the bottom of the slab shall not be less than $\frac{2.5Q}{f_{yk}}$.

11.8 General Arrangements of Transverse Reinforcements

11.8.1 If the concrete by itself is insufficient to take the longitudinal shear, sufficient transverse reinforcements shall be provided to transfer longitudinal shear force from the beam to the effective width of the slab. The area of transverse reinforcement per unit length of the beam will be the sum total of all the reinforcement [A_t, A_b or A_h, as shown in Fig. 14(a), Fig. 14(b) and Fig. 14 (c)], which are intersected by the shear plane and are fully anchored on both the sides of the shear plane considered.



(a) STUD CONNECTORS IN UN-HAUNCHED BEAM (b) CHANNEL CONNECTORS IN UN-HAUNCHED BEAM

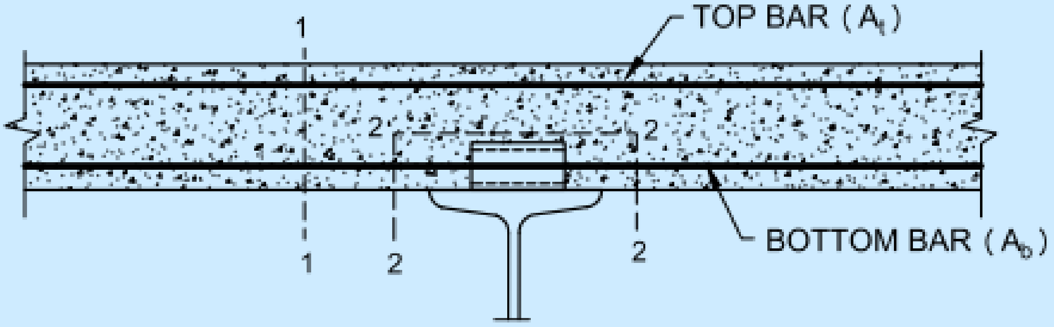


(c) STUD CONNECTORS IN HAUNCHED BEAM (d) CHANNEL CONNECTORS IN HAUNCHED BEAM

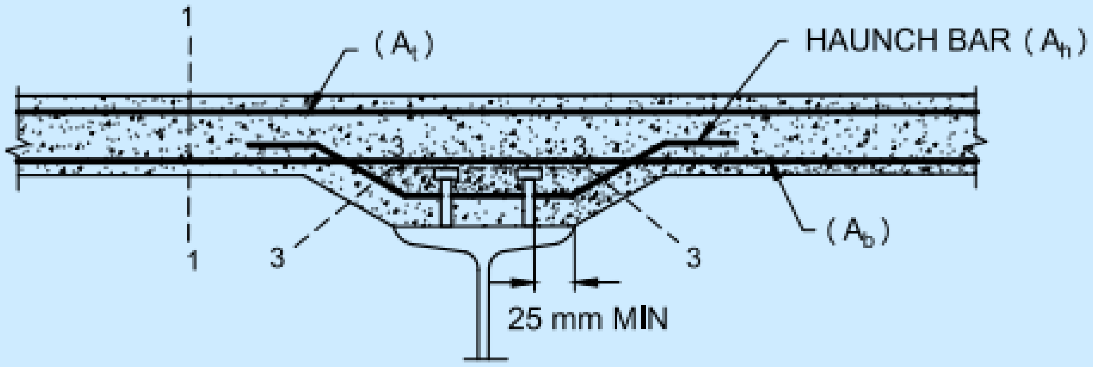
FIG. 13 ARRANGEMENT OF TRANSVERSE REINFORCEMENTS

11.8.2 *Total Transverse Reinforcements*

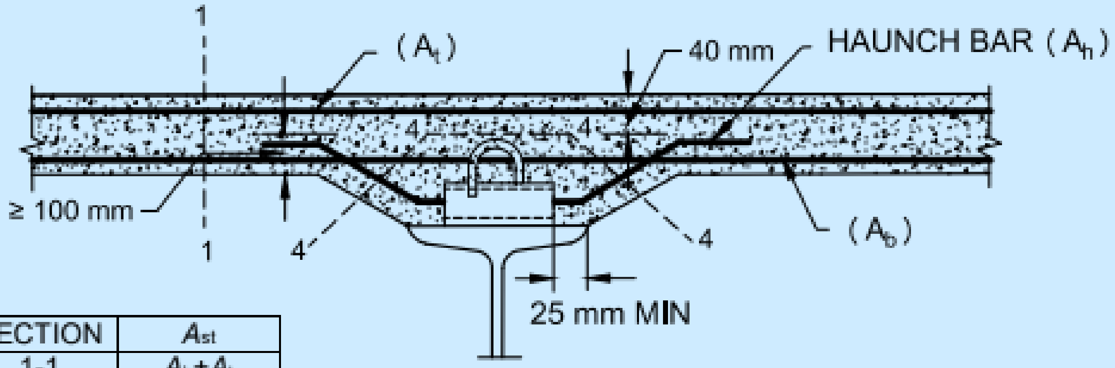
The total transverse reinforcements Ast· per unit length of the beam in case of shear plane 1 – 1, which crosses the whole thickness of the slab, will be the sum of (A_t + A_b) [Fig. 14(a)]. Area of reinforcements A_t and A_b include those provided for flexure. The total transverse reinforcements across plane 2-2 [Fig. 14(a)] is $A_{st} = 2\,A_b$ and that across plane 3-3 [Fig. 14(b)] is $Ast = 2Ah$ as these planes do not cross the full thickness of the slab. In the case of shear plane 4 – 4 [Fig. 14(c)], the total transverse reinforcement is $Ast = 2(A_h + A_b)$. The transverse reinforcements shall be placed at locations as shown in Fig. 14. The haunch bars shall be extended beyond the junction of bottom bars by a length equal to the anchorage length.


TOP BAR (A_t)
1
2
2
1
2
2
BOTTOM BAR (A_b)

(a) NON- HAUNCHED BEAM


1
(A_t)
HAUNCH BAR (A_h)
3
3
1
3
3
(A_b)
25 mm MIN

(b) LARGE HAUNCHED BEAM


1
(A_t)
40 mm
HAUNCH BAR (A_h)
4
4
≥ 100 mm
1
4
4
(A_b)
25 mm MIN

SECTION	A_{st}
1-1	A_b+A_t
2-2	$2A_b$
3-3	$2A_h$
4-4	$2(A_b+A_h)$

(c) SMALL HAUNCHED BEAM

FIG. 14 TRANSVERSE REINFORCEMENTS ALONG SHEAR PLANES

12 COMPOSITE SLABS WITH PROFILED STEEL SHEETING

12.1 General

The provisions in this section deal with composite floor slabs spanning only in the direction of ribs of the decking. The provisions are applicable in buildings, wherein the slabs are subjected to predominantly static imposed loads. The application of the provision is limited to narrowly spaced web, which is defined by the ratio of the width of the sheet rib to the rib spacing $b_r/b_p \leq 0.6$ (*see* Fig. 15).

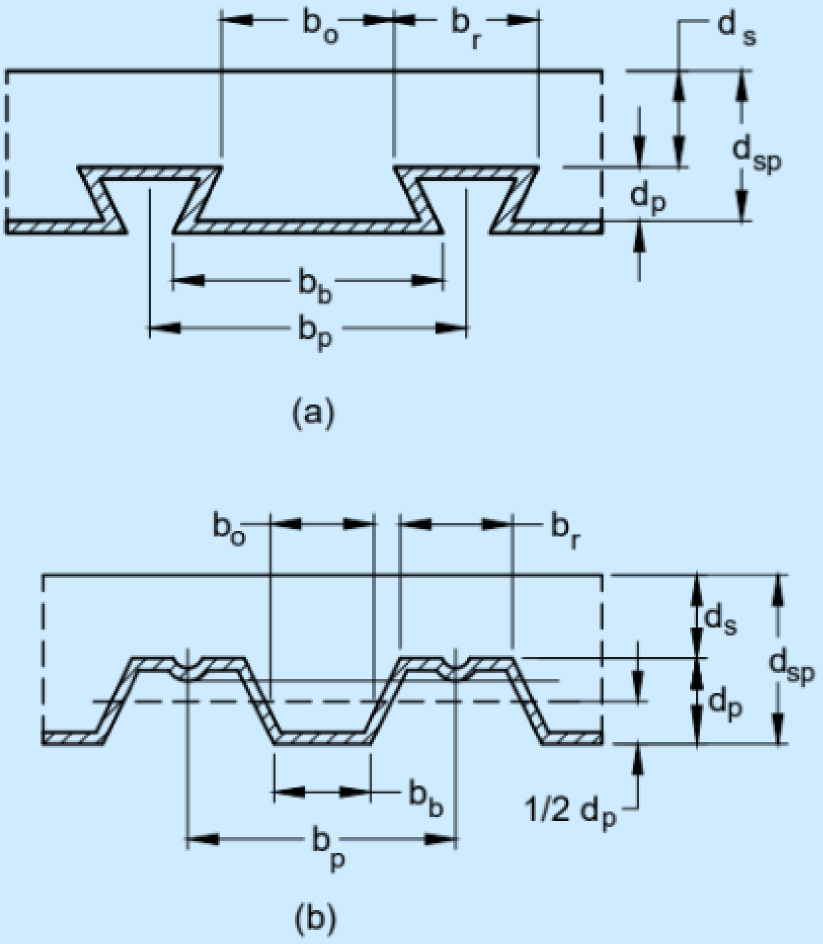


FIG. 15 PROFILE DIMENSION FOR COMPOSITE SLABS.

12.2 Prequalifications

12.2.1 *Prequalification of Slab dimension*

The prequalification of composite and non-composite slabs are presented below:

a) Where the slab acts composite with a steel beam or used as a diaphragm:
  1) the overall depth of the slab should not be less than 90 mm; and
  2) the thickness of concrete above the main top flat surface of the sheeting ribs should not be less than 50 mm.

b) Where the slab does not act composite with a steel beam or has no other stabilizing function:
  1) the overall depth of the slab should not be less than 80 mm; and
  2) the thickness of concrete above the main flat top surface of the sheeting ribs should not be less than 40 mm.

12.2.2 *Bearing Length*

The recommended minimum bearing lengths of steel decking on the support (L_{bs}) and the composite slab, including the cast in place concrete (L_{bs}) shall be as given in (*see* Fig. 16):

a) For composite slab bearing on steel or concrete: L_{bc}=75 mm, L_{bs}=50 mm; and

b) For composite slab bearing on other material: L_{bc}=100 mm, L_{bs}= 70mm.

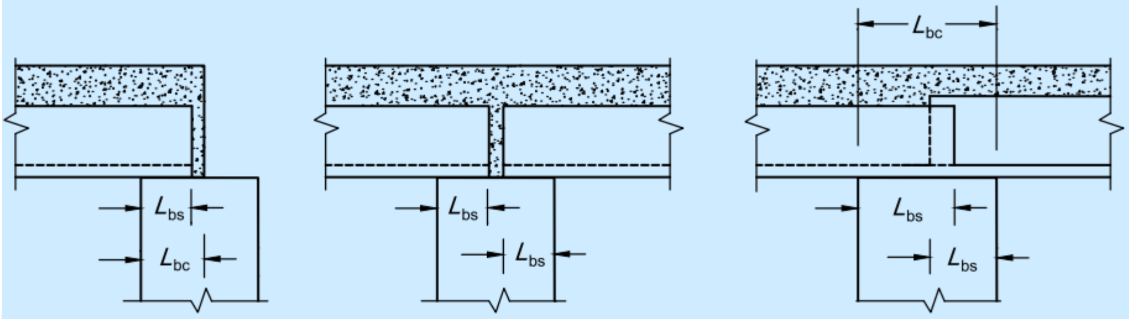


FIG. 16 MINIMUM BEARING LENGTHS

12.2.3 *Reinforcement for Shrinkage and Temperature Stresses*

The effect of temperature stress in composite slabs in buildings is normally neglected unless required in special conditions. The effect of shrinkage is to be considered. The total shrinkage strain for design may be taken as 0.000 3 in the absence of test data.

12.2.4 *Minimum Reinforcement*

The minimum reinforcement in either direction should be according to [C-6B(2)]. The spacing of the reinforcement bar should be in accordance with as per good practice [C-6B(2)].

12.2.5 *Size of Aggregates*

In addition to the above, the largest nominal aggregate size should be according to as per good practice [C-6B(2)].

12.3 Analysis for Internal Forces and Moments

12.3.1 *Analysis of Profile Steel Sheeting as Shuttering*

a) The elastic analysis shall be used where sheeting is considered. The design based on the elastic distribution of bending moment is conservative, as it does not take into account of redistribution of moments that can occur between support and mid span sections;

b) In the analysis of propped profile steel sheeting, the magnitude of bending moments and shear forces could be conservatively calculated by using the coefficients of bending moment and shear force as per good practice [C-6B(2)] ;

c) More accurate analysis and design of profile steel sheeting as a shuttering should be in accordance with as per good practice [C-6B(18)] ;

d) If the deflection at the center of the shuttering due to its own weight and the wet weight of concrete is less than (1/10) of the depth of the composite slab, the effect of 'ponding' due to shuttering deflection can be disregarded. Otherwise, that effect of additional load shall be evaluated by taking the additional uniform depth of concrete over the span as 0.7 times the central deflection. Ponding is explained in C-3'

e) The effect of ponding, especially in longer span, can be reduced by propping the shuttering during concreting until the concrete hardens. Plastic redistribution of moments in the propped shuttering is not allowed in evaluating stresses due to self-weight and wet concrete weight.

12.3.2 *Analysis of Composite Slab*

a) The application of linear methods of analysis is suitable for the serviceability limit states as well as for the ultimate limit states. Plastic methods shall be used only in the ultimate limit state;

b) The following method of analysis may be used for ultimate limit states:

1) Linear analysis without redistribution (serviceability limit state), and with redistribution (Ultimate limit state). If the effects of cracking of concrete are neglected in the analysis for ultimate limit states, the hogging bending moments at internal supports may be optionally reduced by up to 30 percent and corresponding increases are made to the sagging bending moments in the adjacent spans;

2) Rigid-plastic global analysis may be used provided it is shown that sections where plastic rotations are required have sufficient rotation capacity. Plastic analysis without any direct check on rotation capacity may be used for the ultimate limit state if reinforcing steel satisfying the ductility requirement in **6.2.3** is used and the span length is not greater than 3.0 m. (Ultimate limit state); and

3) Elastic-plastic analysis accounting for the non-linear material behavior. (Ultimate limit states).

c) A continuous slab may be designed as a series of simply supported spans. Nominal reinforcement should be provided in accordance with as per good practice [C-6B(2)], over the intermediate supports to manage crack size; and

d) Concentrated loads may be assumed to be distributed over an effective width of the slab, assuming the load is distributed at an angle of 45° to the horizontal up to the top surface of the decking.

12.4 Design of Composite Slabs

Proprietary data backed by analysis and tests may be used in the design. Otherwise, the procedure given below may be used to evaluate the strength of composite slabs.

12.4.1 *Effective Span*

a) When a continuous composite slab is designed as a series of simply supported spans, for simplicity, the effective span can be taken as the lesser of the following:

1) Distance between centres of the supports; and

2) The clear span plus the effective depth of the slab.

b) Where the composite slab is designed as continuous, it is permitted to use an equivalent isostatic span for the determination of the resistance. The span length should be taken as:

1) 0.8 L for internal span (effective span L); and

2) 0.9 L for external span (effective span L).

12.4.2 *Design of Profile Steel Sheeting as Shuttering During Construction*

The stress analysis of the profiled steel sheeting should be evaluated using the design equations or tests. For the ultimate limit state, the resistance of the sheet to sagging and hogging bending, together with the effects of combined bending and web crushing, are normally critical:

a) For the serviceability limit state, the limiting value of deflection $\delta_{\max}$ of steel sheeting under its own weight plus the weight of wet concrete may be considered as $L/180$ (where L is the effective span between supports) as per good practice [C-6B(3)];

b) Profiled decking acting alone resists construction, dead, and imposed load until the concrete hardens and gains strength. 'Ponding' effect, especially in long spans due to excessive deflection of decking, has to be accounted while evaluating design forces and design strength unless sufficient propping is provided during the construction stage until the concrete hardens; and

c) The longer spans will require propping to eliminate substantial deflection. Otherwise, a significant increase in concrete weight due to ponding has to be accounted.

12.4.3 *Design of Composite Slab for the Ultimate States*

The bending moment and shear force distribution in continuous beams for secondary, as well as primary moment resistant frames/beams, have to be determined by structural analysis. The design values of load effects shall not exceed the design values of resistance for the relevant ultimate limit states.

12.4.3.1 *Design flexural resistance*

The design flexural resistance calculation shall take the following provisions into consideration:

a) The design bending resistance, M_d of any cross section should be in accordance with Annex C, where the yield stress of the steel sheeting should be taken as f_{yp};

b) The effect of local buckling of compressed parts of the sheeting should be considered by using effective widths not exceeding twice the limiting values of Class-1 steel webs as discussed in as per good practice [C-6B(3)];

c) For the effective area A_p of the steel sheeting, the width of embossments and indentations in the sheet should be neglected unless tests infer that a larger area is effective;

d) The sagging bending resistance of a cross-section should be calculated from the equilibrium of stress distribution as shown in **C-4**;

e) In hogging bending regions, the contribution of steel sheeting shall be taken into account only where the sheet is continuous. The redistribution of moments that can occur between support and mid-span sections shall not be considered. If the contribution of the steel sheeting is neglected, the hogging bending resistance of a cross-section should be calculated as reinforced concrete for the stress distribution, as shown in **C-4.3**; and

f) In the case of partial shear connection, the sagging design bending resistance, M_d, shall be calculated as per **C-5**.

12.5 Shear Resistance of Composite Slab

12.5.1 *Punching Shear*

The punching shear resistance of a composite slab should be calculated as per good practice [C-6B(2)], where the critical perimeter is as shown in Fig. 17.

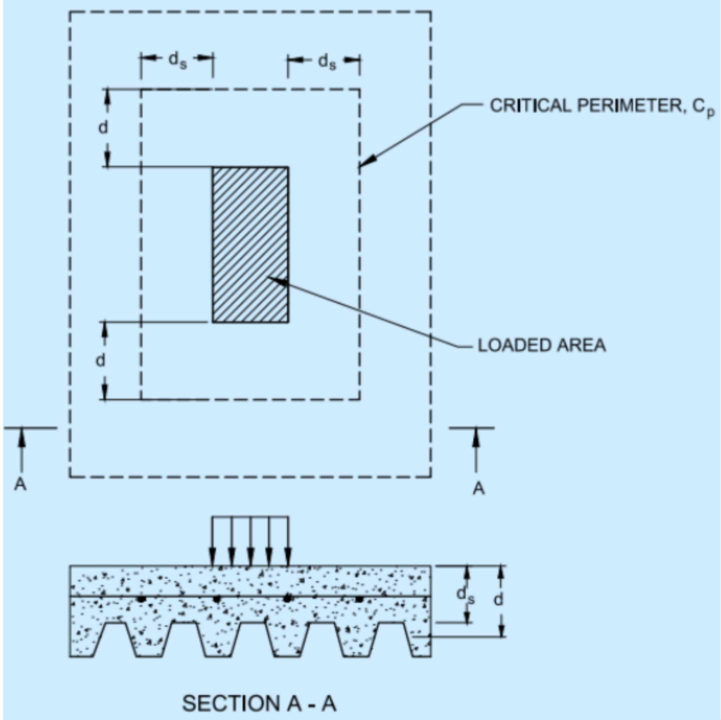


FIG. 17 PUNCHING PERIMETER IN A PROFILED COMPOSITE SLAB

12.5.2 *Resistance to Shear*

The vertical shear resistance V_{dvd} of composite slab over a width equal to the distance between centres of ribs and the effective depth, which depends on the effective depth of the cross section to the centroid of the tensile reinforcement, should be in accordance with as per good practice [C-6B(2)].

The sheeting may be considered as the tensile reinforcement, provided that it is fully anchored beyond the section considered. For heavily loaded slabs, additional reinforcement may be required at the support when the profiled steel sheeting is discontinuous and has only limited anchorage.

In the case of partial shear connection, the shear capacity may be governed by the interface shear strength between steel decking and concrete, as presented in Annex C.

12.6 Serviceability Limit State

12.6.1 *Design against Cracking*

The crack width is calculated at the top surface in the hogging moment region using standard methods prescribed for reinforced concrete in as per good practice [C-6B(2)]. Crack width should not exceed 0.3 mm. The provision of 0.4 percent steel at the top of the slab will normally avoid cracking problems in propped construction. The provision of 0.2 percent of steel is normally sufficient for the same in un-propped construction.

If the environment is corrosive, it is advisable to design the slab as continuous at supports and take advantage of steel provided for negative bending moment resistance and for minimizing cracking during service loads.

12.6.2 *Deflection Limits*

As per good practice [C-6B(2)] gives a stringent deflection limitation of span/350 or 20 mm whichever is less, which may be unrealistic for un-propped construction. The span to depth ratio in the range of 25 to 35 for the composite condition is recommended for the simply supported slabs and the continuous slabs. The deflection of the composite slabs is influenced by the slip between sheeting and concrete. Testing is the best method to estimate the actual deflection for the conditions adopted.

12.6.3 *Fire Resistance*

The fire resistance is based on (a) thermal insulation criterion concerned with limiting the transmission of heat by conduction and (b) integrity criteria concerned with preventing the spread of flames and hot gases to nearby compartments. These are met by specifying the adequate thickness of insulation below the metal decking. When the metal decking is used as a permanent shuttering, the fire resistance of the slab shall be considered as per as per good practice [C-6B(2)].

13 COMPOSITE COLUMNS

13.1 General

13.1.1 This section applies to various forms of steel-concrete composite columns, including fully or partly encased steel columns and concrete in-filled rectangular or circular steel tubes, provided:

a) The columns or compression members consist of structural steel with grade conforming to the accepted standard [C-6B(4)] and normal weight concrete of strength M20 to M60.

b) This clause applies to isolated columns or compression members in framed structures where the other structural members are either composite or steel members.

c) The steel contribution ratio δ (Table 12) should fulfill the criteria:

$$0.2 \leq \delta \leq 0.9$$

d) Further:

   1) The influence of local buckling of the structural steel section on the resistance of the composite section as a whole shall be considered in the design; and

2) The effects of local buckling may be neglected for a steel section fully encased in accordance with **13.2**, and for other types of cross-section, the maximum width to thickness ratio given in as per good practice [C-6B(3)] shall not be exceeded.

13.1.2 *Types of Composite Columns*

Composite columns can be of two types:

a) Encased where concrete encases the steel section (*see* Fig. 18); and

b) In-filled where concrete fills rectangular or circular steel tube (*see* Fig. 19).

13.2 Details for Composite Action

In composite columns with fully encased steel sections, concrete cover to structural steel sections shall be at least 40 mm or one-sixth of the breadth *b* of the flange, over steel section. The concrete shall be adequately held by steel reinforcements and stirrups all around. The steel section shall be unpainted to ensure bond and friction between steel and concrete, but cleaned to ensure protection against corrosion and spalling of concrete. The cover to steel reinforcement should be in accordance with as per good practice [C-6B(2)].

Shear transfer between steel-concrete interfaces is ensured basically through bond for which calculated shear stress at interface shall be limited in accordance with Table 15, beyond which mechanical shear connectors are to be provided.

13.3 Members Under Axial Compression

Standard composite sections used as columns are as shown at Fig. 18 and Fig. 19.

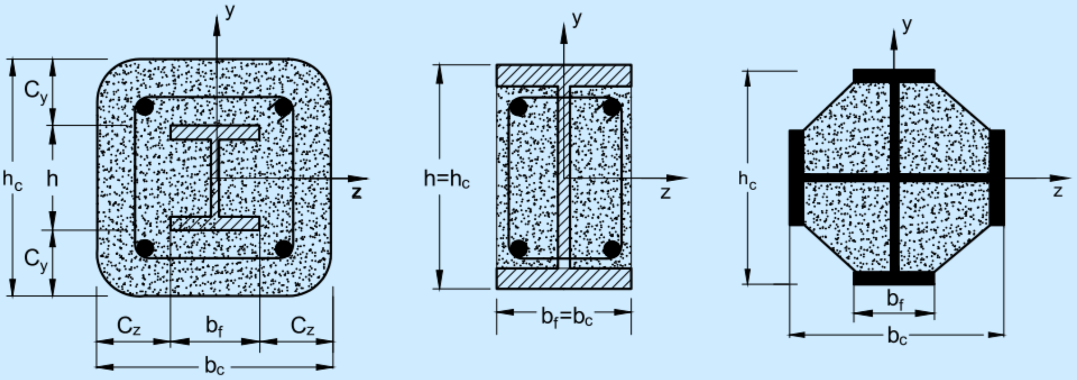


FIG. 18 FULLY AND PARTIALLY CONCRETE ENCASED COLUMNS

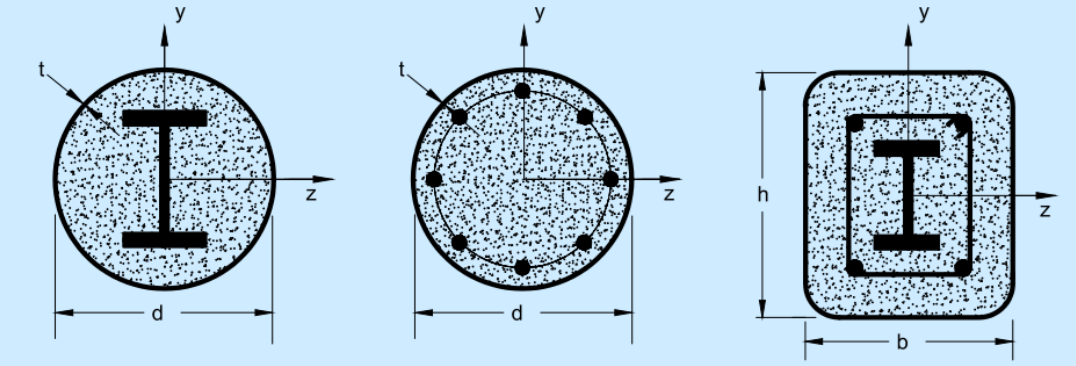


FIG. 19 CONCRETE IN-FILLED COLUMNS

13.3.1 *General Design Philosophy*

To ensure structural stability of a compression member, second-order effects like residual stresses, geometrical imperfections, local instability, cracking of concrete, creep/shrinkage of concrete, yielding of structural steel and reinforcement etc. shall be considered. While designing the compression members, including design for the above effects, the following shall be taken into account:

a) The above effects shall be considered in any direction in which failure might occur if they affect the structural stability significantly;

b) Internal forces shall be determined by any of the analysis methods discussed in **6**;

c) Full composite action between steel and concrete shall be considered up to failure; and

d) Effects of creep and shrinkage shall be considered if they are likely to reduce the structural stability significantly. For simplification, creep and shrinkage effects may be ignored if the increase in the first-order bending moments due to creep deformations from permanent loads is not greater than 10 percent of first-order bending moments due to total design loads.

13.3.2 *Design Guidelines*

The simplified design provisions given in the following sections is applicable for composite members that are doubly symmetrical and uniform in cross-section throughout the length of the member. This method is not applicable to members consisting of two or more unconnected sections. Further, the composite member should conform to the following conditions.

a) The non-dimensional slenderness λ shall not be greater than 2.

b) For a fully encased steel section (Fig. 18), the maximum thickness of concrete cover that may be used in the strength calculation is limited to:

$$c_z\,(Max) = 0.4\,b_f$$

$$c_y\,(Max) = 0.3\,h$$

c) The longitudinal steel reinforcement that may be used in the calculation should not exceed 6 percent of the concrete area; and

d) The ratio of the cross-section's depth h_c to width b_c, (*see* Fig. 18), should be within limits ($0.2 \leq h_c/b_c \leq 5.0$)

13.4 Local Buckling of Steel Sections

13.4.1 To prevent premature local buckling of structural steel components in partly encased steel section and concrete filled steel sections (Fig. 18 and Fig. 19), the width to thickness ratio of individual elements of the steel sections in compression must satisfy the following limits:

$\frac{d}{t} \leq 88\varepsilon^2$	for concrete-filled circular tubular sections
$\frac{h}{t} \leq 50\varepsilon$	for concrete-filled rectangular tubular sections
$b_f/t_f \leq 43\varepsilon$	for partially encased I sections

where

$\varepsilon = \sqrt{\frac{250}{f_y}}$ and f_y is the yield strength of the steel section, in MPa.

13.4.2 For fully encased steel sections, the above local buckling check is not required. However, the concrete cover to the flange of a fully encased steel section should not be less than 40 mm, nor less than one-sixth of the breadth, b_f, of the flange.

13.4.3 Design of concrete-filled rectangular tubular sections where *h/t* ratios exceed the local buckling limits for semi-compact sections should be verified by tests.

13.4.4 The cover to reinforcement should be in accordance with as per good practice [C-6B(2)].

13.4.5 The steel section shall not be painted to ensure friction between steel and concrete but cleaned at the abutting surface to ensure protection against corrosion and spalling of concrete.

13.5 Design Compressive Resistance of Short Composite Columns

13.5.1 A column is termed as a 'short column' when one of the following conditions is satisfied.

a) its non-dimensional slenderness ratio $\lambda \leq 0.2$; and

b) If the actual design compressive force on the composite column, P, is less than 0.1 P_{cr}.

where

$$\lambda = \sqrt{\frac{P_{\mathrm{n}}}{P_{\mathrm{cr}}}}$$

P_{cr} = the elastic buckling load of the column = $\frac{\pi^2 (EI)_{\mathrm{e}}}{L^2}$;

$(EI)_{\mathrm{e}}$ = effective elastic flexural stiffness of the composite column (13.5.2); and

L = the effective length of the column, which may be conservatively taken as the overall length L for an isolated non-sway composite column.

The design compressive strength P_{n} of short columns of plastic and compact sections may be evaluated using the design strength of the material with appropriate partial safety factors. The most common column sections are bi-symmetric. The design compressive strength of short bi-symmetric columns is evaluated using equations given in **D-2**.

NOTE — While providing spiral ties it must be designed as per of [C-6B(2)], and the ratio of the volume of helical reinforcement to the volume of the core is not less than 0.36 $(A_{\mathrm{g}}/A_{\mathrm{co}}-1)f_{\mathrm{ck}}/f_{\mathrm{yk}}$.

(Where, A_{g} = Gross area of section; A_{co} = Area of core of the confined core of column measured to the outer diameter of the helix).

13.5.2 *Effective Elastic Flexural Stiffness*:

a) *Short Term Loading* — The effective elastic flexural stiffness, $(EI)_{\mathrm{e}}$, is obtained by adding up the flexural stiffness of the individual components of the cross-section:

$$(EI)_{\mathrm{e}} = E_{\mathrm{s}} I_{\mathrm{s}} + 0.6\, E_{\mathrm{cm}} I_{\mathrm{c}} + E_{\mathrm{st}} I_{\mathrm{st}}$$

where

E_{s} and E_{st} = modulus of elasticity of the structural steel section and the reinforcement, respectively; and

E_{cm} = secant modulus of the concrete.

b) *Long Term Loading* — In slender columns ($\lambda > 0.2$), the effect of long-term loading should be considered.

$$(EI)_{\mathrm{e}} = E_{\mathrm{s}} I_{\mathrm{s}} + 0.6 E_{\mathrm{ceff}} I_{\mathrm{c}} + E_{\mathrm{st}} I_{\mathrm{st}}$$

$$E_{\mathrm{ceff}} = E_{\mathrm{cm}} \frac{1}{1 + \left(\frac{P_{\mathrm{G,E_d}}}{P_{\mathrm{E_d}}}\right) \varphi_{\mathrm{t}}}$$

where

φ_{t} = creep coefficient according to [C-6B(2)]

$P_{\mathrm{E_d}}$ = Total design axial load

$P_{\mathrm{G,E_d}}$ = Part of the *axial load* $P_{\mathrm{E_d}}$ that is caused due to the permanent gravity loads

If the eccentricity *'e'* of loading is more than twice the cross-section dimension *'D'* ($e > 2D$), the effect on the bending moment distribution caused by increased deflections due to creep and shrinkage of concrete will be very small and may be neglected. The effect of long-term loading need not be considered if the non-dimensional slenderness (λ) of the composite column is less than the limiting values given in Table 12.

Table 12 Limiting Values of λ or Long Term Loading

(*Clause* 13.1 *and* 13.5.2)

Sl No.	Cross-sections	Braced Non-sway Systems	Un-braced and/or Sway System
(1)	(2)	(3)	(4)
i)	Concrete encased cross-section	0.8	0.5
ii)	Concrete filled cross-section	$\frac{0.8}{1-\delta}$	$\frac{0.5}{1-\delta}$

NOTE — δ is the steel contribution ratio defined as $\delta = \frac{A_s.f_y}{P_d \gamma_{mo}}$.

P_d is defined in **D-2**.

When λ exceeds the limits prescribed above and $e/D < 2$, the effect of creep and shrinkage of concrete should be considered by adopting the modulus of elasticity of concrete E_{cs} instead of E_{cm} where E_{cs} is defined as follows:

$$E_{cs} = 0.75E_{cm}\left[1 - \frac{0.5P_{dd}}{P}\right]$$

where

P =the applied factored axial load; and

P_{dd} =the part of the factored load permanently acting on the column.

The effect of long-term loading may be ignored for concrete filled tubular sections with $\lambda \leq 2.0$ provided that $\delta > 0.6$ for braced (non-sway) columns and $\delta > 0.75$ for unbraced (sway) columns.

13.6 Long Members Subjected to Axial Compression

The non-sway composite columns need not be checked for buckling if any one of the following conditions is satisfied:

a) $P < 0.1P_{cr}$ where P is the axial force in the column, and P_{cr} is the elastic buckling load of the column, defined in **13.5.1**.

b) Non-dimensional slenderness $\lambda < 0.2$.

For columns not satisfying the above conditions, safety against buckling strength shall be checked about the corresponding axis. The following equation needs to be satisfied for buckling load:

$$P \leq \chi \cdot P_d$$

where

P = the applied factored axial load;

P_d = is the design plastic resistance to compression (**D-2**);

$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \lambda^2}}$ = is the stability reduction factor;

$\phi = 0.5[1 + \alpha(\lambda - 0.2) + \lambda^2]$;

λ = Non-dimensional slenderness ratio;

α = A value that represents initial imperfections and residual stresses which is based on the buckling curve to be adopted, which is further dependent on the type of section and the axis of bending as given below (*see* Table 13):

Curve *a* = for concrete-filled tubular sections with reinforcement percentage less than 3 percent of gross cross section area and buckling about both axes.

Curve b = for fully or partially concrete-encased I-sections buckling about the strong axis (z-z axis) of the steel sections and for concrete-filled tubular sections with steel reinforcement percentage more than 3 percent of gross cross section area and buckling about both axes or concrete filled tubular section with the addition of I section at the core and buckling about both axes.

Curve c = for fully and partially concrete-encased I-sections buckling about the weak axis (y-y axis) of the steel sections.

Table 13 Imperfection Factor α for the Buckling Curves

(*Clause* 13.6)

Sl No.	Buckling Class	a_0	a	b	c	d
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	α	0.13	0.21	0.34	0.49	0.76

13.7 Members Subjected to Combined Compression and Bending

When the bending moment in the section is zero (that is, M = 0), the design compressive strength is as given in **13.5**. Similarly, the plastic moment of resistance of a column at zero compression load is as given **D-3**. The equations for evaluating the design bending resistance of symmetric column sections are given in **D-4**.

13.7.1 *Bending Resistance under High Shear*

While determining the plastic resistance when the simultaneous shear force is high at the section as given below, the bending resistance shall be reduced as given below:

If the shear force V on the steel section exceeds 60 percent of the design shear resistance V_d of the steel (**8.3.6.1**), the influence of the transverse shear on the resistance in combined bending and compression shall be taken into account by a reduced design steel strength $(1 - \beta) f_y / \gamma_{m0}$ in the shear area A_v (β is determined as per **8.3.6.2**).

a) Unless a more accurate analysis is used, the design shear action, V_d, may be distributed into (V_s, acting on the structural steel) and (V_c, acting on the reinforced concrete section) as:

$$V_s = V \frac{M_{ds}}{M_d}$$

$$V_c = V - V_s$$

where

M_{ds} = design moment of resistance of steel section alone;

M = design moment of resistance of the entire composite section; and

V_d = may be assumed to be resisted by steel sections alone as a simplifying approximation.

13.7.2 *Second Order Effects on Bending Moment*

If neither of the two conditions (a) and (b) for short compression members in **13.5.1** is satisfied, then the second-order effects on first-order analysis moment shall be considered by modifying the maximum first-order bending moment (moment obtained linear elastic analysis), $M_{\max}$, with an amplification factor k, which is defined as:

$$k = \frac{C_\mathrm{m}}{1 - \frac{P}{P_\mathrm{cr}}} \geq 1.0$$

where

P = the applied factored axial load;

P_{cr} = elastic critical load for the relevant axis and corresponding to a modified effective flexural stiffness given by $(EI)_e$ as given in **13.5.2** and the effective length of the column is taken as per [C-6B(3)];

C_m = equivalent moment factor given in Table 14 to account for non-uniform bending moment over the length of the member; and

ψ = the ratio of moments at the ends of the laterally unsupported members.

13.8 Members Subjected to Axial Force and Uniaxial Bending

13.8.1 While checking a section for combined axial force and bending moment, first, it should be ensured that the section is safe against an axial force acting alone, considering buckling along each principal axis. The resistance of the section shall then be checked for combined axial compression and uniaxial bending moment, as described below:

The design against combined bending and axial compression are adequate when the following condition is satisfied:

$$M'_\mathrm{d} = \alpha_\mathrm{m}\mu_\mathrm{d}M_\mathrm{d}$$

where

α_m = reduction coefficient based on steel yield strength;

= 0.9 for $250 \geq f_y \leq 400$ MPa;

= 0.8 for $f_y > 400$ MPa;

M'_d = design bending moment, which is to be amplified to account for the second-order effects as discussed in **13.7.2**, when the column is not short; and

M_d = Design bending resistance of the section about the bending axis evaluated as in **D-3**.

The moment resistance reduction ratio μ_d for a long composite column under combined compression and uniaxial bending shall be evaluated as follows:

$$\mu_\mathrm{d} = \frac{(\chi - \chi_\mathrm{d})}{(1-\chi_\mathrm{c})\chi} \quad \text{when} \quad \chi_\mathrm{d} \geq \chi_\mathrm{c} \text{ and}$$

$$\mu_\mathrm{d} = 1 - \frac{(1-\chi)\chi_\mathrm{d}}{(1-\chi_\mathrm{c})\chi} \quad \text{when} \quad \chi_\mathrm{d} < \chi_\mathrm{c}$$

χ_c = Axial resistance ratio to the concrete P_c/P_d;

χ_d = Design axial resistance ratio to the concrete P/P_d;

χ = reduction factor due to column buckling as per good pratice [C-6B(3)];

P_c = axial compressive strength of concrete;

= $A_\mathrm{c}\frac{\alpha_\mathrm{cc.}}{\gamma_\mathrm{c}}.\eta.\lambda.f_\mathrm{ck}$; and

P_d = *see* **D-2**.

13.8.2 *Members Subjected to Axial Force and Bi-axial Bending*

Members subjected to combined axial compression and biaxial bending shall satisfy the following interaction relationships equations:

$$\frac{M_z}{\mu_{dz} M_{dz}} + \frac{M_y}{\mu_{dy} M_{dy}} \le 1$$

$$\frac{M_z}{\mu_{dz} M_{dz}} \le \alpha_{mz}$$

$$\frac{M_y}{\mu_{dy} M_{dy}} \le \alpha_{my}$$

where

μ_{dz} and μ_{dy} = moment resistance reduction factors in z and y directions, respectively. (*see* **13.8**)

$\alpha_{mz} = \alpha_{my} = \alpha_m$ (*see* **13.8**)

Table 14 Equivalent Uniform Moment Factor

(*Clause* 13.7.2)

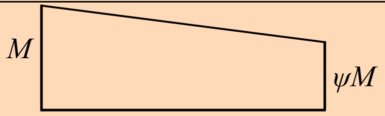
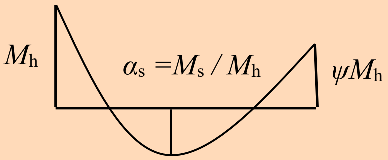
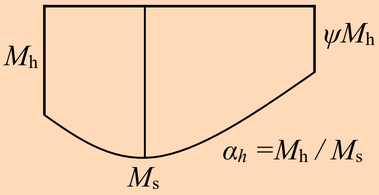
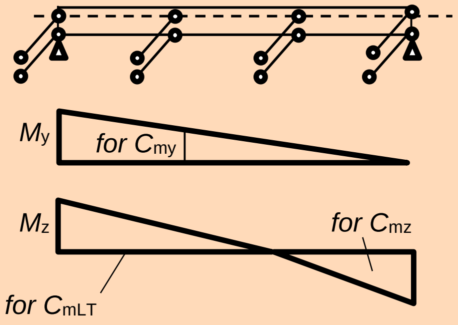
Bending Moment Diagram (1)	**Range** (2)		***C*** C_{my}, C_{mz}, C_{mLT}	
			Uniform Loading (3)	Concentrated Load (4)
	$-1 \le \psi \le 1$		$0.6 + 0.4\,\psi \ge 0.4$	
	$0 \le \alpha_s \le 1$	$-1 \le \psi \le 1$	$0.2 + 0.8\,\alpha_s \ge 0.4$	$0.2 + 0.8\,\alpha_s \ge 0.4$
	$-1 \le \alpha_s \le 0$	$0 \le \psi \le 1$	$0.1 \quad - 0.8\,\alpha_s \ge 0.4$	$-0.8\,\alpha_s \ge 0.4$
		$-1 \le \psi \le 0$	$0.1(1-\psi) - 0.8\,\alpha_s \ge 0.4$	$0.2(-\psi) - 0.8\,\alpha_s \ge 0.4$
	$0 \le \alpha_h \le 1$	$-1 \le \psi \le 1$	$0.95 - 0.05\,\alpha_h$	$0.90 + 0.10\,\alpha_h$
	$-1 \le \alpha_h \le 0$	$0 \le \psi \le 1$	$0.95 + 0.05\,\alpha_h$	$0.90 + 0.10\,\alpha_h$
		$-1 \le \psi \le 0$	$0.95 + 0.05\,\alpha_h\,(1 + 2\,\psi)$	$0.90 + 0.1\alpha_h\,(1 + 2\,\psi)$
For members with sway buckling mode, the equivalent uniform moment factor $C_{my} = C_{mz} = 0.9$.				

Table 14 (*Concluded*)

<table>
<tr><th rowspan="2">Bending Moment Diagram
(1)</th><th rowspan="2">Range
(2)</th><th colspan="2">C_{my}, C_{mz}, C_{mLT}</th></tr>
<tr><th>Uniform Loading
(3)</th><th>Concentrated Load
(4)</th></tr>
<tr><td colspan="4">C_{my}, C_{mz}, C_{mLT} shall be obtained according to the bending moment diagram between the relevant braced points
<table>
<tr><th>Moment factor</th><th>Bending axis</th><th>Points braced in direction</th></tr>
<tr><td>C_{my}</td><td>y-y</td><td>z-z</td></tr>
<tr><td>C_{mz}</td><td>z-z</td><td>y-y</td></tr>
<tr><td>C_{mLT}</td><td>z-z</td><td>z-z</td></tr>
</table>


</td></tr>
</table>

13.9 Mechanical Shear Connection and Load Introduction

Proper sharing of loads between the steel section and concrete of composite columns should be ensured at points of load introduction due to load and moment reactions coming from members connected to the ends of the column and also for axial loads applied anywhere within the length of the column, considering the shear resistance at the interface between steel and concrete.

Where composite columns and compression members are subjected to significant transverse shear, for example, by local transverse loads and by end moments, the provision shall be made for the transfer of the corresponding local longitudinal shear stress at the interface between steel and concrete. For axially loaded columns and compression members, longitudinal shear outside the region of load introduction need not be considered.

13.9.1 *Load Introduction*

Shear connectors should be provided at regions of load introduction and at regions with change in cross section, if the design shear resistance at the concrete-steel interface, τ, (Table 15) is exceeded. The shear forces should be determined from the change of sectional forces of the steel or reinforced concrete section within the introduction length. If the loads are introduced into the concrete cross section only, the values resulting from an elastic analysis considering creep and shrinkage should be taken into account. Otherwise, the forces at the interface should be determined by elastic theory or plastic theory to determine the more severe case. In the absence of any accurate method, the introduction length should not exceed $2d$ or $L/3$, where d is the minimum transverse dimension of the column and L is the column length.

Table 15 Design Shear Strength (τ)

(*Clauses* 13.2, 13.9.1 *and* 13.9.3)

Sl No.	Type of Cross-section	Design Shear Strength τ (N/mm^2)
(1)	(2)	(3)
i)	Completely concrete-encased steel sections	0.30
ii)	Concrete filled circular hollow sections	0.55
iii)	Concrete filled rectangular hollow sections	0.40
iv)	Flanges of partially encased sections	0.20
v)	Webs of partially encased columns	0.00

Due to the action of creep and shrinkage, no shear connection is required for composite columns or compression members if the load application is by endplate, where the full interface between steel and concrete is permanently under compression. Otherwise, the load application/introduction should be verified as given below:

a) If the cross-section is partially loaded, as shown in Fig. 20 (a), the loads may be distributed with a ratio of 1 : 2.5 over the thickness, t_e of the endplate. The concrete stresses should then be limited in the area of effective load introduction.

b) For concrete-filled circular hollow section or square hollow section, under partial loading as shown in Fig. 20(b), for example, by gusset plates or by stiffeners, the local design strength of concrete σ_c under the gusset or stiffener resulting from the sectional forces of the concrete section shall be determined as:

$$\sigma_c = \frac{\alpha_{cc} f_{ck}}{\gamma_c}\left[1 + \eta_0 \frac{t}{d} \frac{f_y}{\alpha_{cc} f_{ck}}\right]\sqrt{\frac{A_c}{A_1}} \leq \frac{A_c.\, \alpha_{cc} f_{ck}.}{A_1.\, \gamma_c};\ \leq \frac{f_y}{\gamma_{m0}}$$

where

$A_c/A_1 \leq 20$

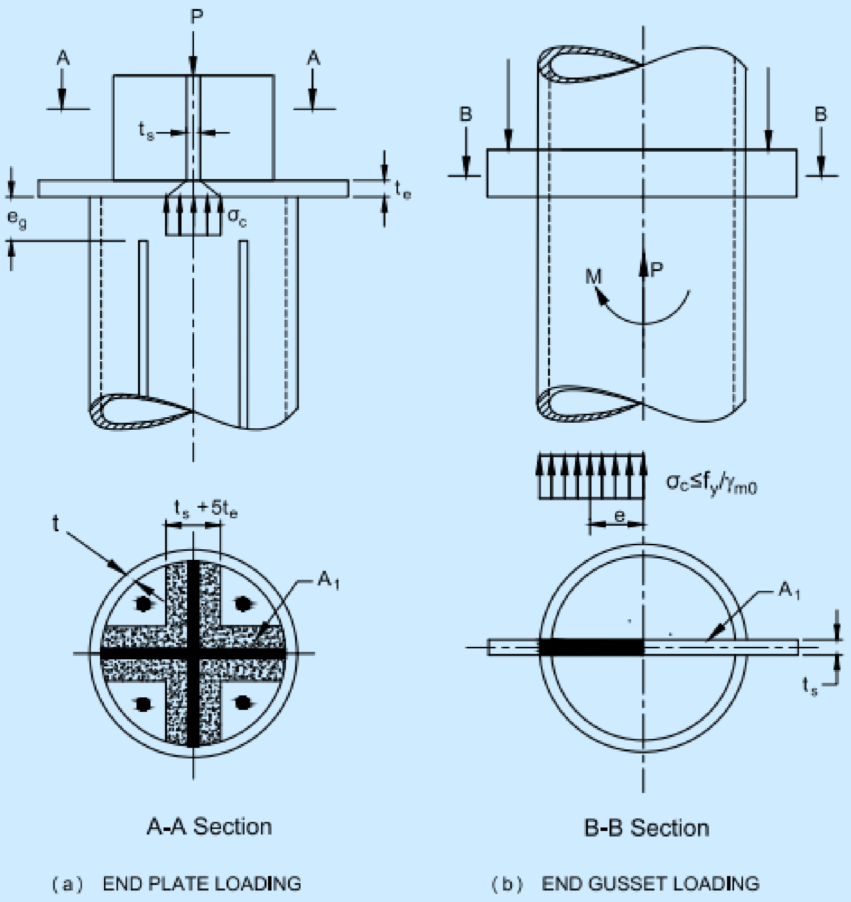
t = is the wall thickness of the steel tube;

d = diameter of the tube or width of the square section;

A_c = is the cross sectional area of the concrete section of the column;

A_1 = is the loaded area under the gusset plate (*see* Fig. 20); and

η_0 = 4.9 for circular steel tubes and 3.5 for square sections.



(a) END PLATE LOADING (b) END GUSSET LOADING

FIG. 20 PARTIALLY LOADED CIRCULAR CONCRETE FILLED HOLLOW SECTION

c) For concrete-filled circular hollow sections, longitudinal reinforcements may be taken into account while determining the resistance of the composite column, even if the reinforcement is not directly connected to the endplate, provided that the gap [Fig. 20(a)] between the end of reinforcement and the surface of the endplate does not exceed 30mm.

13.9.2 *Shear connection*

When a mechanical connection is introduced in the form of stud connectors to the web of a fully or partially concrete-encased steel I-section, an account may be taken of the frictional forces that develop due to the restraint in lateral expansion of the concrete by the adjacent steel flanges. This resistance is assumed to be equal to $\mu.Q_u/2$ on each flange and each horizontal row of studs, as shown in Fig. 21 and may be added to the calculated resistance of the shear connectors. μ is the relevant coefficient of friction and be taken as 0.5. Q_u is the resistance of a single stud as per **11.2**.

The clear distance between the flanges should not exceed the values given in Fig. 21 to ensure the development of the frictional forces between concrete and steel flanges.

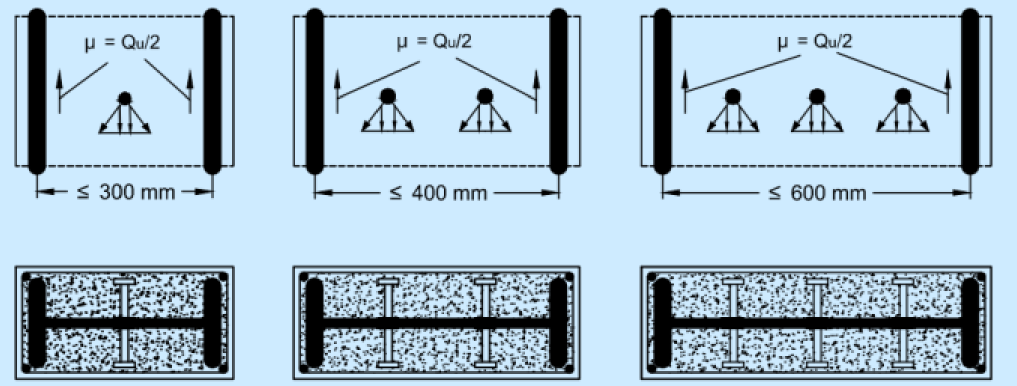


FIG. 21 ADDITIONAL FRICTIONAL FORCES IN COMPOSITE COLUMNS BY USE OF HEADED STUDS

13.9.3 *Longitudinal Shear Outside Area of Load Introduction*

a) Outside the area of load introduction, longitudinal shear at the interface between concrete and steel should be verified where it is caused by transverse loads and /or end moments. Shear connectors should be provided based on the distribution of the design value of longitudinal shear, where this exceeds the design shear resistance τ. In the absence of a more accurate method, elastic analysis, considering long-term effects and cracking of the concrete, may be used to determine the longitudinal shear at the interface. Provided that the surface of the steel section, in contact with the concrete, is unpainted and free from oil, grease, and loose scale or rust, the values given in Table 15 may be assumed for τ. The value of τ given in Table 15 for fully concrete-encased steel sections applies to sections with a minimum concrete cover of 40 mm. For greater concrete cover and adequate reinforcement, higher values of τ may be used. Unless verified by tests, for completely encased sections, the increased value β_c. τ may be used, with β_c given by:

$$\beta_c = 1 + 0.02\, c_z \left[1 - \frac{c_{z,\min}}{c_z}\right] \leq 2.5$$

where

c_z = is the wall thickness of the steel tube; and

$c_{z,\min}$ = diameter of the tube or width of the square section.

b) Unless otherwise verified, for partially encased I-sections with transverse shear due to bending about the weak axis caused by lateral loading or end moments, shear connectors should always be provided. If the resistance of the structural steel section alone against transverse shear is not sufficient to take care of the total transverse shear on the composite section, then the required transverse reinforcement for the shear force, V_c according to **12.5.2**, should be welded to the web of the steel section or should pass through the web of the steel section.

13.10 Shear Check

The factored shear force in the compression members should be less than the design shear strength of the member, which is the sum total of the shear resistance given by the concrete section along with steel reinforcements as per good practice [C-6B(2)] and the shear resistance given by the steel section as per **8.3.6**. The shear force shall be distributed between the steel section and the concrete section in accordance with **13.9**.

14 CONSTRUCTION AND ERECTION

14.1 Fabrication and Inspection Procedure for Structural Steel

Fabrication and erection of steel sections and components, as and where situated in a composite structure would include fabrication procedures, both shop and site fabrications, along with fabrication tolerances, inspection, testing, handling, transportation, site storage, erection along with erection tolerances, etc.

Fabrication and erection specifications of all steel components of a composite structure shall refer to stipulations laid down in good practice [C-6B(3)].

15 FIRE RESISTANCE AND FIRE DESIGN

15.1 In closed structures, an accidental fire may lead to a rise in temperature under which failure of the material may take place unless a proper design and construction against fire is carried out. Open structures such as bridges are not generally vulnerable to failure under fire since the temperature does not go up to the level which may cause material damage. Also, in an open structure, the fire can be extinguished easily and quickly. Fire tests on open structures such as elevated parking lots and bridges have shown that the structure does not undergo any material damage due to reasons indicated above. However, all structures, including both closed and open ones, shall be protected from all possible accidental fires caused by different kinds of hazards.

Fire-resistant designs for open and closed structures at specialized locations, such as those in proximity to oil installations or pipelines carrying inflammable materials, etc as in the case of industrial buildings and structures, shall be done based on recommendations given in specialized literature. Also, adequate provisions may be made for firefighting equipment to access all parts of the structure as per Part F ‘Fire and Life Safety’ of this NBCS. After the occurrence of fire in a structure, it should be mandatory for the concerned authorities to have the structure inspected by competent experts in order to ascertain the condition of the structure before it can be declared safe for re-use.

In addition to the above, locations in any structural system that may be prone to accidental occurrence of fire, shall be adequately provided with basic fire protection methods as per specialist literature. These will include both active as well as passive fire protection.

15.2 Response to Fire

Steel is a good conductor of heat that experiences an almost uniform temperature increase over its entire volume. Concrete is a poor conductor of heat has a large temperature gradient within its volume. Due to this, the entire steel member gains the heat faster, whereas the surfaces of concrete exposed directly to heat experience high temperature, with the temperature dropping off drastically in the interior of the concrete mass.

Both steel and concrete exhibit a drastic reduction in strength with an increase in temperature above 400 °C. Due to this, the resistance of steel members tends to decrease drastically above 400 °C, whereas concrete at the surfaces exposed to high temperature tends to spall off due to high temperature gradient. The steel structure, if it does not fail under fire, regains its strength after the fire, the damage at the surface of the concrete is permanent due to chemical changes. The steel reinforcement in concrete is protected from loss of strength due to an increase in temperature by providing adequate concrete cover as per good practice [C-6B(2)]. Composite floor system deck sheeting is to be provided with fire protection.

However, literature shows that the minimum necessary fire resistance can be achieved by using the composite floor systems and the composite columns, without applying fire protection. Interaction of the steel beam and the concrete slab in the composite flooring leads to a higher critical temperature and higher fire resistance.

The requirements for fire resistance shall apply to steel elements of steel-concrete composite structure designed to exhibit a required fire resistant level as per the relevant specifications.

15.2.1 *Design Fire*

The design of a structure against fire load is dependent on the required fire resistant level (FRL), which is dependent on the function of the structure itself and the period of structural adequacy (PSA). These shall be calculated based on the stipulation laid down in as per good practice [C-6B(3)].

The response of steel elements of a composite structure against fire as laid down in as per good practice [C-6B(3)] shall be binding on all steel elements of the composite structures which are susceptible to rise in temperature during its design life. For all general buildings, an adequate fire protection methodology shall be adopted.

15.2.2 *Fire Protection Methodology*

Apart from the direct design of steel components against fire as required in as per good practice [C-6B(3)] (protected as well as unprotected section), other protective measures, (both active and passive), also may be adopted as recommended in literature as fire-resistant procedures.

For active fire resistance, provisions of fire locating and fighting measures like the smoke detectors, fire extinguishers inside a building along with accessory fire water supply, sprinkler system, etc, shall be made available at vantage points. The planning of the structure shall be made in such a way that it is accessible from all sides to fire extinguishing vehicles.

For passive fire resistance, protective paints and materials like intumescent paints, vermiculite boards etc, may be used on exposed steel surfaces, and their provision shall be made as per the required fire-resistant level and as per their properties and specification provided by the manufacturers. The design of protected sections shall be done as per the stipulations laid down in the relevant section of as per good practice [C-6B(3)]. Detailed design against the fire may be based on provisions of other composite codes and specialized literature.

15.2.3 *Fire Resistance of Composite Slabs*

The fire resistance is assumed based on the following two criteria:

a) Thermal insulation criterion, concerned with limiting the transmission of heat by conduction; and

b) Integrity criterion is concerned with preventing the flames and hot gases from nearby compartments. It is met by specifying an adequate thickness of insulation.

16 TESTING METHODS

For testing methods, Annex E may be referred.

ANNEX A

(*Clause* 4)

SYMBOLS

A-1 The letter symbols and notations given below apply to the provision of this section:

a	Span length of the slab transverse to the steel beams
A_s	Area of structural steel cross section
A_{sl}	Area of structural steel cross section in tension
A_c	Gross area of concrete
A_{co}	Equivalent area of the cracked composite beam section
A_{ec}	Area of concrete effective in compression
A_p	Effective cross-sectional area of profile steel sheeting
A_{st}	Area of steel reinforcements
A_f	Area of each flange of steel section
A_e	Effective cross sectional area
A_{sv}	Area of shear resistance
B	Centre to centre distance between beams and is equal to the transverse span of inner beam
b_c	Width of concrete encasement
b_p	Distance between the centres of adjacent ribs or one wave length of a profile deck
b_e	Effective width of the flange between pair of bolts
b_{eff}	Effective width of concrete flange
b_f	Width of the structural steel flange
D	Overall depth of girder/diameter of the steel cross section.
d	Depth of the web, Nominal diameter of bolts/rivets/studs.
d_2	Twice the clear distance from the compression flange of angles, plates, or tongue plates to the neutral axis
d_c	Vertical distance between the centroid of concrete slab and centroid of steel beam
d_s	Overall depth of the concrete slab
d_o	Nominal diameter of the pipe column or the dimensions of the column in the direction of depth of the base plate
d_p	Depth of profiled sheet deck
d_{sp}	Overall depth of the profiled sheet deck and concrete slab
e	Distance between the C.G. axis of the profiled steel sheeting and the extreme tension fiber of the composite slab
e_p	Distance between the plastic neutral axis and the extreme tension fiber of the composite slab
$E_{c,l}$	Modulus of elasticity of lightweight concrete
E_s	Modulus of elasticity of structural steel
E_{cm}	Secant Modulus of elasticity of concrete
E_{st}	Modulus of elasticity of steel reinforcements
F_f	Axial capacity of a single flange
F_{sr}	Axial capacity of reinforcing steel

F_{cc}	Compressive force in the concrete above the neutral axis
F_{sc}	Compressive force in the steel section above the neutral axis
F_{st}	Tensile force in the steel section below the neutral axis
F_{w}	Design capacity of the web in bearing
f	Actual normal stress range for the detail category
f_{c}	Actual axial compressive stress in concrete at service load
$f_{ctm, l}$	Tensile strength of lightweight concrete
f_{ck}	Characteristic compressive cube strength of concrete at 28 days
$f_{ctk(0.05)}$	Characteristic axial tensile strength of concrete based on 5 percent fractile
f_{ctm}	Mean axial tensile strength of concrete
f_{f}	Fatigue stress range corresponding to 5×10^{6} cycles of loading
f_{fd}	Design fatigue normal stress range
f_{feq}	Equivalent constant amplitude stress
$f_{f\,max}$	Highest normal stress range
f_{fn}	Normal fatigue stress range
f_{o}	Proof stress
f_{yk}	Characteristic yield strength of reinforcement
f_{yf}, f_{yw}	Yield strength of flange and web, respectively
f_{u}	Characteristic ultimate tensile stress
f_{up}	Characteristic ultimate tensile stress of the profiled deck
f_{y}	Characteristic yield stress of structural steel
f_{yp}	Characteristic yield stress of profiled deck
h	Depth of the section/total depth of steel beam
H	Distance between top of concrete and bottom of bottom flange of steel beam
h_{s}	Distance between centroids of top and bottom flanges /nominal height of stud
h_{y}	Distance between shear centre of the two flanges of the cross section
I	Moment of inertia of the member about an axis perpendicular to the plane of the frame
I_{c}	Moment of inertia of concrete (assumed uncracked) about the axis of bending for column
I_{co}	Moment of inertia of the composite section
$I_{fc,y}$	Moment of Inertia of the compression flange about the minor axis of the steel beam
$I_{ft,y}$	Moment of Inertia of the tension flange about the minor axis of the steel beam
I_{s}	Moment of inertia of the steel section about the axis of bending for column
I_{st}	Moment of inertia of reinforcement about the axis of bending for column
I_{z}	Moment of inertia about the major axis
I_{ys}, I_{zs}	Second moment of area of steel section about the minor and major axis respectively
I_{ybf}	Moment of inertia of the bottom flange about the minor axis of the steel section
I_{zco}	Second moment of the equivalent area of the cracked composite beam section for major axis bending
k_{1}	Flexural stiffness of the steel web per unit length along the beam
k_{2}	Flexural stiffness of the cracked concrete or composite slab transverse to the spanning direction of steel beam

KL	Effective length of the member
KL/r	Appropriate, effective slenderness ratio of the section
KL/r_y	Effective slenderness ratio of the section about the minor axis
KL/r_z	Effective slenderness ratio of the section about the major axis
L	Actual span of composite beams
L_{bs}	Minimum bearing lengths of steel decking on the support
L_{bc}	Composite slab including the cast in place concrete
L_c	Effective span of the cantilever for overhang
L_o	Length between points of zero moments (inflection) in the span
L_s	Shear span
L_x	Distance of the maximum moment cross section under consideration to the support
M	Bending moment
M_v	Reduced bending moment due to effect of shear force
M_{cr}	Elastic critical moment corresponding to lateral torsional buckling
M_d	Design bending strength/design bending resistance under only bending moment
M'_d	Design bending resistance under combined bending and compression
M_{dp}	Design bending resistance of profiled steel sheeting
M_e	Elastic moment capacity of the section
M_f	Design plastic resistance of the flange alone for steel section
M_p	Plastic moment capacity of the section
M_y	Factored applied moments about the minor axis of the cross section
M_z	Factored applied moments about the major axis of the cross section
m	Modular ratio
m_{dl}	Modular ratio (long term)
m_{ll}	Modular ratio (short term)
N_{SC}	Number of stress cycles
P	Design axial force
P_{cr}	Elastic critical buckling load
P_p	Plastic resistance of encased steel column section or concrete filled rectangular or square column section
R_h	Flange stress reduction factor for hybrid section
r	Appropriate radius of gyration
r_y	Radius of gyration about the minor axis
r_z	Radius of gyration about the major axis
S	Spacing
S_l	Spacing of shear connectors for longitudinal shear due to flexural force
S_r	Spacing of shear connectors due to bending moment
t	Thickness of element/angle, time in minutes
t_f	Thickness of flange of steel section
t_p	Thickness of profiled deck sheet

t_w	Thickness of web of steel section,
V, V_v, V_L	Factored applied shear force
V_d	Design shear resistance
V_{dvd}	Vertical shear resistance
V_p	Plastic shear resistance under pure shear
V_{vd}	Design vertical shear resistance
W	Total equivalent load
X	Distance from the centre line of edge beam to the edge of slab
x_e	Depth of elastic neutral axis of the composite section from the centroid of steel section
x_u	Depth of neutral axis at limit state of flexure from top of the concrete
Z_e	Elastic section modulus
Z_p	Plastic section modulus
Z_{pc}, Z_{pcn}	Plastic section modulus of concrete about its own centroid and about the neutral axis of the composite section, respectively
Z_{pr}, Z_{prn}	Plastic section modulus of reinforcement about its own centroid and about the neutral axis of the composite section, respectively
Z_{ps}, Z_{psn}	Plastic section modulus of structural steel section about its own centroid and about the neutral axis of the composite section, respectively
y_g	Distance between the point of application of the load and shear centre of the cross section
α	Imperfection factor
α_c	Strength coefficient of concrete
δ	Steel contribution ratio
χ	Stress reduction factor due to buckling under compression
χ_m	Stress reduction factor, χ at f_{ym}
χ_m	Stress reduction factor to account for lateral torsional buckling of a beam
γ	Unit weight of steel
γ_c	Partial safety factor for material (concrete)
γ_f	Partial safety factor for load
γ_{m0}	Partial safety factor against yield stress and buckling (structural steel)
γ_{m1}	Partial safety factor against ultimate stress (structural steel)
γ_{mf}	Partial safety factor for the strength of bolt
γ_{fft}	Partial safety factor for fatigue load
γ_{mft}	Partial safety factor for fatigue strength
γ_{mv}	Partial safety factor against shear failure
γ_{mw}	Partial safety factor for the strength of the weld
γ_k	Partial safety factor for material (reinforcements)
ε	Yield stress ratio, $(250/f_y)$ 1/2
λ, λ_r	Non dimensional slenderness ratio = $\sqrt{f_y(KL/r)^2/\pi^2E} = \sqrt{f_y/f_{cr}} = \sqrt{P_y/P_{cr}}$
λ_e	Equivalent slenderness ratio
μ_s	Poisson's ratio of structural steel

μ_c	Correction factor
η_1, η_2	Strength coefficients
η_{10}, η_{20}	Strength coefficients
τ	Actual shear stress range for the detail category
τ_f	Fatigue shear stress range
τ_{fd}	Design fatigue shear stress range
$\tau_{f,max}$	Highest shear stress range
τ_{fn}	Fatigue shear stress range at N_{SC} cycle for the detail category

ANNEX B

(*Clauses* 8.1.1, 8.1.2, 8.3.5.2, 8.3.5.3 *and* 8.3.7)

BENDING RESISTANCE OF COMPOSITE BEAMS

The stress distribution and the methods of evaluation of the sagging and hogging bending resistances under full and partial shear interaction of composite beams are discussed in this Annex.

B-1 SAGGING MOMENT RESISTANCE OF COMPOSITE SECTION WITH PLASTIC OR COMPACT STRUCTURAL STEEL BEAMS

B-1.1 Sagging Bending Resistance with Full Shear Interaction

The equations for calculating the bending resistance of composite beams are presented in this section. It is assumed that sufficient shear connectors are provided between the structural steel and concrete to develop full shear with no-slip during the service load.

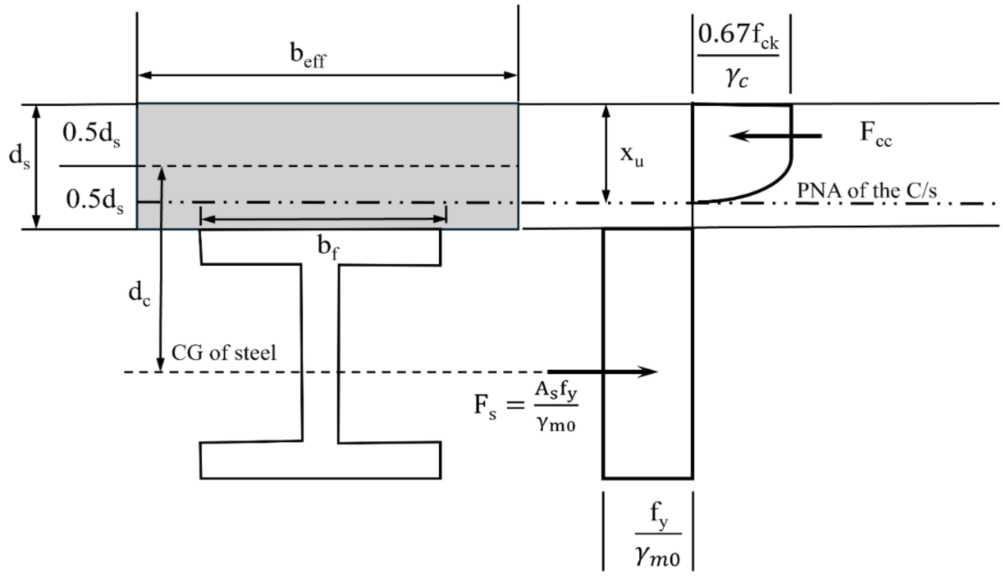
Initially, evaluating the resistance is based on parabolic stress block as per good practice [C-6B(2)], over the entire depth of concrete in compression is presented. This is theoretically more accurate than the rectangular stress block (maximum of 2-3 percent difference), but computationally more tedious, particularly when it comes to sections subjected to combined bending and compression.

Subsequently, equations based on rectangular stress block for concrete in compression is presented. This is assumed so that the calculations are simplified. This method is easy to use, particularly when the neutral axis is in or closer to compression flange of the steel section.

In both the above methods, the stress in the reinforcing steel in the concrete slab under compression is disregarded.

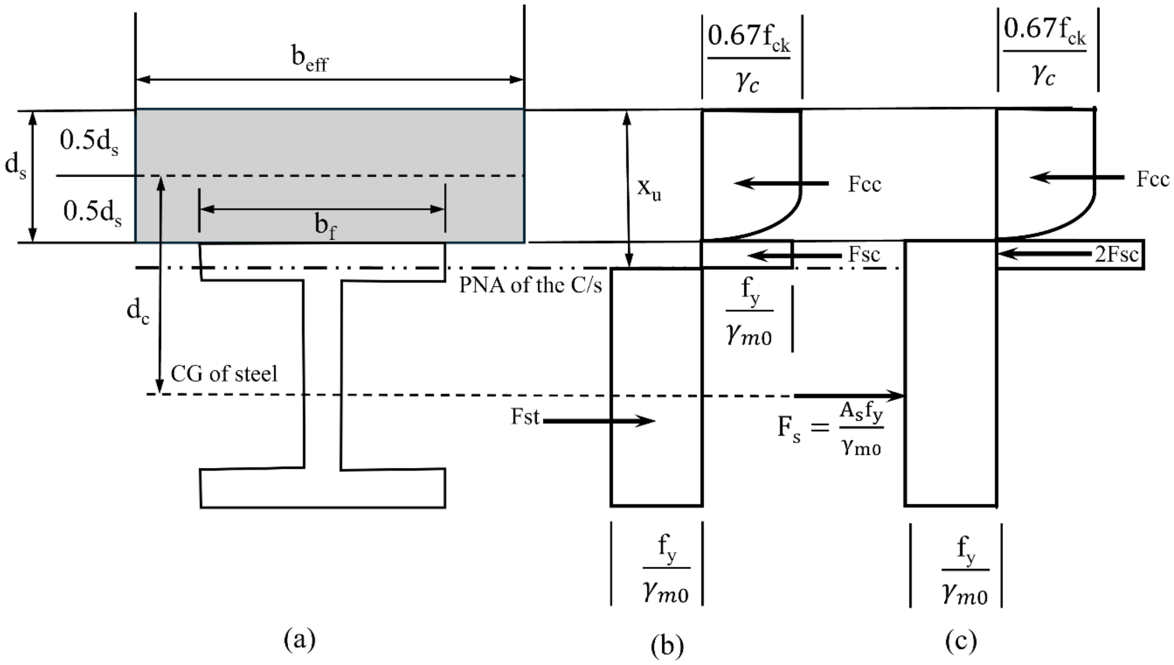
B-1.1.1 *Based on Parabolic Stress Block Satisfying Stress Strain Relationship*

Calculation of bending resistance is based on parabolic stress block, which is compatible with strain diagram. The design bending resistance depends on the location of the plastic neutral axis. Table 16 gives the various cases of design bending moments of a composite section depending upon the location of the plastic neutral axis as shown in Fig. 22, Fig. 23 and Fig. 24. For hybrid sections, appropriate yield strength in flanges and web shall be considered for calculation of the plastic moments.



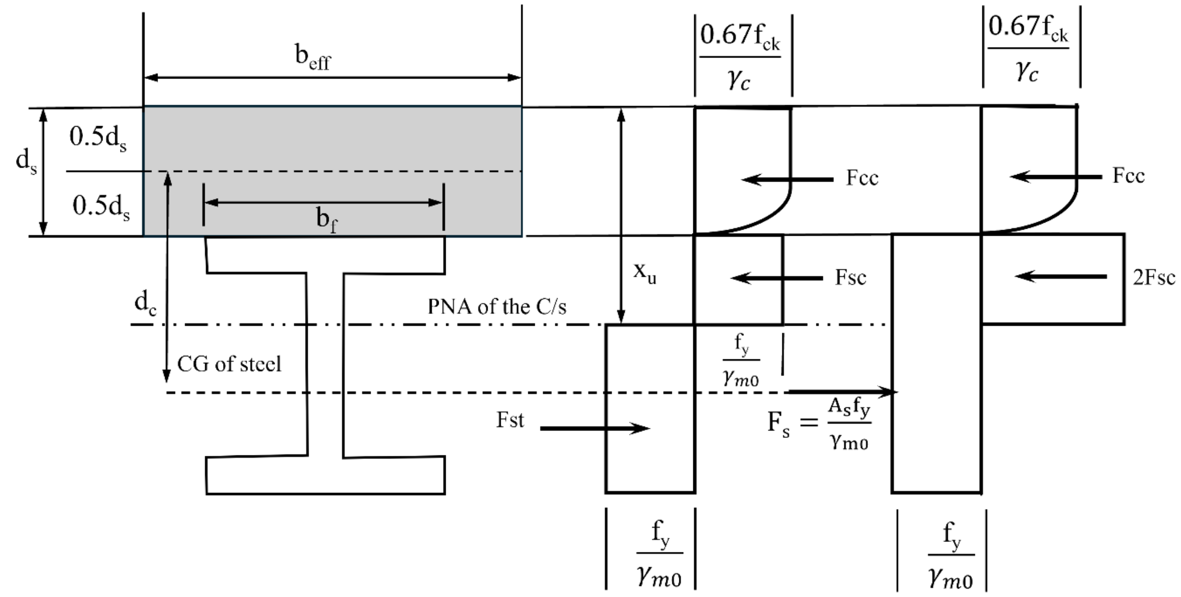
b_{eff}
$\frac{0.67f_{ck}}{\gamma_c}$
d_s
$0.5d_s$
$0.5d_s$
x_u
F_{cc}
PNA of the C/s
b_f
d_c
CG of steel
$F_s = \frac{A_s f_y}{\gamma_{m0}}$
$\frac{f_y}{\gamma_{m0}}$

FIG. 22 STRESS DISTRIBUTION IN A COMPOSITE BEAM WITH PLASTIC NEUTRAL AXIS WITHIN THE CONCRETE SLAB AT ULTIMATE MOMENT



b_{eff}
$\frac{0.67f_{ck}}{\gamma_c}$
$\frac{0.67f_{ck}}{\gamma_c}$
d_s
$0.5d_s$
$0.5d_s$
x_u
Fcc
Fcc
b_f
Fsc
2Fsc
PNA of the C/s
$\frac{f_y}{\gamma_{m0}}$
d_c
CG of steel
Fst
$F_s = \frac{A_s f_y}{\gamma_{m0}}$
$\frac{f_y}{\gamma_{m0}}$
$\frac{f_y}{\gamma_{m0}}$
(a)
(b)
(c)

FIG. 23 STRESS DISTRIBUTION IN A COMPOSITE BEAM WITH PLASTIC NEUTRAL AXIS WITHIN THE FLANGE OF STEEL BEAM AT ULTIMATE MOMENT



(a) (b) (c)

FIG. 24 STRESS DISTRIBUTION IN COMPOSITE BEAM WITH PLASTIC NEUTRAL AXIS WITHIN THE WEB OF STEEL BEAM AT ULTIMATE MOMENT

Table 16 Sagging Moment Resistance of Composite Section with full Shear Interaction (Parabolic Stress Block)

(*Clause* B-1.1.1)

Case	**Position of Plastic Neutral Axis**	**Location of PNA** x_u	**Design Moment Capacity** M_d
(1)	(2)	(3)	(4)
1	Within slab (Fig. 22) $b_{eff}\ d_s > a.A_s$	$x_u = aA_s/b_{eff}$	$M_d = A_s\ (f_y/\gamma_{m0})\ (d_c + 0.5d_s - 0.42\ x_u)$
2	In steel flange (Fig. 23) $b_{eff}.d_s < a\ A_s < (b_{eff}\ d_s + 2a\ A_f)$	$x_u = d_s + \dfrac{(aA_s - b_{eff}d_s)}{2b_f a}$	$M_d = (f_y/\gamma_{m0})\ [\{A_s\ (d_c + 0.08d_s)\} - \{b_f\ (x_u - d_s)\ (x_u + 0.16\ d_s)\}]$
3	In web (Fig. 24) $a\ A_s > (b_{eff}\ d_s + 2a\ A_f)$	$x_u = d_s + t_f + \{a(A_s - 2A_f) - b_{eff}\ d_s\}\ /(2at_w)$	$M_d = (f_y\ /\gamma_{m0})\ [\ \{A_s\ (d_c + 0.08d_s)\} - \{2A_f\ (0.5t_f + 0.58d_s)\} - \{2t_w\ (x_u - d_s - t_f)\ (0.5\ x_u + 0.08\ d_s + 0.5\ t_f\}]$
where $a = \dfrac{\frac{f_y}{\gamma_{m0}}}{0.36\ f_{ck}}$ and d_s is taken as per **8.1.2.1**			

B-1.1.2 *Based on Rectangular Stress Block*

The design bending resistance depends on the location of the plastic neutral axis, as shown in Fig. 25, Fig. 26 and Fig. 27. Table 17 gives the equations for evaluating the bending resistance of a composite section, depending upon the location of the plastic neutral axis. For hybrid sections appropriate yield strength in flanges and web shall be considered for calculation of the plastic moments.

Fig. 26 (b) and 27 (b), show the actual stress distribution and Fig. 26 (c) and 27 (c), show the equivalent stress distribution to simplify the equations.

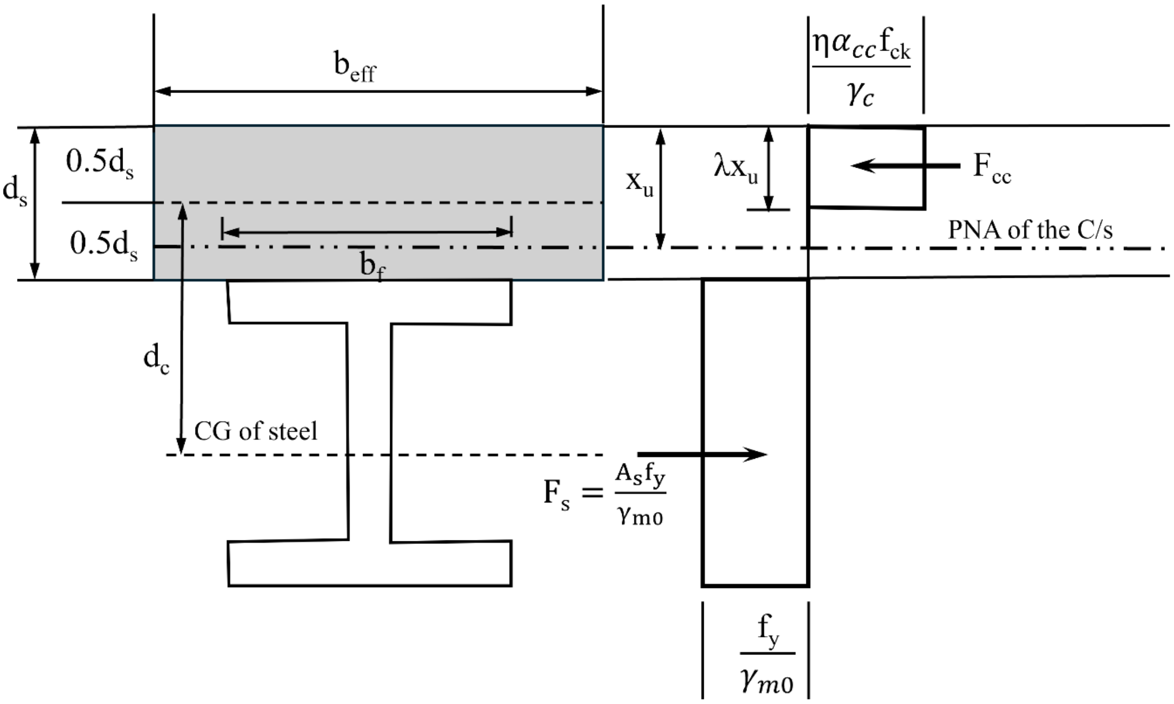

b_{eff}
$\frac{\eta\alpha_{cc}f_{ck}}{\gamma_c}$
d_s
$0.5d_s$
$0.5d_s$
x_u
λx_u
F_{cc}
PNA of the C/s
b_f
d_c
CG of steel
$F_s = \frac{A_s f_y}{\gamma_{m0}}$
$\frac{f_y}{\gamma_{m0}}$

FIG. 25 STRESS DISTRIBUTION IN A COMPOSITE BEAM WITH PLASTIC NEUTRAL AXIS WITHIN CONCRETE SLAB AT ULTIMATE MOMENT

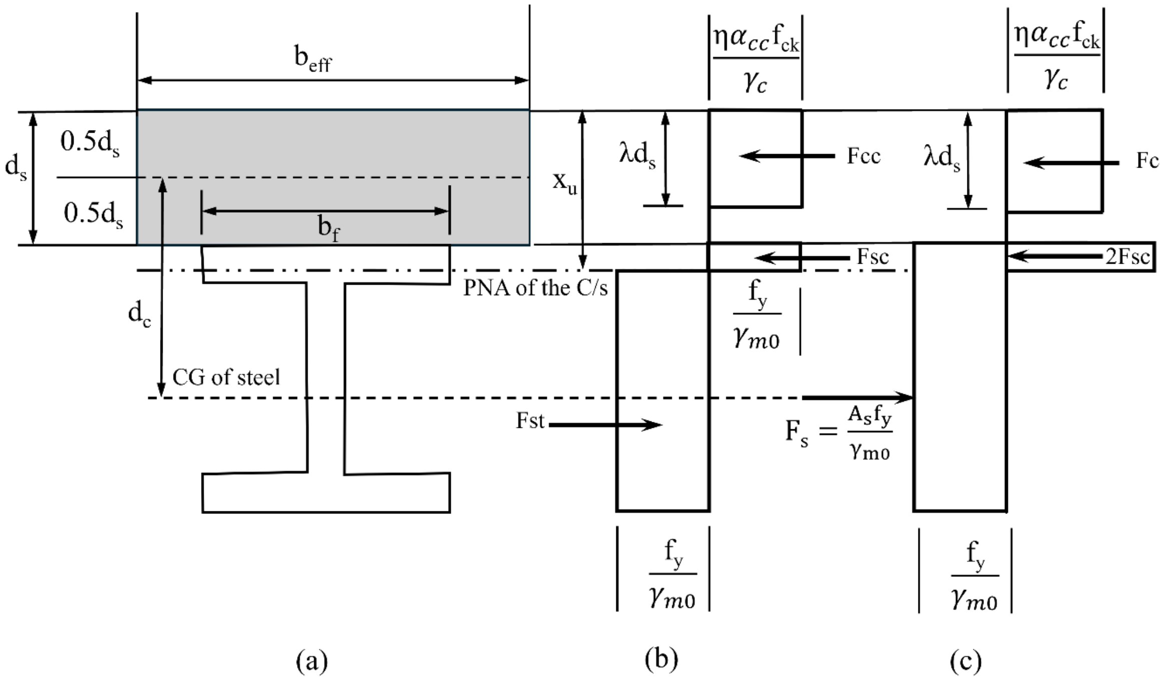

b_{eff}
$\frac{\eta\alpha_{cc}f_{ck}}{\gamma_c}$
$\frac{\eta\alpha_{cc}f_{ck}}{\gamma_c}$
d_s
$0.5d_s$
$0.5d_s$
x_u
λd_s
Fcc
λd_s
Fcc
Fsc
2Fsc
b_f
PNA of the C/s
$\frac{f_y}{\gamma_{m0}}$
d_c
CG of steel
Fst
$F_s = \frac{A_s f_y}{\gamma_{m0}}$
$\frac{f_y}{\gamma_{m0}}$
$\frac{f_y}{\gamma_{m0}}$
(a)
(b)
(c)

FIG. 26 STRESS DISTRIBUTION IN A COMPOSITE BEAM WITH PLASTIC NEUTRAL AXIS WITHIN THE FLANGE OF THE STEEL BEAM AT ULTIMATE MOMENT

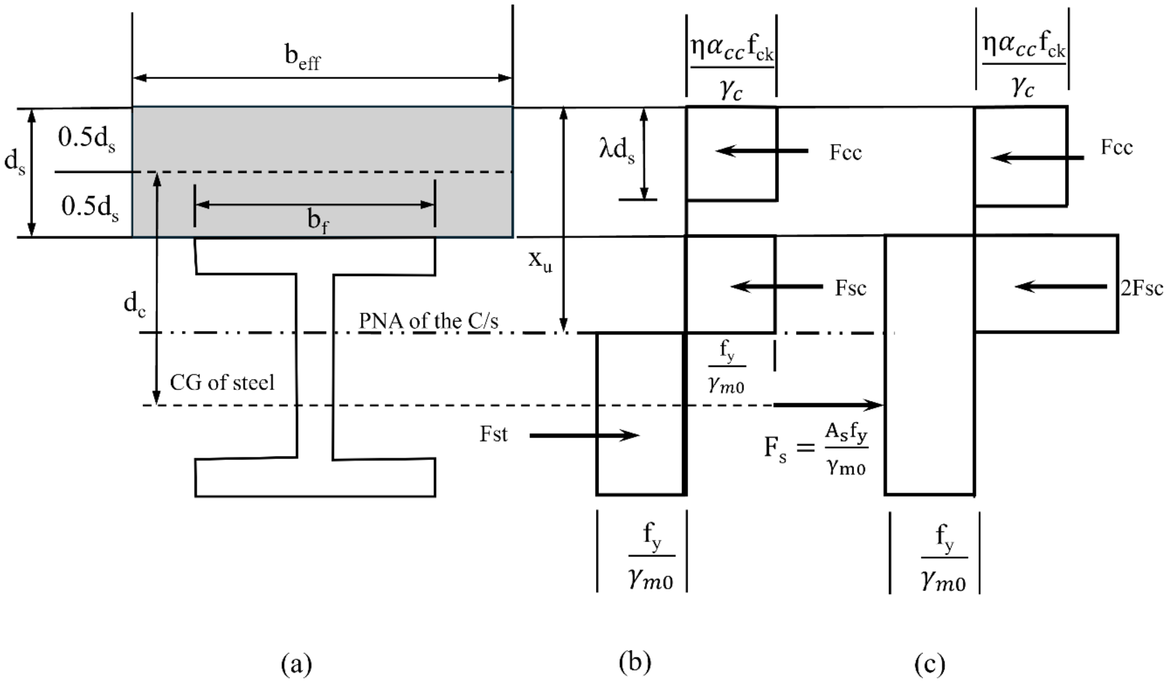

b_eff
d_s
0.5d_s
0.5d_s
b_f
d_c
CG of steel
PNA of the C/s
x_u
λd_s
ηα_cc f_ck / γ_c
Fcc
Fsc
Fst
f_y / γ_m0
F_s = A_s f_y / γ_m0
2Fsc
(a)
(b)
(c)

FIG. 27 STRESS DISTRIBUTION IN A COMPOSITE BEAM WITH PLASTIC NEUTRAL AXIS WITHIN THE WEB OF THE STEEL BEAM AT ULTIMATE MOMENT

Table 17 Sagging Moment Resistance of Composite Section with Full Shear Interaction (Rectangular Stress Block)

(*Clause* B-1.1.2)

Case	Position of Plastic Neutral Axis	Location of PNA x_u	Design Moment Capacity, M_d
(1)	(2)	(3)	(4)
1	Within slab (Fig. 25) $b_{eff}\, d_s > a\, A_s$	$x_u = aA_s / b_{eff}$	$M_d = A_s f_y / \gamma_{m0}\, (d_c + 0.5d_s - \lambda\, x_u / 2)$
2	Plastic neutral axis in steel flange (Fig. 26) $b_{eff}\, d_s < a\, A_s < (b_{eff}\, d_s + 2a\, A_f)$	$x_u = d_s + \frac{(aA_s - b_{eff} d_s)}{2 b_f a}$	$M_d = f_y / \gamma_{m0}\, [A_s\, \{d_c + 0.5d_s\, (1 - \lambda)\} - b_f\, (x_u - d_s)\, \{ x_u + (1 - \lambda)\, d_s \}]$
3	Plastic neutral axis in web (Fig. 27) $b_{eff}\, d_s + 2a\, A_f < a\, A_s$	$x_u = d_s + t_f + \frac{a(A_s - 2A_f) - b_{eff} d_s}{2 a t_w}$	$M_d = f_y / \gamma_{m0}\, [\, A_s\, \{d_c + 0.5\, d_s\, (1 - \lambda)\} - 2A_f\, \{0.5 t_f + (1 - \lambda/2)\, d_s \} - t_w\, (x_u - d_s - t_f)\, \{x_u + (1 - \lambda)\, d_s + t_f \}]$

where

$a = \frac{\frac{f_y}{\gamma_{m0}}}{\frac{\alpha_{cc.}}{\gamma_c}.\eta.\lambda.(f_{ck})}$ and d_s is taken as per **8.1.2.1**.

Table 17 (*Concluded*)

Case	Position of Plastic Neutral Axis	Location of PNA x_u	Design Moment Capacity, M_d
(1)	(2)	(3)	(4)

NOTE — Notations used in the determination of plastic bending resistance

A_f = area of the top flange of steel beam of a composite section.

A_s = cross sectional area of structural steel beam of a composite section.

b_{eff} = effective width of concrete slab.

b_f = width of top flange of steel section.

d_s = overall depth of concrete slab.

d_c = vertical distance between centroids of concrete slabs and steel beam in a composite section.

t_f = average thickness of the top flange of the steel section.

t_w = thickness of the web of the steel section.

x_u = depth of neutral axis at ultimate limit state of flexure from top of concrete.

M_d = design bending resistance.

α_{cc} = 0.67.

γ_c = material safety factor for concrete .

= 1.50 (for basic and seismic combinations).

= 1.0 (for accidental combinations).

γ_{m0} = material safety factor for structural steel = 1.10

γ_k = material safety factor for reinforcing steel = 1.15

η = 1.0 [for $f_{ck} \leq 60$ MPa]

= $1.0 - (f_{ck} - 60) / 250$ [for $60 < f_{ck} \leq 110$ MPa]

λ = 0.8 [for $f_{ck} \leq 60$ MPa]

= $0.8 - (f_{ck} - 60) / 500$ [for $60 < f_{ck} \leq 110$ MPa]

B-1.2 Bending Moment with Partial Shear Interaction

B-1.2.1 Partial shear connection is applicable only in the case of plastic resistance of sections with plastic and compact classifications. Provisions for partial shear connection is applicable either for attaining economy without losing much in moment capacity of the composite section or in conditions where the number of shear connectors required for full shear interactions cannot be provided due to lack of space or increased spacing of shear connectors due to provision of lesser numbers of shear connectors than that needed for full composite action.
Degree of shear connection S_c is given as

$$S_c = \frac{n_p}{n_f} = \frac{F_{cp}}{F_{cf}} = \frac{M - M_{ds}}{M_d - M_{ds}}$$

where

n_p = Number of shear connectors provided for partial shear connection;

n_f = Number of shear connectors required for full shear connection;

F_{cp} = Capacity of shear connectors in partial shear connection with n_p numbers of connectors;

F_{cf} = Capacity of shear connectors in full shear connection with n_f numbers of connectors;

M = Required bending resistance of the section;

M_d = Design bending resistance of the composite section; and

M_{ds} = Design bending resistance of steel section alone.

B-1.2.2 To obtain required bending resistance M, the number of shear connectors required (assuming all connectors have equal capacity) is given as:

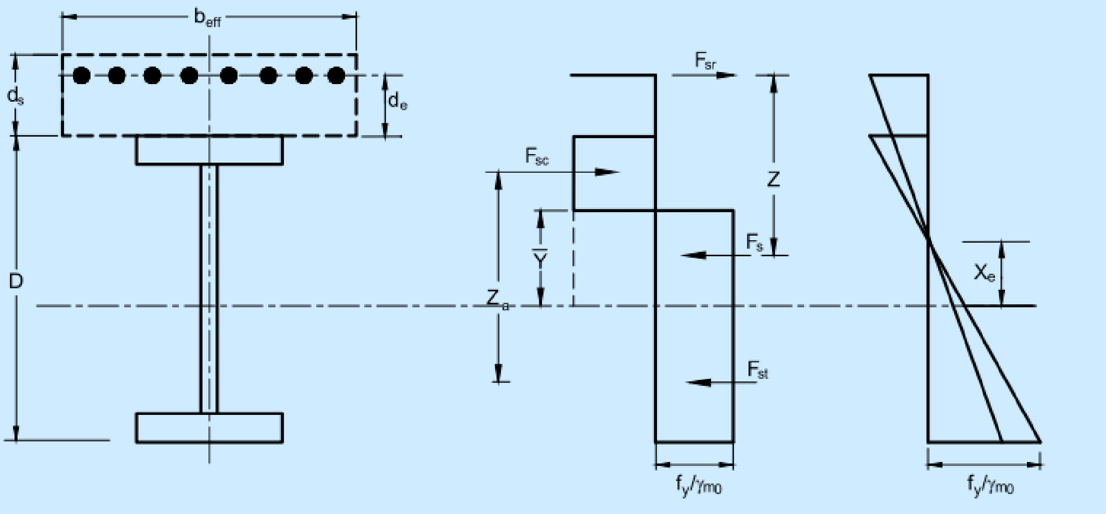
$$n_{\mathrm{p}} = n_{\mathrm{f}}\,\{(M - M_{\mathrm{ds}})/(M_{\mathrm{d}} - M_{\mathrm{ds}})\}$$

B-1.3 Sagging Bending Resistance of Composite Section with Non-Compact Structural Steel Beams

Since the compression flange of semi-compact steel sections buckle locally under compression on reaching yield stress f_y, the design resistance of the composite section consisting of semi-compact sections is evaluated using equations of compact sections as per **B-1**, wherein the effective width of elements of section like the compression flange is restricted to limiting value of that of the compact section.

B-2 MOMENT OF RESISTANCE OF COMPOSITE SECTION (NEGATIVE MOMENT-CONTINUOUS BEAMS)

Figure 28 shows stress distribution across a composite beam section subjected to hogging bending moment. Since the steel bottom flange is in compression section classification shall be done as per [C-6B(3)]. For classification of the web, the distance, $\bar{y}$, of the plastic neutral axis above the centroid of the area of the steel section shall first be found.



(a) Plastic and compact section (b) Semi-compact section

FIG. 28 STRESS DIAGRAM FOR HOGGING MOMENT REGION AT ULTIMATE MOMENT

B-2.1 Hogging Bending Resistance for Plastic and Compact Structural Steel Sections

The design tensile force in reinforcement is given as:

$$F_{\mathrm{sr}} = f_{\mathrm{yk}}.A_{\mathrm{st}}/\gamma_{\mathrm{k}}$$

where

γ_{k} = partial safety factor for reinforcing steel = 1.15;

f_{yk} = Characteristic yield strength of the reinforcing steel; and

A_{st} = the effective area of longitudinal reinforcement within the effective width b_{eff} of the beam

The plastic moment of resistance for plastic and compact structural steel section is given as:

$$M_{\mathrm{ds}} = \frac{Z_{\mathrm{p}} . f_{\mathrm{y}}}{\gamma_{\mathrm{m0}}}$$

where

Z_p is the plastic section modulus of the structural steel section and γ_{m0} is the material safety factor to be taken as 1.10. In the absence of any tensile reinforcements, the bending resistance of the section would be that of the structural steel section as given by M_{ds} above. To allow for reinforcements, it is assumed that the stress in a depth $\overline{y}$ changes from tension to compression for Plastic and compact section. The corresponding depth for a non-compact section is x_e. For plastic and compact sections, stress distribution $\overline{y}$ may be determined from

$$\overline{y}\, t_{\mathrm{w}} \frac{2 f_{\mathrm{y}}}{\gamma_{\mathrm{m0}}} = F_{\mathrm{s}}$$

The locations of the neutral axis and the bending resistance for the plastic and compact section are given in Table 18.

Table 18 Hogging Bending Resistance of Plastic and Compact Composite Section

(*Clause* B-2.1)

Case	Position of Plastic Neutral Axis	Value of $\overline{y}$	Moment Capacity M_{dh}
(1)	(2)	(3)	(4)
1	In Web	$\overline{y} \leq \frac{D}{2} - t_{\mathrm{f}}$	$M_{\mathrm{dh}} = M_{\mathrm{ds}} + F_{\mathrm{sr}} Z$
2	In Flange	$\frac{D}{2} \geq \overline{y} > \frac{D}{2} - t_{\mathrm{f}}$	$M_{\mathrm{dh}} = F_{\mathrm{b}} \frac{D}{2} + F_{\mathrm{sr}}\, d_{\mathrm{s}} - \frac{(F_{\mathrm{b}} - F_{\mathrm{sr}})^2}{F_{\mathrm{f}}} \frac{t_{\mathrm{f}}}{4}$

where

$Z = \frac{D}{2} + d_{\mathrm{s}} - \frac{\overline{y}}{2}$

F_{f} = Axial capacity of a single flange $= \frac{f_{\mathrm{y}} . A_{\mathrm{f}}}{\gamma_{\mathrm{m0}}}$

F_{b} = Axial capacity of steel section $= \frac{f_{\mathrm{y}} . A_{\mathrm{s}}}{\gamma_{\mathrm{m0}}}$

F_{sr} = Axial capacity of reinforcing steel $= \frac{f_{\mathrm{yk}} . A_{\mathrm{st}}}{\gamma_{\mathrm{k}}}$

A_{s} = area of structural steel cross section

A_{f} = area of top flange of structural steel cross section

A_{st} = area of reinforcing steel within the effective width of concrete flange

d_{s} – overall depth of the concrete slab

d_{e}= Effective depth of the slab

t_{f} = Average thickness of the top flange of the steel section

t_{w} = Thickness of the web of the steel section

NOTE — The web shall be classified as being in compression throughout.

B-2.2 Hogging Bending Resistance for Non-Compact Section

Where elastic analysis is used, creep is considered in the choice of modular ratio m (= E_s/E_{cm}). Here, at the section considered, the loading causes hogging bending moment $M_{e(s)}$ in the steel member alone and [$M_{e(c)}$] in the composite member.

The location of the elastic neutral axis of the composite semi-compact section [*see* Fig. 28(b)] is given as:

$$x_e(A_s + A_{st}) = A_{st}\left(\frac{D}{2} + d_s\right)$$

and the second moment of area of the composite section is:

$$I_{co} = I_s + A_s.x_e{}^2 + A_{st}\left(\frac{D}{2} + d_s - x_e\right)^2$$

Where, I_s is the second moment of area of the steel section alone.

The yield moment is mostly governed by the total stress in the steel bottom flange. The locations of the neutral axis and the moment of resistance for non-compact section is given in Table 19.

The bending moment [$M_{e(s)}$] causes no stress in the slab reinforcements. In propped construction, the tensile stress in the reinforcement may govern the design. It is given in the following equation:

$$\sigma_{sr} = \frac{\left(\frac{f_y}{\gamma_{m0}} - f_s\right)\left(\frac{D}{2} + d_s - x_e\right)}{\left(\frac{D}{2} + x_e\right)} \leq \frac{f_{yk}}{\gamma_k}$$

Table 19 Hogging Bending Resistance of Non-compact Composite Section

(*Clause* B-2.2)

Location of Neutral Axis	**Moment Capacity of Steel Section Alone [f_s] $\bar{y}$**	**Moment Capacity $M_{d(c)}$**
(1)	(2)	(3)
$x_e(A_s + A_{st}) = A_{st}\left(\frac{D}{2} + d_s\right)$	$f_s = M_{e(s)}.\frac{D/2}{I_s}$	$M_{d(c)} = M_{e(s)} + \frac{\left(\frac{f_y}{\gamma_{m0}} - f_s\right) I_{co}}{\left(\frac{D}{2} + x_e\right)}$

NOTE — The web shall be classified as being in compression throughout.

where

A_{st} = cross sectional area of reinforcements within the effective width of the concrete flange;

A_s = cross sectional area of steel beam of a composite section;

d_s = overall depth of the slab;

d_e = effective depth of the slab;

$M_{e(s)}$ = hogging moment in the steel section alone;

f_s = compressive stress in steel flange due to moment $M_{e(s)}$;

I_s = moment of inertia of the steel beam alone;

I_{co} = moment of inertia of the composite section;

t_f = average thickness of the top flange of the steel section; and

t_w = thickness of the web of steel section.

B-3 FLANGE STRESS REDUCTION FACTOR (R_h) FOR HYBRID SECTIONS

Flange stress reduction factor is applicable for hybrid sections using higher-grade steel flanges where the section is non-compact, or in other words, where the section reaches the plastic moment capacity. In such cases, design limiting stress for both compression and tension shall be modified by the reduction factor R_h and shall be taken as:

$$f_n = R_h \,.\, f_{yf} / \gamma_{m0}$$

where

R_h = $(D.f_{yw}) / (d.f_{yf}) \leq 1.0$;

f_{yf}, f_{yw} = the yield strength of the flange and web respectively; and

D, d = the distance of the extreme compression/tension flange and the corresponding extreme fiber of the web from the neutral axis of the composite section respectively.

For homogeneous grade steel sections, R_h shall be 1.0. The reduction factor shall not apply to compact or plastic sections because the effect of lower strength material in the web is accounted for in calculating the plastic moment as specified in B-1.1.

B-4 MOMENT OF RESISTANCE AGAINST LATERAL-TORSIONAL BUCKLING (CONSTRUCTION STAGE)

At the construction stage, before the concrete hardens, the structural steel beam strength may be dictated by the lateral buckling strength. This may be evaluated as per good practice [C-6B(3)].

Effect of lateral-torsional buckling on flexural strength need not be considered if $\lambda_{LT} \leq 0.4$.

B-4.1 Sagging Lateral Buckling Resistance of Structural Steel Beams

The design buckling resistance moment of a laterally unrestrained beam under un-propped condition during the construction stage shall be taken as:

$$M_d = \beta_b Zp \left(\frac{\chi_{LT} \, f_y}{\gamma_{m0}} \right)$$

where

$\chi_{LT} = \frac{1}{[\varphi_{LT} + (\varphi_{LT}^2 - \lambda_{LT}^2)^{\frac{1}{2}}]} \leq 1.0$ and

$\varphi_{LT} = 0.5[1 + \alpha_{LT}(\lambda - 0.2) + \lambda_{LT}^2]$ and

$\alpha_{LT} =$ As per Table 13

The non-dimensional slenderness ratio, λ_{LT}, is given by:

$$\lambda_{LT} = \sqrt{\frac{\beta_b Z_p f_y}{M_{cr}}} \leq \sqrt{\frac{1.2\, Z_e f_y}{M_{cr}}}$$

$$\lambda_{LT} = \sqrt{\frac{f_y}{f_{crb}}}$$

where

β_b = 1.0 for Plastic and Compact sections;

= Z_e / Z_p for semi-compact sections; and

M_{cr} = the elastic critical moment corresponding to lateral torsional buckling.

In the case of simply supported prismatic members with symmetric cross-section, the elastic critical moment, M_{cr}, can be determined as:

$$M_{\mathrm{cr}} = \sqrt{\left\{\left(\frac{\pi^2 EI_y}{(L_{\mathrm{LT}})^2}\right)\left[GI_t + \frac{\pi^2 EI_w}{(L_{\mathrm{LT}})^2}\right]\right\}} = \beta_{\mathrm{b}} Z_{\mathrm{p}} f_{\mathrm{crb}}$$

The maximum bending compressive stress corresponding to lateral buckling, $f_{cr.b}$ of non-slender rolled I-sections may be approximately calculated using the following equation:

$$f_{\mathrm{crb}} = \frac{1.1\pi^2 E}{(L_{\mathrm{LT}}/r_y)^2}\left[1 + \frac{1}{20}\left(\frac{L_{\mathrm{LT}}/r_y}{h_{\mathrm{f}}/t_{\mathrm{f}}}\right)^2\right]^{0.5}$$

The following simplified conservative equation may be used in the case of prismatic members made of standard rolled I-sections and welded doubly symmetric I-sections for calculating the elastic critical lateral buckling moment.

$$M_{cr} = \frac{\pi^2 EI_y h_f}{2L_{LT}^2}\left[1 + \frac{1}{20}\left(\frac{L_{LT}/r_y}{h_f/t_f}\right)^2\right]^{0.5} = \beta_{\mathrm{b}} Z_{\mathrm{p}} f_{\mathrm{cr,b}}$$

where

$f_{\mathrm{cr,b}}$ = lateral torsional buckling stress;

I_{w} = warping constant;

I_{t} = torsional constant = $\sum b_{\mathrm{i}}\, t_{\mathrm{i}}^3 / 3$ for open sections;

I_{y} = moment of inertia about the weak axis;

r_{y} = radius of gyration of the section about the weak axis];

L_{LT} = effective length for lateral torsional buckling;

h_{f} = Center to center distance between flanges; and

t_{f} = thickness of the flange.

M_{cr} for different beam sections, considering loading, support condition, and non-symmetric cross-section, shall be more accurately calculated using the method given in as per good practice [C-6B(3)].

B-4.2 *Hogging Lateral Buckling Resistance of Composite Beams*

The effective unsupported length, L_{LT}, in case of bare steel section may be taken as recommended in as per good practice [C-6B(3)]. When a slab connects in the hogging moment region the top flange of two or more beams running parallel, then the effect of U-Frame action in restraining the lateral buckling of bottom flange under compression (Fig. 29) may be considered as given below:

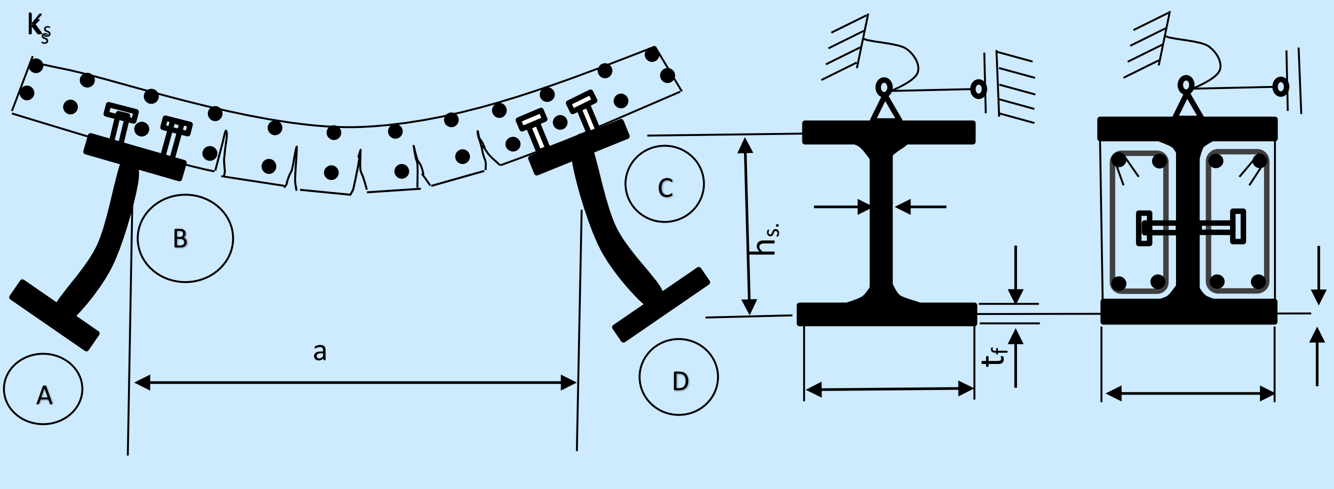


FIG. 29 INVERTED U-FRAME ACTION TO RESTRAIN LATERAL BUCKLING OF BOTTOM FLANGE

B-4.2.1 The rotational spring restraint stiffness of the concrete slab, k_s, per unit length of steel beam is given by

$$k_s = k_1\,k_2/(k_1 + k_2)$$

where

k_1 = Flexural stiffness of the cracked concrete or composite slab transverse to the spanning direction of steel beam = $\alpha\ (EI)_s/a$

α = 2 for an edge beam,

= 3 for inner beam and

= 4 for inner beam with four or more such beams running parallel and supporting the continuous slab;

a = span length of the slab transverse to the steel beams

$(EI)_s$ = cracked flexural stiffness of the concrete or composite slab per unit width parallel to the steel beam, taken as the lower of the sagging bending slab stiffness of the slab in between the steel beams and hogging bending stiffness of the slab at the supporting steel section;

k_2 = flexural stiffness of the steel web per unit length along the beam,

= $E_s\,t_w{}^3/[4(1 - \nu_s{}^2)h_s)]$ in un-encased steel section

= $E_s\,t_w\,b_c{}^2/[16\ h_s\,(1 + 4\ m\ t_w/b_c)]$ in encased steel section as per 8.3.8

E_s = modulus of elasticity of structural steel;

E_s = Poisson's ratio of structural steel;

t_w = thickness of the steel section web;

b_c = width of concrete encasement (Fig. 27);

h_s = distance between centroids of top and bottom flanges

m = long term modular ratio of encasing concrete as per good practice [C-6B(2)].

B-4.2.2 The torsional rigidity of the steel section may be taken as $G_s\,I_{st}$, where Gs is the shear modulus of steel, I_{st}, is the St. Venant's torsion constant of the steel section. The torsional rigidity stiffness contribution of encasing concrete may be taken as being equal to $G_c I_{ct}/10$, where G_c, may be taken as equal to 0.3 E_s/m and I_{ct} is the St. Venant's torsion constant of encasing concrete of rectangular shape and m is the modular ratio for long term effects.

B-4.2.3 The elastic hogging critical buckling moment of the composite beam at an internal support of a continuous beam is given by:

$$M_{cr} = (k_c C_4/L)\ [(G_s\,I_{st} + k_s\,L^2/\pi^2)\ E_s\,I_{ybf}]^2$$

where

I_{ybf} = moment of inertia of the bottom flange about the minor axis of the steel section;

I_{zco} = second moment of the equivalent area, A_{co}, of the cracked composite beam section for major axis bending;

K_c = composite beam section property = $(h_s\,I_{zc}/I_{ys})/[(h_s^2/4 + (I_{ys} + I_{zs})/A_s)/e + h_s]$;

e = $A_{co}\,I_{zs}/[A_s\,Z_c\,(A_{co} - A_s)]$;

h_s = distance between the centers of the flanges of the steel section;

I_{ys}, I_{zs} = second moment of area of steel section about the minor and major axis, respectively;

Z_c = distance between the centroid of steel section and the mid depth of concrete slab; and

C_4 = constant depending upon the bending stress distribution over the span length as given in Table 20 and Table 21.

Table 20 Linear BMD over the Span

(*Clause* B-4.2.3)

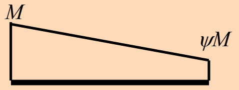
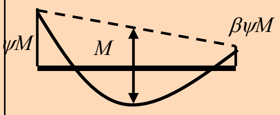
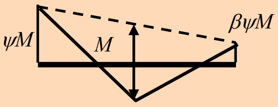
BMD	C_4								
	Ψ = - 1	- 0.75	- 0.5	- 0.25	0.0	0.25	0.5	0.75	1.0
	18.1	16.3	14.6	12.8	11.1	9.5	8.2	7.1	6.2

Table 21 Non-Linear BMD over the Span

(*Clause* B-4.2.3 *and* D-4.1)

BMD	β	C_4								
		Ψ = 0.5	0.75	1.0	1.25	1.5	1.75	2.0	2.25	2.5
	0.00	41.5	30.2	24.5	21.1	19.0	17.5	16.5	15.7	15.2
	0.50	33.9	22.7	17.3	14.1	13.0	12.0	11.4	10.9	10.6
	0.75	28.2	18.0	13.7	11.7	10.6	10.0	9.5	9.1	8.9
	1.00	21.9	13.9	11.0	9.6	8.8	8.3	8.0	7.8	7.6
	0.00	28.4	21.8	18.6	16.7	15.6	14.8	14.2	13.8	13.5
	1.00	12.7	9.8	8.6	8.0	7.7	7.4	7.2	7.1	7.0

B-5 MOMENT OF RESISTANCE FOR FILLER BEAM DECKS

Filler Beam decks most likely to be designed for structures with wide column-free zones having higher imposed loads. The stress distribution diagram for a standard filler beam decks is as shown in Fig. 30.

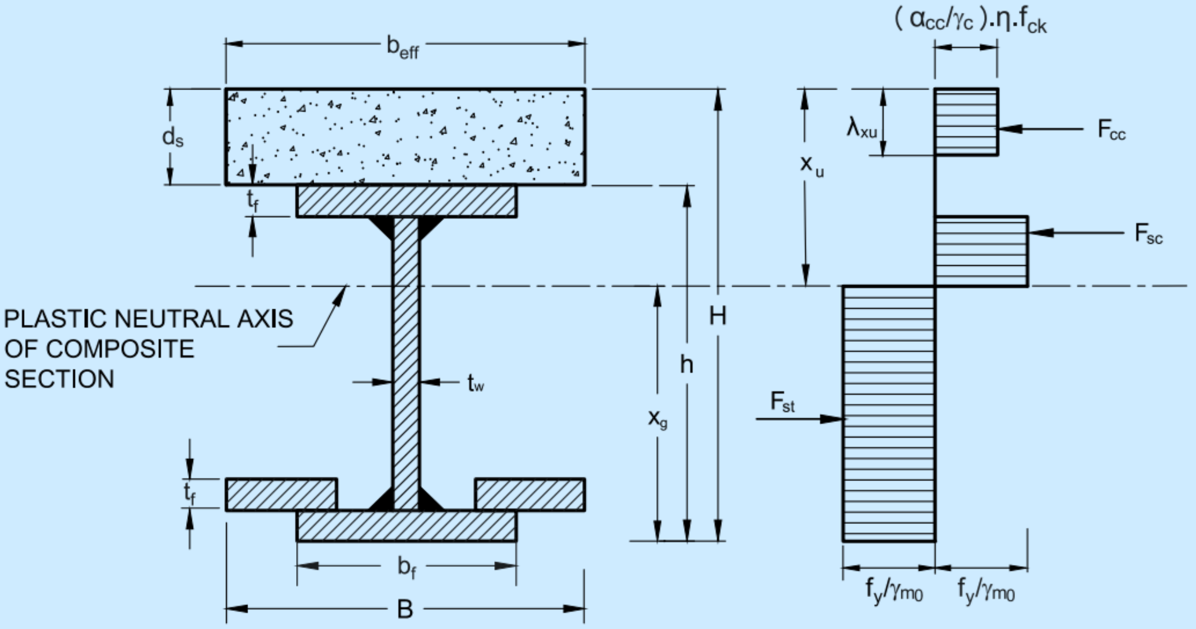

b_eff
d_s
t_f
PLASTIC NEUTRAL AXIS
OF COMPOSITE
SECTION
t_w
t_f
b_f
B
x_g
h
H
x_u
λx_u
(α_cc/γ_c).η.f_ck
F_cc
F_sc
F_st
f_y/γ_m0
f_y/γ_m0

FIG. 30 STRESS DIAGRAM FOR FILLER BEAM

For equilibrium, $F_{st} = F_{sc} + F_{cc}$

where

F_{st} = Tensile force in the steel section below the neutral axis;

F_{sc} = Compressive force the steel section above the neutral axis; and

F_{cc} = Compressive force in the concrete above the neutral axis.

The depth of the neutral axis is given as,

$$x_u = H - x_g$$

where

$$x_g = \frac{\frac{\alpha_{cc}}{\gamma_c}\,\eta\, f_{ck}\,[BH - b_f t_f - t_w(h - t_f)] + t_w h \frac{f_y}{\gamma_{m0}}}{\frac{\alpha_{cc}}{\gamma_c}\eta f_{ck}(B - t_w) + 2t_w \frac{f_y}{\gamma_{m0}}}$$

Bending resistance,

$$M_p = F_{sc} . X_{sc} + F_{cc} . X_{cc} + F_{st} . X_{st}$$

where

X_{sc}, X_{cc} *and* X_{st} are respectively the distance between the neutral axis of the composite beam and the individual centre of gravities of the corresponding forces].

B = center-to-center distance between two filler beams;

b_{eff} = effective width of concrete for one filler beam;

b_f = width of the top flange of the steel section;

t_w = thickness of the web of steel section;

H = distance between top of concrete and bottom of bottom flange of steel beam;

h = total depth of steel girder;

x_g = distance of neutral axis from bottom of bottom flange of steel beam;

A_{st} = cross sectional area of reinforcements within the effective width of the concrete flange;

A_s = cross sectional area of steel beam of a composite section;

d_s = overall depth of the slab;

d_e = effective depth of the slab; and

M_p = ultimate bending moment.

ANNEX C

(*Clauses* 12.4.3.1 *and* 12.5.2)

COMPOSITE SLABS

C-1 GENERAL

Composite slabs consist of metal decking spanning between the supports and acting integrally with the concrete after the concrete hardens (Fig. 31). The steel decking performs several roles as given below:

a) It supports loads during construction and acts as a working platform;

b) It develops adequate composite action with concrete to resist the imposed loading;

c) It transfers in-plane loading by diaphragm action to vertical bracing or shear walls;

d) It may stabilize the compression flanges of the beams against lateral buckling until the concrete hardens;

e) It reduces the volume of concrete in the tension zone of the slab; and

f) It distributes shrinkage strains, thus preventing serious cracking of concrete.

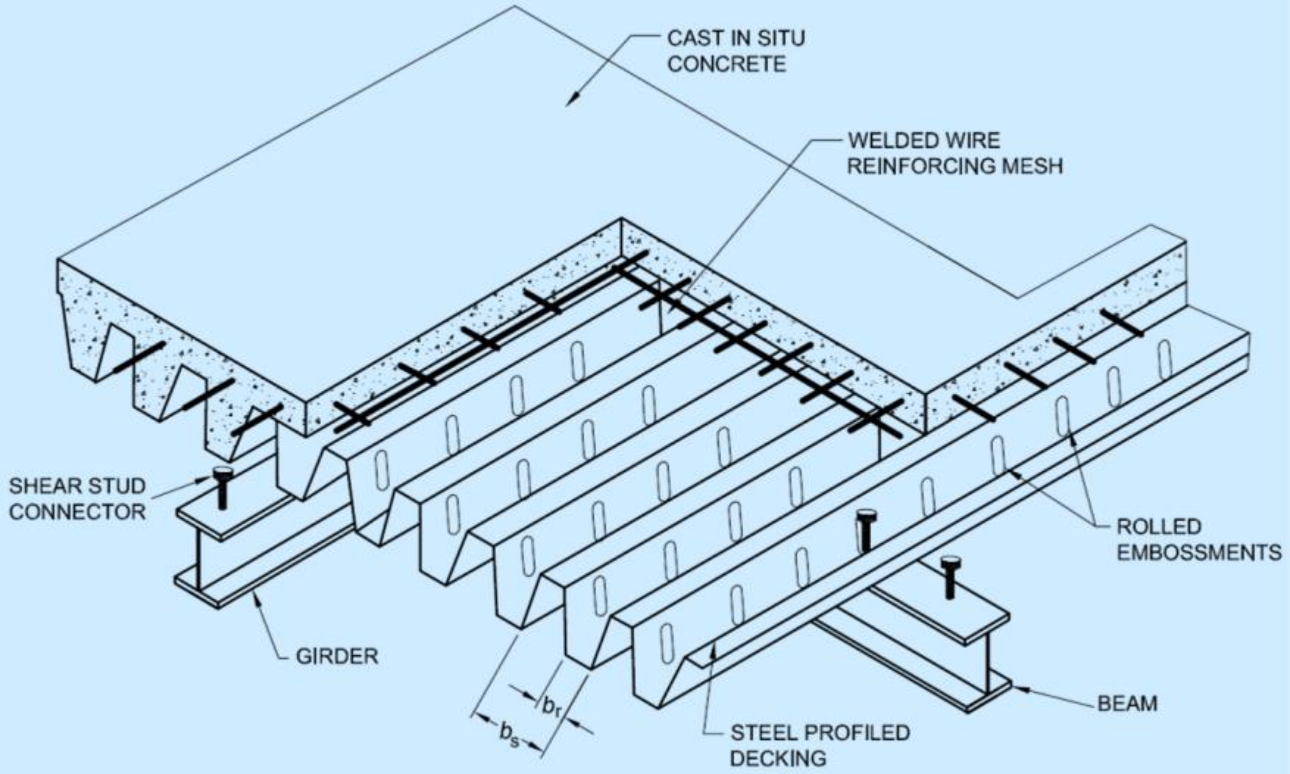

CAST IN SITU CONCRETE
WELDED WIRE REINFORCING MESH
SHEAR STUD CONNECTOR
ROLLED EMBOSSMENTS
GIRDER
b_r
b_s
STEEL PROFILED DECKING
BEAM

FIG. 31 COMPOSITE SLAB

C-2 STRUCTURAL ELEMENTS

C-2.1 Composite floors with profiled decking consist of the following structural elements along with in-situ concrete and steel beams:

a) Profiled decking;

b) Shear connectors; and

c) Reinforcement for shrinkage and temperature stresses.

Connections between the structural steel beam and decking elements are generally designed as 'simple', that is, not moment-resisting. Stud shear connectors are welded through the sheeting onto the top flange of the beam to facilitate the shear transfer between concrete and steel decking, serving as end anchorage, as well as the shear transfer between the slab and steel beam for mobilising composite action along the beam span.

C-2.2 Profile Decking

The steel deck is normally rolled into the desired profile from 0.9 mm to 1.5 mm galvanized coil sheets. It is profiled such that the profile heights are usually in the range of 38 mm to 75 mm, and the pitch of corrugations is between 150 mm and 350 mm. Generally, composite slab spans of the order of 2.5 m to 3.5 m between the beams are chosen, and the beams are designed to span between 6 m to 12 m. There are two well-known generic types of profiles as given below (Fig. 32):

a) Dovetail profile with flange indentations; and

b) Trapezoidal profile with web indentations.

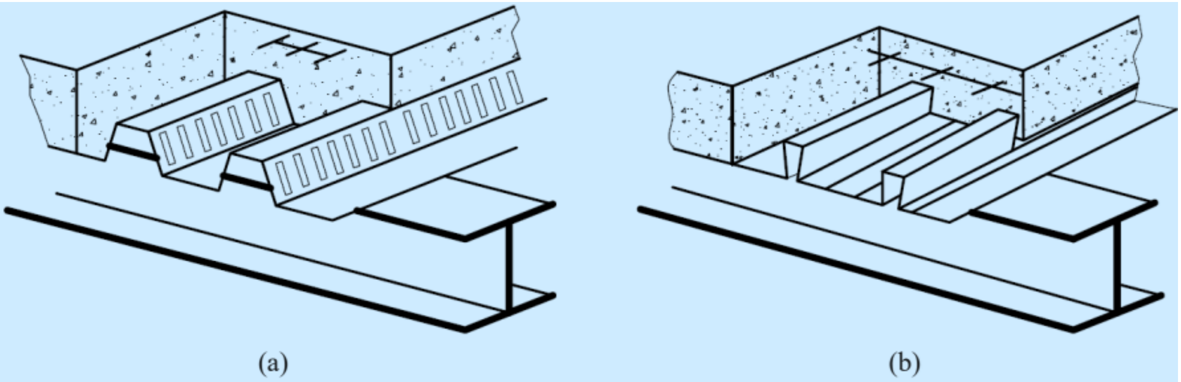


FIG. 32 COMPOSITE SLAB DECKING PROFILE

C-2.3 Shear Connectors

To enable composite action to be assumed between the profiled steel sheet and the concrete, the longitudinal shear force be transferred by the sheet by the above following form of connection (Fig. 33):

a) Mechanical interlock through the provision of indentations or embossments rolled into the profile;

b) Frictional interlock of re-entrant profile;

c) Through-deck welded stud connectors or any other local connection between the steel and the concrete; and

d) Deformation of the ends of the ribs at the ends of the sheeting.

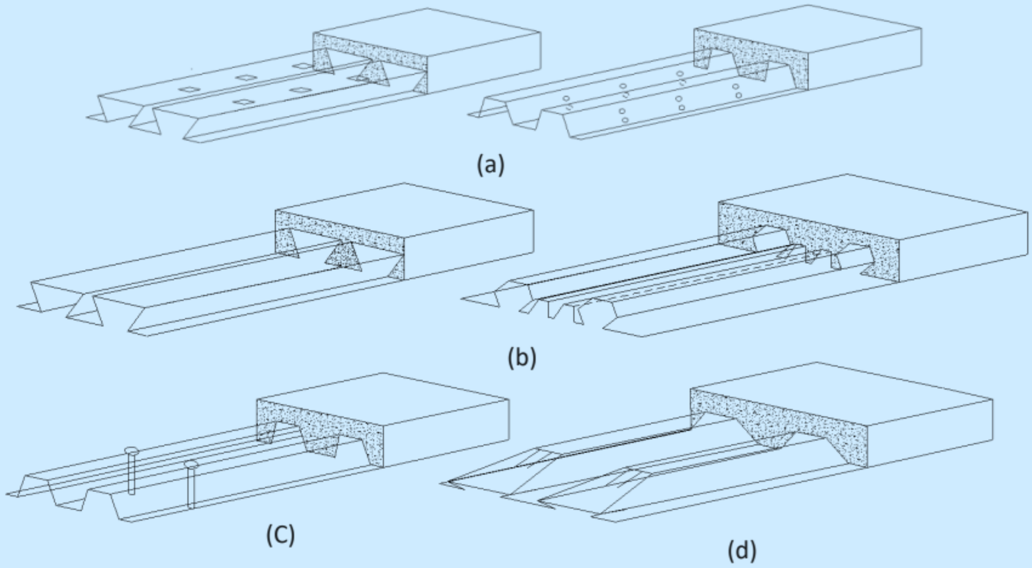


FIG. 33 TYPICAL FORMS OF SHEAR CONNECTORS IN COMPOSITE SLAB

C-2.4 Reinforcement for Shrinkage and Temperature Stresses

In buildings, the temperature difference in the slabs is negligible; thus, there is no need to provide reinforcement to account for temperature stresses. The effect of shrinkage is to be considered, and the total shrinkage strain for design may be taken as 0.003 in the absence of test data.

C-3 PONDING OF PROFILED DECKING

Fig. 34 shows ponding of the profiled deck. In unpropped construction, the profiled decking acting as a formwork to support wet concrete and construction imposed load. Due to this, the deck sheeting may deflect and cause an increase in the thickness of concrete at or closer to mid-span. This is referred to as 'Ponding.' Ponding increases the volume of concrete consumed as well as dead load. These effects should be accounted for, particularly in long spans.

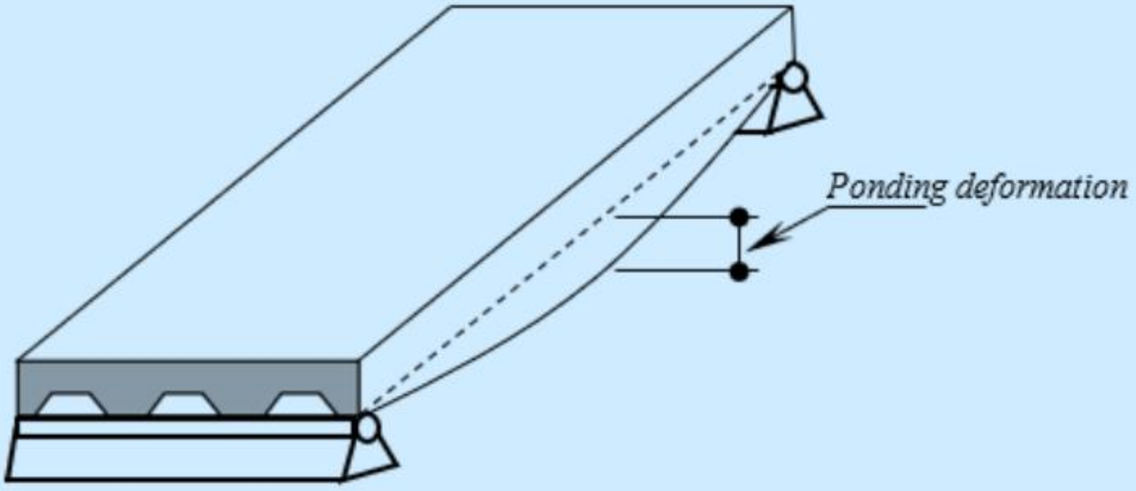


FIG. 34 PONDING IN PROFILE DECKING DUE TO WEIGHT OF CONCRETE SLAB

C-4 BENDING RESISTANCE OF COMPOSITE SLAB WITH FULL SHEAR CONNECTION

NOTE — In C-4, instead of the usual F_{cc}, the concrete compressive force is denoted as F_{ccf} to represent the concrete compressive force with a full shear connection.

C-4.1 Sagging Bending Resistance [Neutral Axis is above the Steel Decking (Fig. 35)]

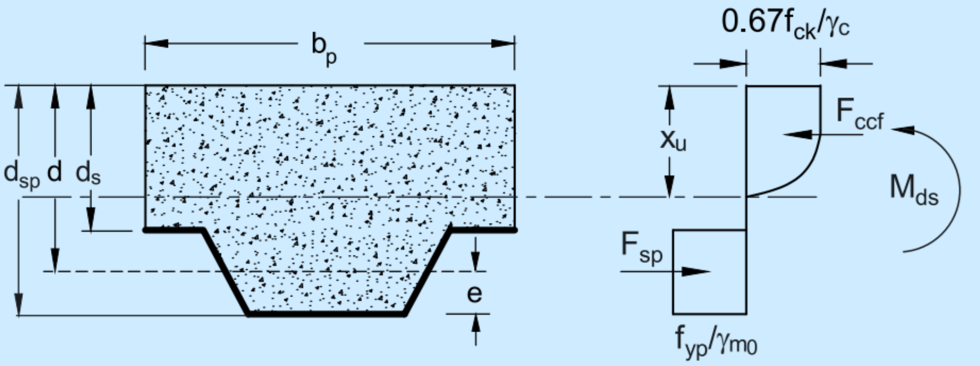


FIG. 35 STRESS DISTRIBUTION UNDER SAGGING BENDING MOMENT ($X_u < D_s$)

The design stress distribution is shown in Fig. 35. This is valid when $x_u \leq d_s$, that is, when the neutral axis lies above steel decking. Centroid of concrete force lies at $0.42x_u$ from top concrete surface. The equations for the design resistance are given in Table 22.

C-4.2 Sagging Bending Resistance [Neutral Axis is within the Steel Decking (Fig. 36)]

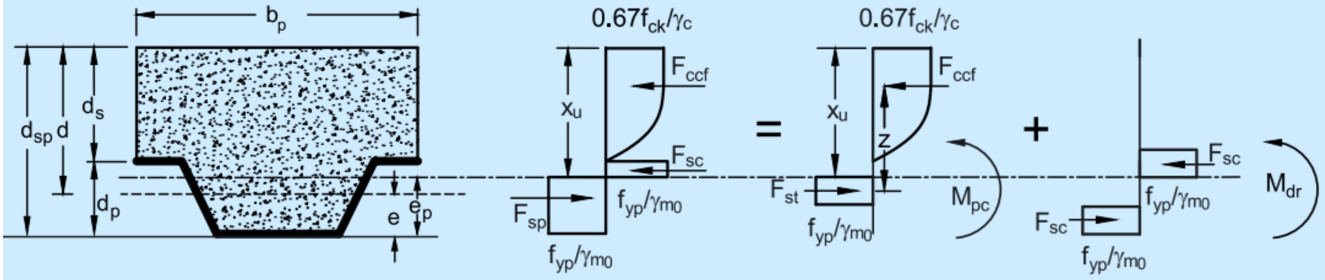


FIG. 36 STRESS DISTRIBUTION UNDER SAGGING BENDING MOMENT ($x_u > d_s$)

The design stress distribution is shown in Fig. 36. This is valid when $x_u > d_s$, that is. when the plastic neutral axis lies in the steel decking. The depth of the parabolic compressive stress block in concrete is between the top of the concrete slab to the top fibre of the deck sheet as shown in Fig. 36. Also, e_p is the distance between the plastic neutral axis of the composite slab to the extreme fibre of the deck sheet in tension and e is the distance between the centroidal axis of the profiled steel sheeting to the extreme fibre of the deck sheet in tension. The centroid of concrete force F_{ccf} lies at $0.42d_s$ from top of the concrete surface. The equations for the design resistance are given in Table 22. The value M_{dp} used in Table 22 is plastic moment capacity of the deck sheet which may be provided by the manufacturer or calculated independently.

C-4.3 Hogging Bending Resistance of Composite Deck

The contribution of steel decking is neglected. The design stress distribution is shown in Fig. 37. This is valid when x_u is in the range of $(d_s < x_u < d_{cp})$, that is., when the neutral axis lies in the steel decking. The centroid of concrete force lies at $0.42x_u$ from the bottom concrete surface b_0 the concrete width at the neutral axis is to be evaluated by trial and error. The equations for the design resistance are given in Table 22.

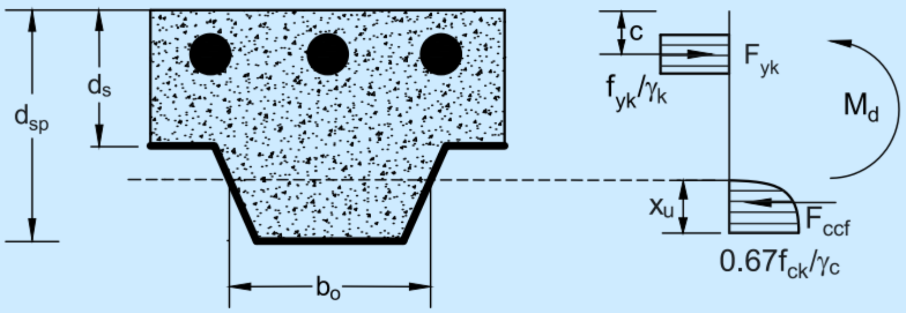


FIG. 37 STRESS DISTRIBUTION UNDER HOGGING BENDING MOMENT ($d_s < x_u < d_{sp}$)

Table 22 Design Moment Capacity, M_{ds}, of Composite Slabs with Full Shear Connection

(*Clauses* C-4.1, C-4.2 *and* C-4.3)

Case	**Position of Plastic Neutral Axis**	**Value of x_u**	**Design Moment Capacity, M_{ds}**
(1)	(2)	(3)	(4)
1	Sagging moment, NA above sheeting material (Fig. 35)	$x_u = \frac{A_p f_{yp}/\gamma_{mo}}{0.36 f_{ck} b_p} \leq d_s$	$M_{ds} = \frac{A_p f_{yp}}{\gamma_{mo}}(d - 0.42x_u)$
2	Sagging moment NA within the steel decking (Fig. 36)	$x_u > d_s$ A simplified stress block is shown in Fig. 36. Using which M_{ds} is calculated without the need for x_u	$M_{ds} = F_{ccf}z + M_{dr}$ $M_{dr} = 1.25\, M_{dp}\left[1 - \left(\frac{F_{ccf}}{A_p f_{yp}/\gamma_{mo}}\right)\right] < M_{dp}$ $z = d_{cp} - 0.42d_S - e_p + \frac{F_{ccf}}{F_{sp}}(e_p - e)$ $F_{ccf} = 0.36 f_{ck} b_p d_s$ $F_{sp} = \frac{A_p f_{yp}}{\gamma_{mo}}$
3	Hogging moment (Fig. 37)	$x_u = \frac{\frac{A_{st} f_{yk}}{\gamma_k}}{0.36 f_{ck} b_o}$	$M_d = \frac{A_{st} f_{yk}}{\gamma_k} \times (d_{sp} - c - 0.42x_u)$

Notations:

A_{st} – area of the reinforcing bar within one wave length b_s of decking sheet

d – distance between the C.G axis of the profiled steel sheeting and the extreme fibre of the composite slab in compression $(d_{sp} - e)$

e – distance between the C.G axis of the profiled steel sheeting and the extreme fibre of the composite slab in tension

e_p – distance between the plastic neutral axis and the extreme tension fibre of the composite slab.

b_p – distance between the centres of adjacent ribs or one wave length of a profile deck

A_p – effective cross-sectional area of profile decking sheeting

M_{dr} – design bending resistance of profile decking sheeting

M_{ps} _ Plastic moment of resistance of the profile decking sheeting

f_{ck} – characteristic compressive strength of concrete

f_{yp} – yield strength of profile decking sheeting

d_{sp} – total depth of the composite slab $(d_{sp} = d_s + d_p)$

C-5 BENDING RESISTANCE OF COMPOSITE SLAB WITH PARTIAL SHEAR CONNECTION

NOTE — In C-5, instead of the usual F_{cc}, the concrete compressive force is denoted as F_{ccp} to represent the concrete compressive force with a partial shear connection.

C-5.1 The stress distribution in slabs with partial shear connection is similar to Fig. 37. However, the compressive force in the concrete above the neutral axis ($F_{ccp} < F_{ccf}$) is controlled by the interface shear resistance due to the partial shear connection. The interface shear resistance is obtained from tests. The details of tests to obtain the shear strength between the interface of decking and concrete is given in **C-5.2**.

C-5.2 Shear Resistance of Composite Slab

The longitudinal shear behaviour may be considered as ductile if the failure load exceeds the load causing a recorded end slip of 0.1 mm by more than 10 percent. If the maximum load is reached at a mid-span deflection exceeding $L/50$, the failure load shall be taken as the load at the mid-span deflection of $L/50$. Otherwise, the behaviour is classified as brittle.

The shear resistance due to the chemical bond shall not be considered. This clause is applicable to the composite slabs with the mechanical or frictional interlock. Literature gives two main methods for determining the shear transfer for partial shear connection from test results. They are (i) the m-k method and (ii) the partial shear connection method. The m-k method is valid for both ductile and brittle failure cases but disregards the effect of overhang beyond the support, whereas the partial shear connection method is valid only for ductile behaviour, but accounts for the effect of the support reaction and the overhang beyond the support.

C-5.2.1 *m-k Method for Composite Slabs without End Anchorage*

The m-k method is based on establishing the gradient and intercept of an assumed linear relationship between two parameters of the slab, obtained from two groups of composite slab tests. The evaluation of m-k values is illustrated in Fig. 38.

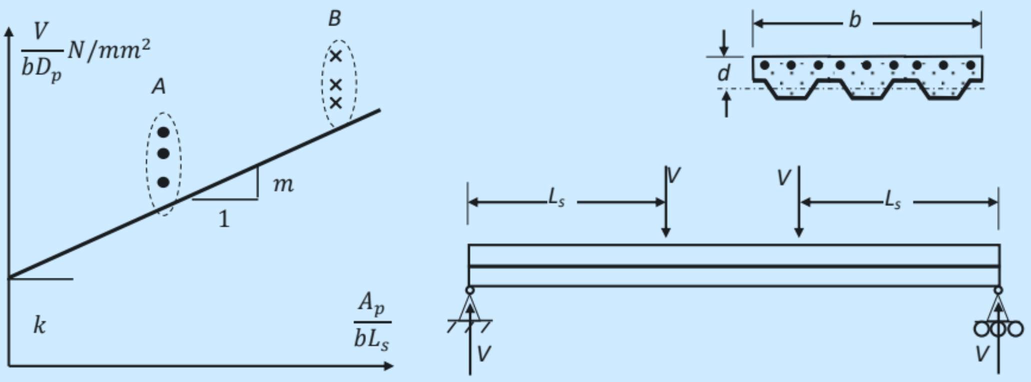


FIG. 38 TEST SETUP TO EVALUATE *M-K* VALUES

For cases when the longitudinal shear behaviour may be considered ductile, V is taken as the value of the support reaction at the failure load. However, if the behavior is brittle, the value should be reduced using a factor 0.8. By plotting the results from the composite slab tests in terms of the vertical shear parameter [$V/(b\,D_p)$] against the shear bond parameter [$A_p/(b\,L_s)$] for two groups of data corresponding to the long specimens (Group-A) and the short specimens (Group-B). The relationship between vertical shear and shear bond capacity is approximated by constructing a straight line through the two groups of data (Fig. 38). The effect of any overhang in the test specimen is neglected in the m-k method, unlike in the partial shear connection approach.

From all the values of V, 5 percent fractile of the characteristic shear strength linear regression line should be calculated to define the characteristic m and k values (Fig. 38). The minimum value of each group is further reduced by 10 percent for design consideration if two groups of three tests are used and the deviation of any individual test result in a group does not differ by more than 10 percent from the mean.

If the m-k method is used, it should be shown that the maximum design vertical shear V for a width of slab ‘b’ does not exceed the design shear resistance V_{ld} specified in Table 23.

C-5.2.2 *Partial Interaction Method*

The degree of shear connection η is defined as,

$$\eta = \frac{F_{\mathrm{ccp}}}{F_{\mathrm{ccf}}}$$

where

F_{ccp} = compressive force in the concrete as governed by partial shear transfer, as obtained from a standard tests; and

F_{ccf} = compressive force in the concrete for full shear connection as given in **C-4**.

The variation in bending resistance with the degree of shear connection is shown in Fig. 39. In case $\eta = 0$ composite action between the steel sheet and the concrete does not exist, and it is assumed that the bending resistance is provided by the bending resistance, M_{dp}, of profiled steel sheet alone. For the case $\eta = 1$, in the full shear connection, the full tensile resistance of the sheet is developed, or the full compressive resistance of concrete above the ribs of the sheet is attained. For intermediate cases such that $0 < \eta < 1$, the partial shear connection exists. Typical behaviour of open trough profile steel sheeting with partial shear connection is illustrated in Fig. 39.

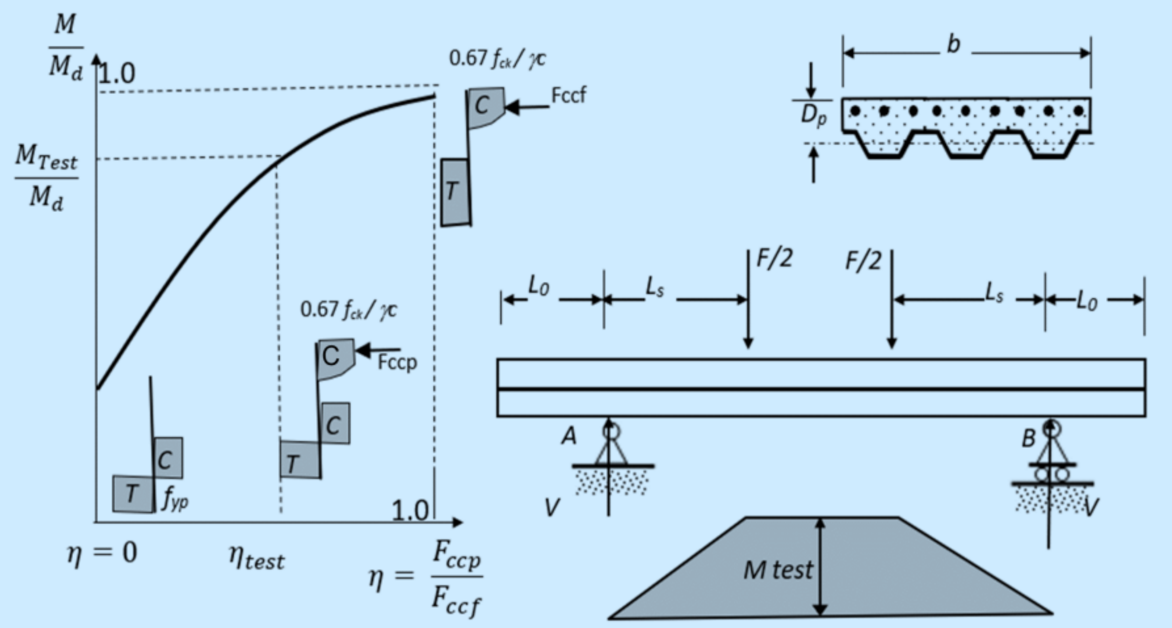


FIG. 39 TEST TO DETERMINATION OF THE DEGREE OF THE PARTIAL SHEAR CONNECTION

For a given bending resistance, the degree of shear connection provided in the test η_{test} can be assessed from the points on the partial shear interaction curve in Fig. 39. By neglecting the effect of the support reaction, the longitudinal shear strength τ_u can be obtained from

$$\tau_u = \frac{\eta_{\mathrm{test}}\, F_{\mathrm{ccf}}}{b\,(L_{\mathrm{s}} + L_{\mathrm{o}})}$$

where

F_{ccf} = Compressive normal force in the concrete flange with full shear connection;

b = Width of the slab;

L_s = Shear span; and

L_o = Length of the overhang (Fig. 39).

If the additional longitudinal shear, the additional resistance caused by the friction due to the support reaction is taken into account, the equation becomes

$$\tau_u = \frac{\eta_{test} F_{ccf} - \mu V}{b\,(L_s + L_o)}$$

where

μ = frictional coefficient taken as 0.5; and

V = support reaction under the test load.

The characteristic shear strength $\tau_{u.fk}$ should be calculated from the test values as the minimum value of stress below which not more than a specified percentage (usually 5 percent) of the corresponding stresses of samples tested are expected to occur. This is divided by the partial safety factor governed by the ultimate state to obtain the design value, $\tau_{u.d}$.

The determination of the design moment resistance of the composite slab with the partial shear connection is similar to the case (Fig. 39). The design bending resistance of the partial shear connection slab is evaluated using equations given in Table 23.

Table 23 Design Moment Capacity, M_{dp}, of Composite Slabs with Partial Shear Connection

(*Clauses* C-5.2.1, C-5.2.2 *and* D-2)

Case	Position of Plastic Neutral Axis	Methods/ Value of x_u	Design Moment Capacity, M_{dp}
(1)	(2)	(3)	(4)
1	Sagging moment (Fig. 38)	*m*-*k* method	$M_{dp} = V_{lp} L_s$ $V_{lp} = \frac{bd_p}{\gamma_{m1}}\left(\frac{mA_p}{bL_s} + k\right)$
2	Sagging moment, NA above profile decking sheet (Fig. 39)	Partial shear connection method $x_u = \frac{F_{ccp}}{0.36 f_{ck} b_p} \leq d_s$	$M_{dp} = \frac{A_p f_{yp}}{\gamma_{mo}}(d - 0.42x_u)$ $F_{ccp} = \tau_{ud} b_p L_x \leq F_{ccf}$
3	Sagging moment, NA within the profile decking sheet (Fig. 39)	Partial shear connection method A simplified stress block is shown in Fig. 39. Using which M_{dp} is calculated with $x_u = \frac{F_{ccp}}{0.36 f_{ck} b_p}$	$M_{dp} = F_{ccp} z + M_{pr}$ $F_{ccp} = \tau_{ud} b_p L_x \leq F_{ccf}$ $z = d_{cp} - 0.42x_u - e_p + \frac{F_{ccp}}{A_p f_{yp}/\gamma_{mo}}(e_p - e)$ $M_{dr} = 1.25\, M_{dp}\left[1 - \left(\frac{F_{ccp}}{A_p f_{yp}/\gamma_{mo}}\right)\right] < M_{dp}$
Where L_x is the distance of the cross section being considered to the nearest support.			

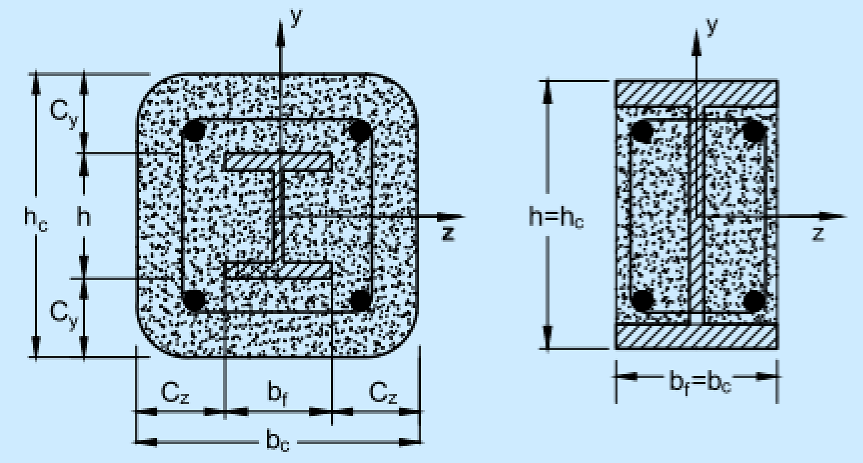
ANNEX D

(*Clause* 13.8.1)

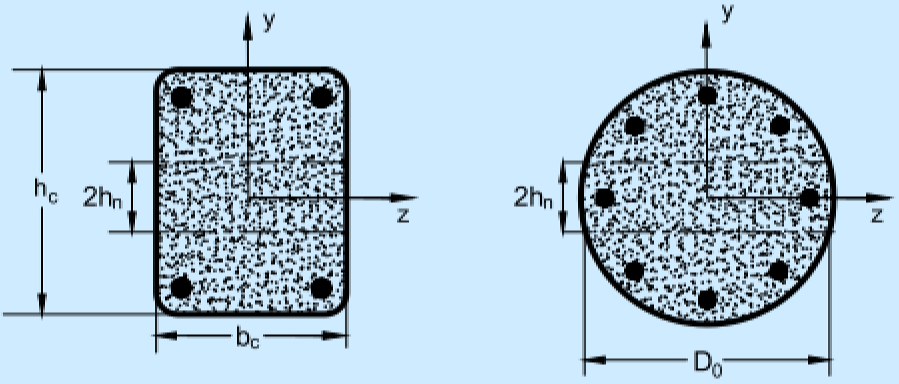
PLASTIC DESIGN RESISTANCE OF SYMMETRIC COMPOSITE COLUMNS

D-1 GENERAL

This section deals with the calculation of the design resistance of the doubly symmetric composite columns. The resistance equations are derived based on the rectangular stress block in concrete. The general dimensional view of the fully or partially concrete-encased single I-section is as given in Fig. 40 (a). The general dimensional view of the concrete infilled tubular composite column section is given in Fig. 40 (b).



a) Fully and partially concrete encased



b) Concrete infilled tubular columns

FIG. 40 TYPICAL COMPOSITE COLUMN DETAILS

The following are the notations used in this section, in addition to the dimensions shown in Fig. 40.

A_c = cross sectional area of concrete;

A_s = cross sectional area of structural steel;

A_{st} = cross sectional area of total steel reinforcement;

A_{stc} = cross sectional area of steel reinforcement in the compression zone;

f_{ck} = characteristic compressive cube strength of concrete;

f_y = minimum guaranteed yield strength of structural steel section;

f_{yk} = minimum Guaranteed yield strength of steel reinforcement;

M_d = design bending resistance under only bending moment;

M_n = ultimate bending resistance under only bending moment;

P_d = design compressive resistance under compression only;

P_n = ultimate compressive resistance under compression only;

M'_d = design bending resistance under combined bending and compression;

M'_n = ultimate bending resistance under combined bending and compression;

P'_d = design compressive resistance under combined bending and compression;

P'_n = ultimate compressive resistance under combined bending and compression;

r = inner radius of the rounded corners in RHS;

γ_c = partial safety factor for the compressive strength of concrete = 1.5;

γ_{m0} = partial safety factor for the yield strength of structural steel = 1.1; and

γ_k = partial safety factor for the yield strength of steel reinforcement = 1.15.

D-2 DESIGN COMPRESSIVE RESISTANCE OF SHORT COMPOSITE COLUMN (Point A)

The stresses on different components of the composite columns at the ultimate stage under only axial force are as shown in Fig. 41. The ultimate design compressive resistance, P_n, of the plastic, compact and semi-compact sections are given by:

$$P_n = A_s f_y + A_{st} f_{yk} + \alpha_c A_c (\alpha_{cc} f_{ck})$$

where

α_c = 0.85, for partially or fully encased column; and

α_c = 1.0, for infilled columns.

α_{cc} = 0.67

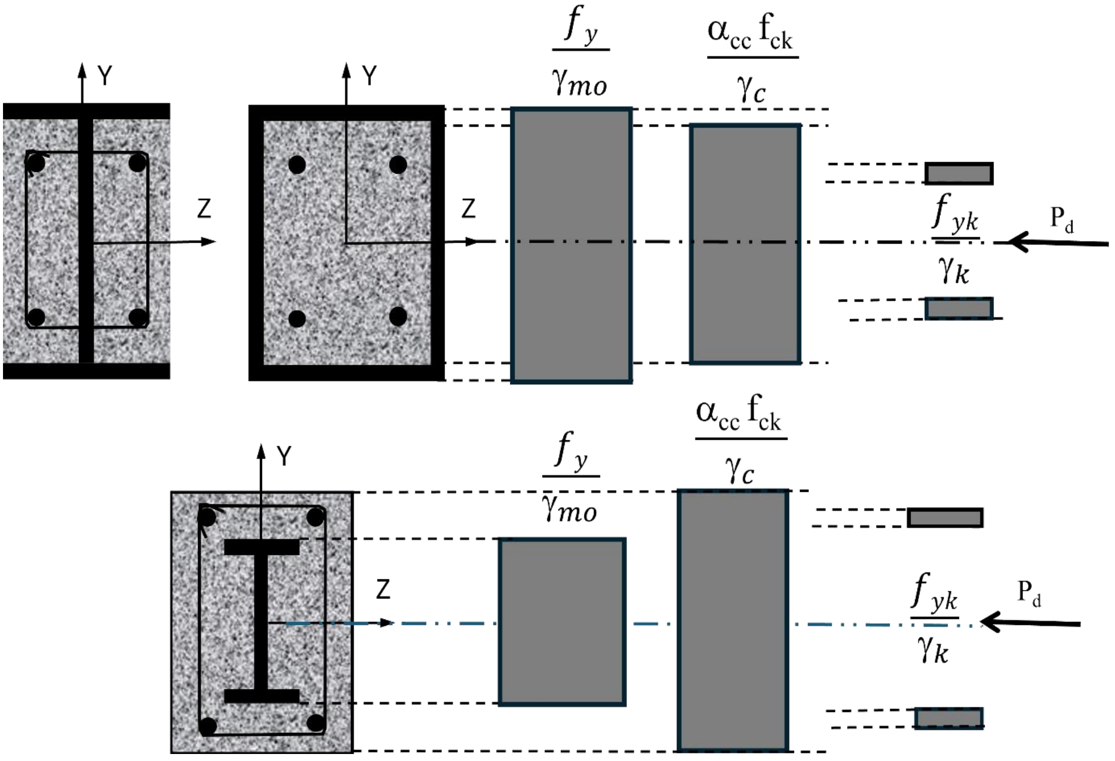

Y
Z
Y
Z
$\frac{f_y}{\gamma_{mo}}$
$\frac{\alpha_{cc} f_{ck}}{\gamma_c}$
$\frac{f_{yk}}{\gamma_k}$
P_d
Y
Z
$\frac{f_y}{\gamma_{mo}}$
$\frac{\alpha_{cc} f_{ck}}{\gamma_c}$
$\frac{f_{yk}}{\gamma_k}$
P_d

FIG. 41 STRESS DISTRIBUTION AT ULTIMATE STAGE UNDER ONLY AXIAL FORCE

The axial design resistances of different types of the composite column are given in Table 24. For concrete filled circular tubular sections in Table 24, the increase in concrete strength due to confinement may be taken, provided $\lambda \leq 0.5$ calculated using **13.5.1** and $e/d < 0.1$ where e is the eccentricity of the loading, given by the ratio of the design moment to design axial load and d is the external diameter of the circular column. If anyone of the conditions is not satisfied then $\eta_1 = 0$ and $\eta_2 = 1$.

To account for minimum eccentricity and grade of reinforcing steel, the design axial capacity can be estimated using the following expression,

$$P_d = A_s \frac{f_y}{\gamma_{m0}} + \propto_k A_{st} \frac{f_{yk}}{\gamma_k} + 0.6 \propto_c A_c \frac{f_{ck}}{\gamma_c}$$

α_k values can be taken as

Grade of Reinforcing Steel	Value of α_k
Fe250	0.90
Fe415	0.82
Fe500	0.77

Table 24 Design Compressive Resistance of Short Composite Compression Members

(*Clause* D-2)

Type of Section	Design Compressive Resistance
(1)	(2)
Partially or fully encased composite section	$P_d = A_s \frac{f_y}{\gamma_{m0}} + A_{st} \frac{f_{yk}}{\gamma_k} + 0.57 A_c \frac{f_{ck}}{\gamma_c}$
Concrete filled rectangular tubular section	$P_d = A_s \frac{f_y}{\gamma_{m0}} + A_{st} \frac{f_{yk}}{\gamma_k} + 0.67 A_c \frac{f_{ck}}{\gamma_c}$
Concrete filled circular tubular section	$P_d = A_s \eta_2 \frac{f_y}{\gamma_{m0}} + A_{st} \frac{f_{yk}}{\gamma_k} + A_c \frac{(\alpha_{cc} f_{ck})}{\gamma_c} \left[1 + \eta_1 \frac{t}{d} \frac{f_y}{(\alpha_{cc} f_{ck})}\right]$ $\eta_1 = \eta_{10} \left[1 - \frac{10e}{d}\right]$ $\eta_2 = \eta_{20} + (1 - \eta_{20}) \frac{10e}{d}$ $\eta_{10} = 4.9 - 18.5\lambda + 17\lambda^2 \geq 0.0$ $\eta_{20} = 0.25(3 + 2\lambda) \leq 1.0$

D-3 DESIGN BENDING RESISTANCE OF COMPOSITE COLUMN

The stresses on the different components of the composite columns at the ultimate stage under only the bending moment about the z-z axis are as shown in Fig. 42.

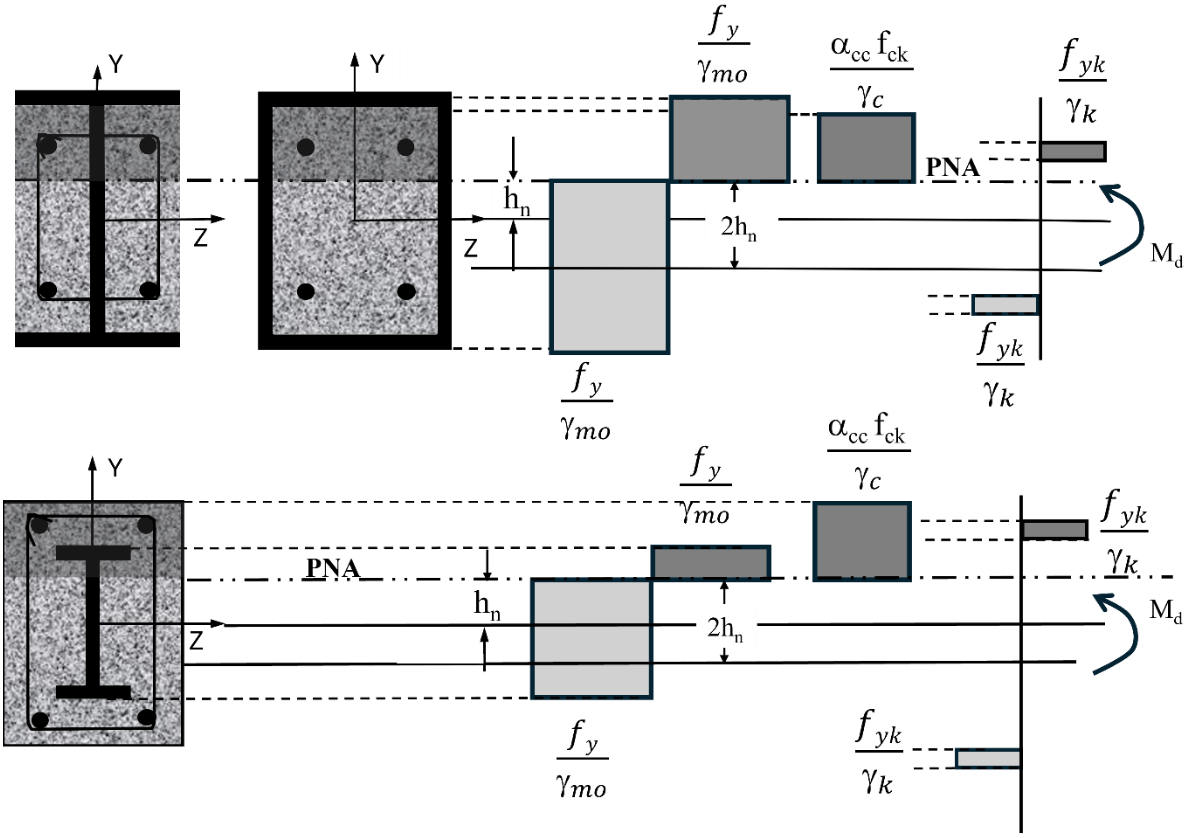

Y
Z
Y
Z
$\frac{f_y}{\gamma_{mo}}$
$\frac{\alpha_{cc} f_{ck}}{\gamma_c}$
$\frac{f_{yk}}{\gamma_k}$
PNA
h_n
$2h_n$
M_d
$\frac{f_{yk}}{\gamma_k}$
$\frac{f_y}{\gamma_{mo}}$
Y
$\frac{\alpha_{cc} f_{ck}}{\gamma_c}$
$\frac{f_y}{\gamma_{mo}}$
$\frac{f_{yk}}{\gamma_k}$
PNA
h_n
$2h_n$
M_d
Z
$\frac{f_y}{\gamma_{mo}}$
$\frac{f_{yk}}{\gamma_k}$

FIG. 42 STRESS DISTRIBUTION AT ULTIMATE STAGE UNDER ONLY BENDING MOMENT

The design bending resistance is given by:

$$M_d = (Z_{ps} - Z_{psn}) f_y / \gamma_{m0} + (Z_{pr} - Z_{prn}) f_{yk} / \gamma_k + 0.5\, \alpha_c (Z_{pc} - Z_{pcn})\, (\alpha_{cc} f_{ck}) / \gamma_c$$

where

Z_{ps}, Z_{pr}, and Z_{pc} = Plastic section moduli of the steel section, reinforcement and concrete about their own centroidal axis, respectively (the concrete in tension region is assumed to be uncracked for this calculation).

Z_{psn},, Z_{prn} and Z_{pcn} = Plastic section moduli of the steel section, reinforcement and concrete, all within the depth h_n on both sides of the neutral axis of the gross section, about the neutral axis of gross section, respectively. (Table 25 gives equations for evaluating the value of h_n)

α_c = the strength coefficient of concrete,

= 0.85 for fully and partially encased composite sections,

= 1.0 for concrete filled hollow sections and

= 0.89 for fully encased or concrete filled hollow sections with spiral ties

Table 25 Location of Neutral Axis in Composite Column at Ultimate Moment

(*Clause* D-3)

Section	**Case**	**Depth, h_n**
(1)	(2)	(3)
$f_{cd} = \frac{(\alpha_{cc} f_{ck})}{\gamma_c}$, A_{sn} = Area of structural steel within $2h_n$ distance A_{stn} = Area of reinforcing steel within $2h_n$ distance		
a) *Major axis Bending*		
Concrete encased sections	$h_n \le [\,h/2 - t_f]$	$\dfrac{A_c\, a_c\, f_{cd} - A_{stn}\left(\dfrac{2f_{yk}}{\gamma_k} - a_c\, f_{cd}\right)}{2b_c\, a_c\, f_{cd} + 2\, t_w\left(2\dfrac{f_y}{\gamma_{m0}} - a_c f_{cd}\right)}$
	$[h/2 - t_f] \le h_n \le h/2$	$\dfrac{a_c A_c\, f_{cd} - A_{stn}\left(2\,\dfrac{f_{yk}}{\gamma_k} - a_c\, f_{cd}\right) + (b - t_w)(h - 2\, t_f)\left(2\,\dfrac{f_y}{\gamma_{m0}} - a_c\, f_{cd}\right)}{2\, b_c a_c f_{cd} + 2\, b\left(2\dfrac{f_y}{\gamma_{m0}} - a_c\, f_{cd}\right)}$
	$h/2 \le h_n \le h_c/2$	$\dfrac{A_c\, a_c f_{cd} - A_{stn}\left(2\dfrac{f_{yk}}{\gamma_k} - a_c f_{cd}\right) - A_{sn}\left(2\dfrac{f_y}{\gamma_{m0}} - a_c f_{cd}\right)}{2b_c a_c f_{cd}}$

Table 25 (*Continued*)

Section	**Case**	**Depth, h_n**
(1)	(2)	(3)
Concrete filled sections	*RHS*	$\dfrac{A_c a_c f_{cd} - A_{stn}\left(2\dfrac{f_{yk}}{\gamma_k} - a_c f_{cd}\right)}{2\, b_c\, a_c f_{cd} + 4\, t\left(2\dfrac{f_y}{\gamma_{m0}} - a_c f_{cd}\right)}$
	CHS	In RHS equation substitute D for b_c as an approximation
b)	*Minor axis Bending*	
Concrete encased sections	$h_n \le t_w/2$	$\dfrac{A_c a_c f_{cd} - A_{stn}\left(2\dfrac{f_{yk}}{\gamma_k} - a_c f_{cd}\right)}{2\, h_c a_c f_{cd} + 2\, h\left(2\dfrac{f_y}{\gamma_{m0}} - a_c f_{cd}\right)}$
	$t_w/2 < h_n < b/2$	$\dfrac{A_c a_c f_{cd} - A_{stn}\left(2\dfrac{f_{yk}}{\gamma_k} - a_c f_{cd}\right) - t_w\left(h - 2t_f\right)\left(2\dfrac{f_y}{\gamma_{m0}} - a_c f_{cd}\right)}{2\, h_c a_c f_{cd} + 4t_f\left(2\dfrac{f_y}{\gamma_{m0}} - a_c f_{cd}\right)}$

Table 25 (*Concluded*)

Section	**Case**	**Depth, h$_n$**
(1)	(2)	(3)
	$b_f/2 \leq h_n \leq b_c/2$	$\dfrac{A_c a_c f_{cd} - A_{stn}\left(2\dfrac{f_{yk}}{\gamma_k} - a_c f_{cd}\right) - A_{sn}\left(2\dfrac{f_y}{\gamma_{m0}} - a_c f_{cd}\right)}{2\, h_c a_c f_{cd}}$
Concrete filled sections	RHS	$\dfrac{A_c a_c f_{cd} - A_{stn}\left(2\dfrac{f_{yk}}{\gamma_k} - a_c f_{cd}\right)}{2\, h_c a_c f_{cd} + 4t\left(2\dfrac{f_y}{\gamma_{m0}} - a_c f_{cd}\right)}$
	CHS	In RHS equation substitute D for h_c as an approximation

D-4 DESIGN RESISTANCE OF COMPOSITE SHORT COLUMN UNDER COMBINED BENDING AND COMPRESSION

The stresses on the different components of the composite columns at the ultimate stage under only the bending moment about the z-z axis are as shown in Fig. 43.

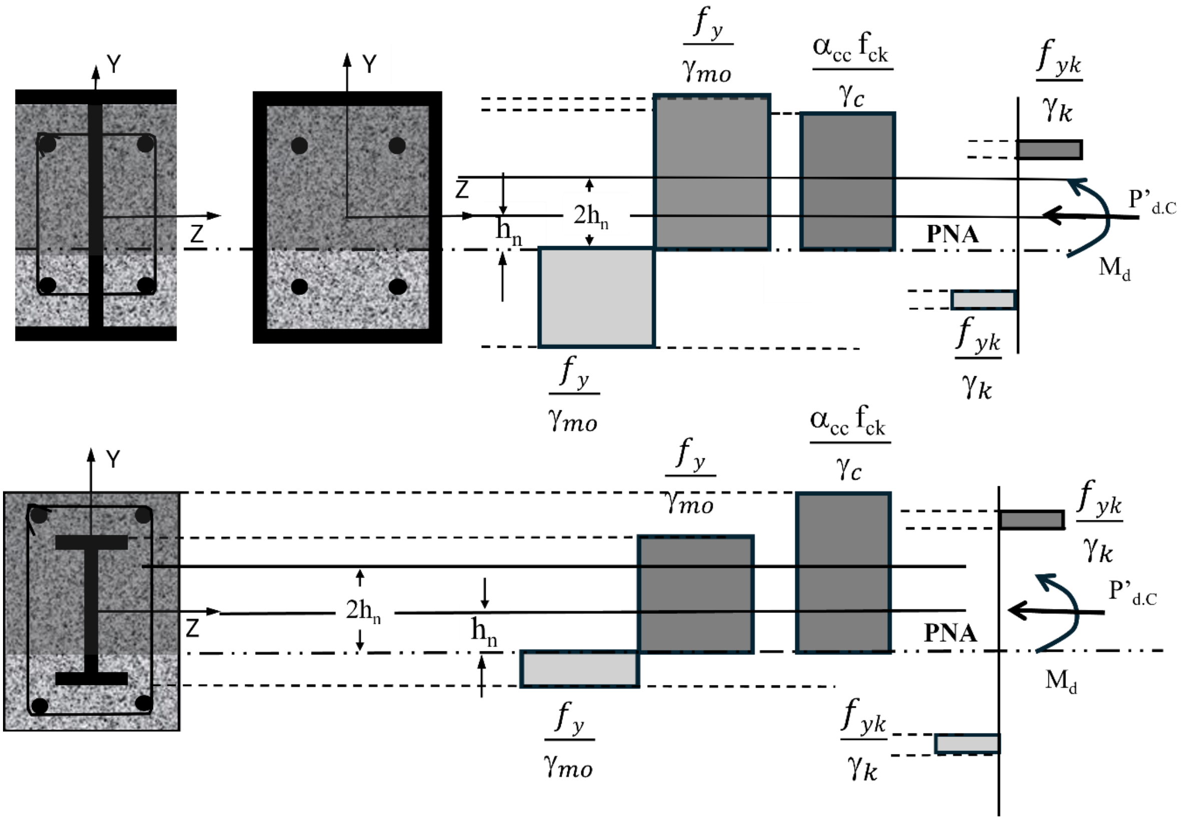

Y
Y
Z
Z
Z
2h_n
h_n
$\frac{f_y}{\gamma_{mo}}$
$\frac{\alpha_{cc} f_{ck}}{\gamma_c}$
$\frac{f_{yk}}{\gamma_k}$
PNA
P'd.C
M_d
Y
Z
2h_n
h_n
PNA

FIG. 43 SHORT COLUMN COMPRESSION AND BENDING INTERACTION

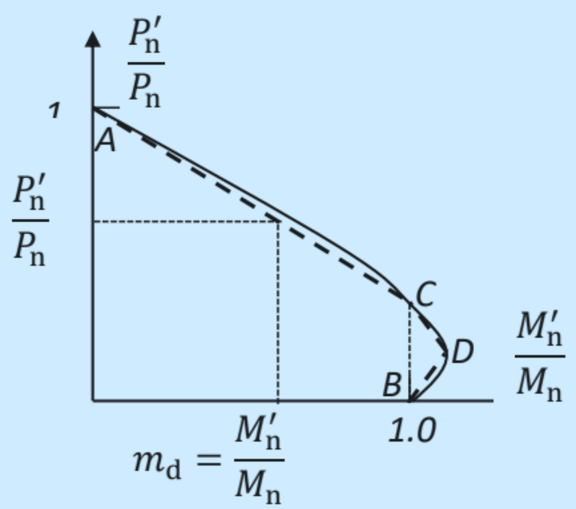


FIG. 44 INTERACTION CURVE OF A COMPOSITE COLUMN SHOWING THE POINTS A, B, C AND D

If the concrete section in compression is below the neutral axis of the gross section, h_n, is assumed. The integration of the stresses over the cross section gives the ultimate nominal compressive resistance, P'_n, for the cross section. The integration of the moment of the stresses over the cross section about the neutral axis of the gross section gives the corresponding ultimate bending resistance, M'_n. For various values of h_n, the corresponding simultaneous compressive and bending resistance of the cross section can be calculated to obtain an interaction curve as shown in Fig. 44.

It is seen that the resistance under only compression (Table 23) is a point, (A), on the curve. The resistance under only bending is point, (B), on the curve. Further, from the case of pure bending, as the axial load is increased from zero value, the bending resistance also increases until point D. Similarly, the point C corresponds to the case, where in spite of the axial compression, the ultimate plastic bending resistance, M_n, is reached.

It is tedious and time-consuming to develop the full interaction curve for every section designed. In order to simplify, the values corresponding to the points A, B, C, and D are computed and in between a straight-line variation is assumed in the design. The simplified procedure and the equations are discussed in the following sections.

The values of P_d and M_d corresponding to plastic section under pure compression (point A, Fig. 41) and pure bending (Point B, Fig. 42) are obtained as in **D-2** and **D-3**.

D-4.1 The Design Resistance at Point C (Fig. 45)

The design bending resistance corresponding to point C is the same as pure bending resistance.

$$M'_{d,C} = M_d$$

The design compressive resistance corresponding to point C on the interaction diagram is obtained as given below. The typical position of the neutral axis for points *B* is shown in Fig. 43 and at the point C in the beam-column interaction curve in Fig. 44. The location of the neutral axis from the CG of section, h_n, can be determined from Table 21. The integration of the stresses shown in Fig. 46 is equal to $P'_{pd,C}$ at point C. The axial force corresponding to point C in the interaction curve is given by the equation in Table 26.

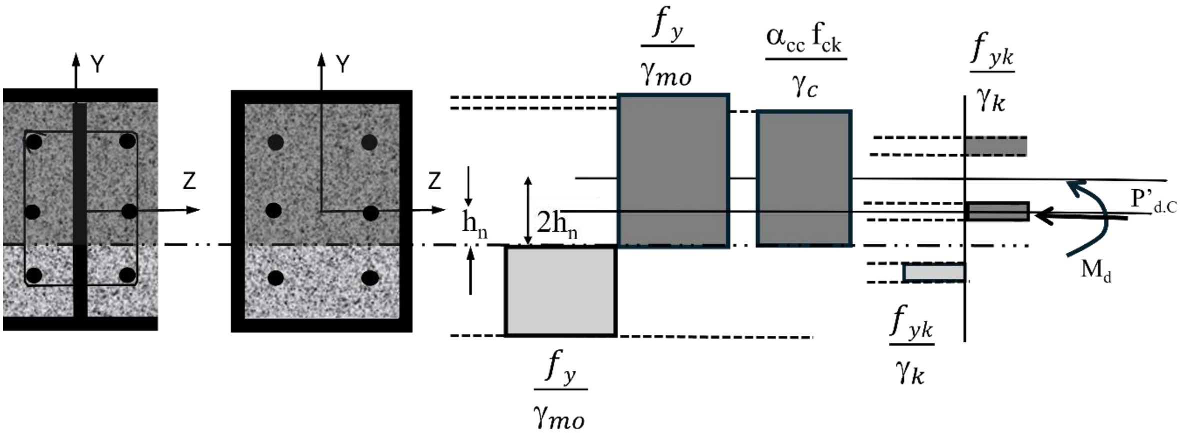


FIG. 45 STRESS DISTRIBUTIONS FOR THE POINT C OF THE INTERACTION CURVE FOR CONCRETE FILLED RECTANGULAR TUBULAR SECTIONS

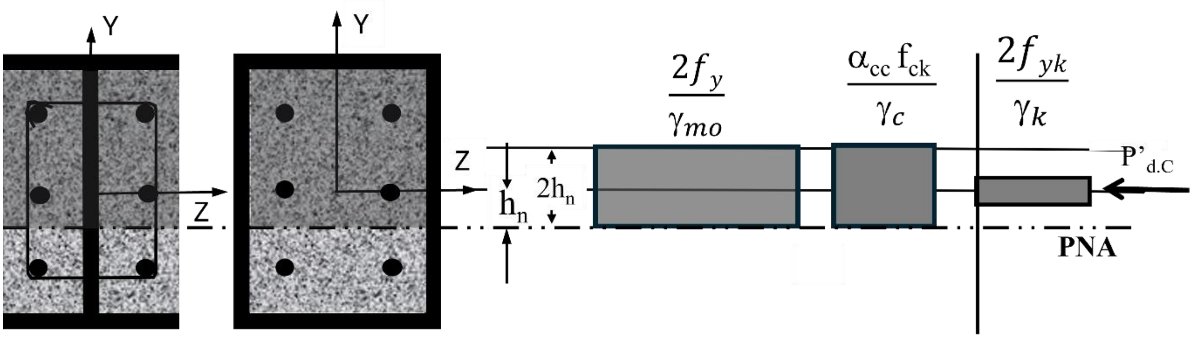

Y
Y
Z
Z
h_n
$2h_n$
$\frac{2f_y}{\gamma_{mo}}$
$\frac{\alpha_{cc} f_{ck}}{\gamma_c}$
$\frac{2f_{yk}}{\gamma_k}$
P'd.C
PNA

FIG. 46 STRESS CAUSING RESISTING COMPRESSION AT POINT C

Table 26 Design Compressive Resistance at Point C

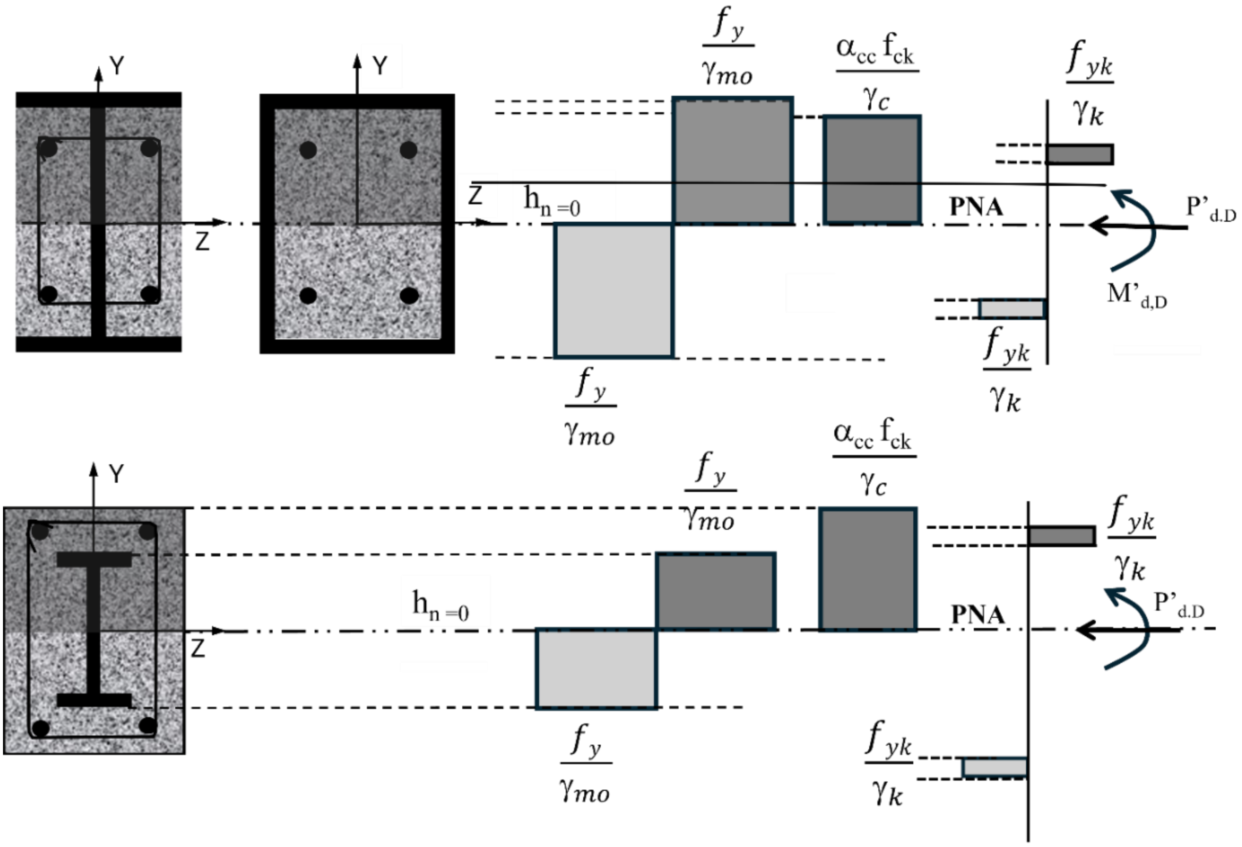
(*Clause* D-4.1)

Section	Case	$P'_{d,C}$
(1)	(2)	(3)
a) *Major Axis Bending*		
Concrete encased column	$h_n \le [\, h/2 - t_f \,]$	$P'_{d,C} = 2\, h_n b_c a_c f_{cd} + 2h_n t_w \left(2\frac{f_y}{\gamma_{m0}} - a_c f_{cd}\right) + A_{stn}\left(2\frac{f_{yk}}{\gamma_k} - a_c f_{cd}\right)$
	$[h/2 - t_f] \le h_n \le h/2$	$P'_{d,C} = 2\, h_n b_c a_c f_{cd} + (A_s - (h - 2h_n)\, b_f)\left(2\frac{f_y}{\gamma_{m0}} - a_c f_{cd}\right) + A_{stn}\left(2\frac{f_{yk}}{\gamma_k} - a_c f_{cd}\right)$
	$h/2 \le h_n \le h_c/2$	$P'_{d,C} = 2\, h_n b_c a_c f_{cd} + (\, A_{sn})\left(2\frac{f_y}{\gamma_{m0}} - a_c f_{cd}\right) + A_{stn}\left(2\frac{f_{yk}}{\gamma_k} - a_c f_{cd}\right)$
	RHS	$P'_{d,C} = 2\, h_n b_c f_{cd} + 4h_n t \left(2\frac{f_y}{\gamma_m} - a_c f_{cd}\right) + A_{stn}\left(2\frac{f_{yk}}{\gamma_k} - a_c f_{cd}\right)$
Concrete infilled sections	CHS	In RHS equation substitute D for b_c
b) *Minor Axis Bending*		
Concrete encased column	$h_n \le t_w/2$	$P'_{d,C} = 2\, h_n h_c a_c f_{cd} + 2h_n \mathrm{h}\left(2\frac{f_y}{\gamma_{m0}} - a_c f_{cd}\right) + A_{stn}\left(2\frac{f_{yk}}{\gamma_k} - a_c f_{cd}\right)$
	$t_w/2 < h_n < b/2$	$P'_{d,C} = 2\, h_n h_c a_c f_{cd} + \left(4h_n t_f + t_w\,(h - t_f)\right)\left(2\frac{f_y}{\gamma_{m0}} - a_c f_{cd}\right) + A_{stn}\left(2\frac{f_{yk}}{\gamma_k} - a_c f_{cd}\right)$
	$b/2 \le h_n \le b_c/2$	$P'_{d,C} = 2\, h_n h_c a_c f_{cd} + A_{sn}\left(2\frac{f_y}{\gamma_{m0}} - a_c f_{cd}\right) + A_{stn}\left(2\frac{f_{yk}}{\gamma_k} - a_c f_{cd}\right)$
Concrete infilled sections	RHS	$P'_{d,C} = 2\, h_n h_c\, a_c f_{cd} + 4h_n t_f \left(2\frac{f_y}{\gamma_{m0}} - a_c f_{cd}\right) + A_{stn}\left(2\frac{f_{yk}}{\gamma_k} - a_c f_{cd}\right)$

D-4.2 The Design Resistance at Point D (Fig. 44)

The stress diagram on the section corresponding to point D on the interaction curve is shown in Fig. 47.

$$P'_{\mathrm{d,D}} = 0.5\, P'_{\mathrm{d,C}}$$



Y
Z
Y
Z
h_{n =0}
$\frac{f_y}{\gamma_{mo}}$
$\frac{\alpha_{cc} f_{ck}}{\gamma_c}$
$\frac{f_{yk}}{\gamma_k}$
PNA
P'd.D
M'd,D
$\frac{f_y}{\gamma_{mo}}$
$\frac{f_{yk}}{\gamma_k}$
Y
Z
h_{n =0}
$\frac{f_y}{\gamma_{mo}}$
$\frac{\alpha_{cc} f_{ck}}{\gamma_c}$
$\frac{f_{yk}}{\gamma_k}$
PNA
P'd.D
$\frac{f_y}{\gamma_{mo}}$
$\frac{f_{yk}}{\gamma_k}$

Fig. 47 Stress Distribution at Point D at Ultimate Stage Under Combined Compression and Bending

$$M'_{\mathrm{d,D}} = M_{\mathrm{max}} = Z_{\mathrm{ps}} \frac{f_{\mathrm{y}}}{\gamma_{\mathrm{m0}}} + Z_{\mathrm{pr}} \frac{f_{\mathrm{yk}}}{\gamma_{\mathrm{k}}} + 0.5 a_{\mathrm{c}}\, Z_{\mathrm{pc}} \frac{a_{\mathrm{cc}}\, f_{\mathrm{ck}}}{\gamma_{\mathrm{C}}}$$

Knowing the values of the compressive and bending design resistances at the points A, B, C and D the values of the resistance at any other point may be obtained approximately by linear interpolation, as shown by dashed lines in Fig. 44, assuming a linear variation.

ANNEX E

(*Clause* 16)

TESTING

E-1 TESTING OF MATERIALS

Testing of materials shall be done as per standard laid down norms given in **E-1.1** to **E-1.3**.

E-1.1 Concrete

For testing of concrete, reference shall be made to as per good practice [C-6B(2)].

E-1.2 Steel Sections

All the structural steel and accessories like rivets, bolts, nuts, washers, welding consumables, steel forging, casting, etc., shall be tested for mechanical and chemical properties as applicable and shall conform to requirements of appropriate Indian standards referred to in as per good practice [C-6B(3)]. Steel shall conform to the requirements of the accepted standard [C-6B(4)] and the accepted standard [C-6B(19)]. Bolts and bolted connection joints with high strength bolts shall be inspected according to as per good practice [C-6B(20)].

For testing of the strength, flexibility, and other relevant properties of the shear connectors, the test procedures as indicated in **E-1.3** shall be adopted.

E-1.3 Testing of Shear Studs for Steel-Concrete Interface Shear

The nominal static strength of a shear connector may be determined by push-out tests. The conditions and procedures which shall be followed while performing the tests are as indicated below:

a) The dimensions of the standard test are as shown in Fig. 48;

b) The bond at the steel-concrete interface shall be prevented by greasing the flanges or by any other suitable method;

c) The rate of application of load should be uniform and such that the failure load is reached in not less than 10 minutes;

d) The strength of the concrete f_c, at the time of testing, should not differ from the specified cube strength f_{ck} of the concrete by more than $\pm$ 20 percent;

e) Not less than three tests shall be done, and the nominal static strength P_u shall be taken as the lowest value of $f_{ck}.P / f_c$ for any of the tests, where P is the failure loads of the connectors at concrete strength f_c and f_{ck} is the characteristic cube strength of the concrete; and

f) The load-deformation curve, the ultimate resistance of the shear per shear connector, relative slip at ultimate load shall be recorded.

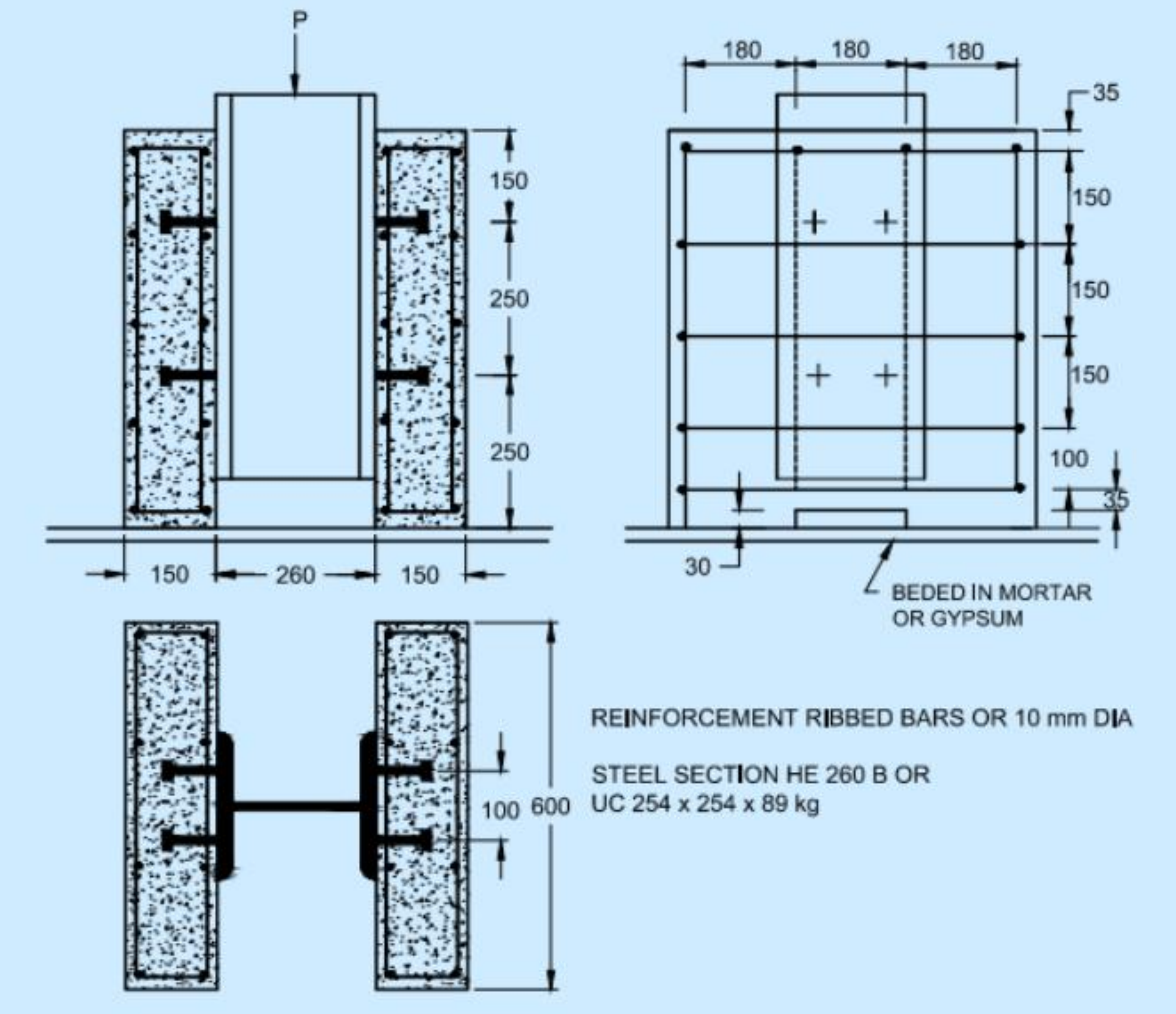

P
150
250
250
150
260
150
180
180
180
35
150
150
150
100
35
30
BEDED IN MORTAR
OR GYPSUM
100
600
REINFORCEMENT RIBBED BARS OR 10 mm DIA
STEEL SECTION HE 260 B OR
UC 254 x 254 x 89 kg

FIG. 48 STANDARD PUSH OUT TEST FOR SHEAR STUDS

ANNEX F

(*Clauses* 5.3.2, 6.1.2, 8.1.2.1, 9.3 *and* 11.2.1)

STRENGTH DETAILS AND ELASTIC MODULUS OF NORMAL CONCRETE

Sl No.	*Symbol*	*Grade of Concrete*	M20	M25	M30	M35	M40	M45	M50	M55	M60	M65	M70	M75
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
i)	f_{ck}, (*MPa*)	Characteristic cube compressive strength	20	25	30	35	40	45	50	55	60	65	70	75
ii)	f_{cm} (*Mpa*)	Mean concrete compressive strength	30	35	40	45	50	55	60	65	70	75	80	85
iii)	f_{ctm} (*MPa*)	Mean tensile strength of concrete	1.91	2.21	2.50	2.77	3.03	3.28	3.52	3.75	3.97	4.42	4.54	4.66
iv)	f_{ctk} (0.05) (MPa)	Characteristic tensile strength at 5 percent fractile of concrete	1.34	1.55	1.75	1.94	2.12	2.29	2.46	2.62	2.78	3.09	3.18	3.26
v)	E_{cm} (*MPa*)	Elastic modulus	28 608	29 962	31 187	32 308	33 346	34 313	35 220	36 076	36 887	37 659	38 395	39 100

LIST OF STANDARDS

The following list records those standards which are acceptable as ‘good practice’ and ‘accepted standards’ in the fulfilment of the requirements of the Code. The latest version of a standard shall be adopted at the time of enforcement of the Code. The standards listed may be used for conformance with the requirements of the referred clauses in the Code.

In the following list, the number appearing in the first column within parentheses indicates the number of the reference in this Part/Section.

Sl No.	*IS No.*	*Title*
(1)	IS 456 : 2000	Plain and reinforced concrete — Code of practice (*fourth revision*)
	IS 800 : 2026	General construction in steel — Code of practice (*fourth revision*)
(2)	IS 456 : 2000	Plain and reinforced concrete — Code of practice (*fourth revision*)
(3)	IS 800 : 2026	General construction in steel — Code of practice (*fourth revision*)
(4)	IS 2062 (Part 1) : 2025	Structural steel: Part 1 Hot rolled medium and high tensile steel (*eighth revision*)
(5)	IS 1608 (Part 1) : 2018	Metallic materials tensile testing: Part 1 Method of test at room temperature (*fourth revision*)
(6)	IS 808 : 2021	Dimensions for hot rolled steel beam, column, channel and angle sections (*fourth revision*)
	IS 1161 : 2014	Steel tubes for structural purposes — Specification (*fourth revision*)
	IS 1239 (Part 1) : 2004	Steel tubes, tubulars and other wrought steel fittings — Specification: Steel tubes (*sixth revision*)
	IS 1239 (Part 2) : 2011	Steel tubes, tubulars and other wrought steel fittings — Specification: Steel pipe fittings (*fifth revision*)
	IS 1730 : 1989	Dimensions for steel plates, sheets, strips and flats for general engineering purposes (*second revision*)
	IS 1732 : 1989	Dimensions for steel bars, round and square for structural and general engineering purposes (*second revision*)
	IS 1852 : 1985	Specification for rolling and cutting tolerances for hot rolled steel products (*fourth revision*)
	IS 2062 (Part 1) : 2025	Structural steel: Part 1 Hot rolled medium and high tensile steel (*eighth revision*)
	IS 4923 : 2017	Hollow steel sections for structural use — Specification (*third revision*)
	IS 11587 : 1986	Specification for structural weather resistant steels
	IS 12779 : 1989	Rolling and cutting tolerances for hot rolled parallel flange beam and column sections
(7)	IS 1875 : 1992	Carbon steel billets, blooms, slabs and bars for forgings (*fifth revision*)
	IS 6911 : 2017	Stainless steel plate, sheet and strip — Specification (*first revision*)
(8)	IS 1030 : 1998	Carbon steel castings for general engineering purposes — Specification (*fifth revision*)
	IS 1875 : 1992	Carbon steel billets, blooms, slabs and bars for forgings (*fifth revision*)
	IS 2004 : 1991	Carbon steel forgings for general engineering purposes — Specification (*third revision*)

Sl No.	*IS No.*	*Title*
	IS 2644 : 1994	High strength steel castings for general engineering and structural purposes — Specification (*fourth revision*)
	IS 4367 : 1991	Alloy steel forgings for general industrial use — Specification (*first revision*)
(9)	IS 1148 : 2009	Steel rivet bars (medium and high tensile) for structural purposes (*fourth revision*)
	IS 1363	Hexagon head bolts, screws and nuts of product grade C:
	Part 1 : 2019	Part 1 Hexagon head bolts (size range M 5 to M 64) (*fifth revision*)
	Part 2 : 2018	Hexagon Head Screws (Size Range M 5 to M 64) (*fifth r*evision)
	Part 3 : 2018	(Style 1) Hexagon nuts (size range M 5 to M 64) (*fifth revision*)
	IS 1364 (Part 1) : 2018	Hexagon head bolts, screw and nuts products grade A and B: Part 1 Hexagon head bolts (size range M 1.6 to M 64) (*fifth revision*)
	IS 1367	Technical supply conditions for threaded steel fasteners:
	Part 1 : 2014	General requirements for bolts, screws, studs and nuts (*fourth revision*)
	Part 2 : 2002	Tolerances for fasteners — Bolts, screws, studs and nuts — Product grades a, b and c (third revision)
	Part 3 : 2017	Mechanical properties of fasteners made of carbon steel and bolts, screws and studs (fifth revision)
	Part 5 : 2018	Mechanical properties of fasteners made of carbon steel and alloy steel — Set screws and similar threaded fasteners with specified hardness classes — Coarse thread and fine pitch thread (fourth revision)
	Part C : 2018	Mechanical properties of fasteners made of carbon steel and alloy steel — Nuts with specified property classes — Coarse thread and fine pitch thread (fourth revision)
	Part 7 : 1980	Mechanical properties and test methods for nuts without specified proof loads (*second revision*)
	Part 8 : 2020	Prevailing torque type steel nuts — Functional properties (*fifth revision*)
	Part 9/Sec 1 : 1993	Surface discontinuities, Section 1 bolts, screws and studs for general applications (*third revision*)
	Part 9/Sec 2 : 1993	Surface discontinuities, Section 2 bolts, screws and studs for special applications (*third revision*)
	Part 10 : 2002	Surface discontinuities — Nuts (*third revision*)
	Part 11 : 2020	Electroplated coatings systems (*fourth revision*)
	Part 12 : 1981	Phosphate coatings on threaded fasteners (*second revision*)
	Part 13 : 2020	Hot — Dip galvanized coatings on threaded fasteners (*third revision*)
	Part 14/Sec 1: 2018	Mechanical properties of corrosion — Resistant stainless — Steel fasteners, Section 1 Bolts, screws and studs (*fourth revision*)
	Part 14/Sec 2 : 2018	Mechanical properties of corrosion-resistant stainless steel fasteners, Section 2 Nuts (*fourth revision*)
	Part 16 : 2002	Designation system for fasteners (third revision)
	Part 17 : 2005	Inspections, sampling and acceptance procedure (*fourth revision*)

Sl No.	*IS No.*	*Title*
	Part 18 : 1996	Packaging (*third revision*)
	IS 1929 : 1982	Specification for hot forged steel rivets for hot closing (12 to 36 mm diameter) (*first revision*)
	IS 2155 : 1982	Specification for cold forged solid steel rivets for hot closing (6 to 16 mm diameter) (*first revision*)
	IS 3640 : 1982	Specification for hexagon fit bolts (*first revision*)
	IS 3757 : 1985	Specification for high strength structural bolts (*second revision*)
	IS 4000 : 1992	High strength bolts in steel structures — Code of practice (*first revision*)
	IS 5369 : 1975	General requirements for plain washers and lock washers (*first revision*)
	IS 5370 : 1969	Specification for plain washers with outside diameter 3 x inside diameter
	IS 5372 : 1975	Specification for taper washers for channels (ISMC) (*first revision*)
	IS 5374 : 1975	Specification for taper washer for I-beams (1SMB) (*first revision*)
	IS 5624 : 1993	Foundation bolts — Specification (*first revision*)
	IS 6610 : 1972	Specification for heavy washers for steel structures
	IS 6623 : 2004	High strength structural nuts (*second revision*)
	IS 6649 : 1985	Specification for hardened and tempered washers for high strength structural bolts and nuts (*first revision*)
	IS 7002 : 2018	Prevailing torque type hexagon nuts (with non-metallic insert), style — Property classes 5, 8 and 10 (*third revision*)
(10)	IS 813 (Part 1) : 2018 ISO 2553:2013	Welding and allied processes symbolic representation on drawings-welded joints (*second revision*)
	IS 814 : 2004	Covered electrodes for manual metal arc welding of carbon and carbon manganese steel — Specification (*sixth revision*)
	IS IS 3613 : 1974	Acceptance tests for wire-flux combinations for submerged-arc welding of structural steels
	IS 1395 : 1982	Specification for low and medium alloy steel covered electrodes for manual metal arc welding (*third revision*)
	IS 6419 : 1996	Welding rods and bare electrodes for gas shielded arc welding of structural steel — Specification (*first revision*)
	IS 6560 : 2017	Welding consumables — wire electrodes, wires rods and deposits for gas shielded arc welding of creep resisting steel — Classification (*second revision*)
	IS 7280 : 1974	Specifications for bare wire electrodes for submerged arc welding of structural steel
	IS 812 : 1957	Glossary of terms relating to welding and cutting of metals
	IS 816 : 1969	Code of practice for use of metal arc welding for general construction in mild steel (*first revision*)
	IS 822 : 1970	Code of procedure for inspection of welds
	IS 1024 : 1999	Use of welding in bridges and structures subject to dynamic loading — Code of practice (*second revision*)
	IS 1182 : 1983	Recommended practice for radiographic examination of fusion welded butt joints in steel plates (*second revision*)

Sl No.	*IS No.*	*Title*
	IS 4853 : 1982	Recommended practice for radiographic inspection of fusion welded butt joints in steel pipes (*first revision*)
	IS 5334 : 2003	Code of practice for magnetic particle flaw detection of welds (*third revision*)
	IS 7307 (Part 1) : 1974	Approval tests for welding procedures: Part 1 Fusion welding of steel
	IS 7310 (Part 1) : 2019	Approval tests for welders procedures: Part 1 Fusion welding of steel (*first revision*)
	IS 7318 (Part 1) : 1974	Approval tests for welders when welding procedure approval is not required: Part 1 Fusion welding of steel
	IS 9595 : 1996	Metal — Arc welding of carbon and carbon manganese steels — Recommendations (*first revision*)
	IS 15977 : 2013	Classification and acceptance tests for bare solid wire electrodes and wire flux combination for submerged arc welding of structural steel — Specification
(11)	IS 1785 (Part 1)	Specification for plain hard-drawn steel wire for pre-stressed concrete: Part 1 Cold drawn stress relieved wire (*second revision*)
	IS 1785 (Part 2)	Specification for plain hard-drawn steel wire for pre-stressed concrete: Part 2 As-drawn wire (*first revision*)
	IS 2266 : 2019	Steel wire ropes for general engineering purposes – Specification (*fifth revision*)
	IS 2315 : 1978	Specification for thimbles for wire ropes (*first revision*)
(12)	IS 432 (Part 1) : 1982	Specification for mild steel and medium tensile steel bars and hard-drawn steel wire for concrete reinforcement: Part 1 Mild steel and medium tensile steel bars (*third revision*)
(13)	IS 1786 : 2008	High strength deformed steel bars and wires for concrete reinforcement — Specification (f*ourth revision*)
(14)	IS 13620 : 1993	Fusion bonded epoxy coated reinforcing bars — Specification
(15)	IS 16651 : 2017	High strength deformed stainless steel bars and wires for concrete reinforcement — Specification
(16)	IS 1343 : 2012	Prestressed concrete — Code of practice (*second revision*)
(17)	IS 808 : 1989	Dimensions for hot rolled steel beam, column, channel and angle sections (*third revision*)
(18)	IS 801 : 1975	Code of practice for use of cold — Formed light gauge steel structural members in general building construction (*first revision*)
(19)	IS 11587 : 1986	Specification for structural weather resistant steels
(20)	IS 4000 : 1992	High strength bolts in steel structures — Code of practice (*first revision*)

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NATIONAL BUILDING CONSTRUCTION STANDARDS

PART C STRUCTURAL DESIGN

SECTION 7 PREFABRICATED CONCRETE CONSTRUCTION

BUREAU OF INDIAN STANDARDS

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National Building Code Sectional Committee, CED 46

FOREWORD

This NBCS (Part C/Section 7) gives recommendations regarding modular planning, component sizes, prefabrication systems, design considerations, joints and manufacture, storage, transportation and erection of prefabricated concrete elements for use in buildings and such related requirements for prefabricated concrete.

Prefabrication, though desirable for large-scale building activities, has been gaining importance in the country over the past decade. Two key aspects of prefabrication that need to be considered are the selection of an appropriate system for different categories of buildings and the sizing of their components. In this context, the principle of modular coordination is of significant value and its use is recommended.

Advantages of recent trends in prefabrication have been taken note of and also the hazards attended to such construction. Some of the essential requirements for the manufacture of the prefabricated components and elements are also included in this section.

Since the aim of prefabrication is to effect economy and improve quality and speed of construction, the selection of proper materials for prefabrication is also an important factor in the popularization of this technique. The use of locally available materials with required characteristics and the materials which, due to their innate characteristics such as lightweight, easy workability, thermal insulation, non-combustibility, etc, that effect economy and improve quality, may also be tried. However, this Section pertains to prefabricated elements with cementitious materials.

The design of prefabricated buildings shall include provision for installations of all services and required piping, wiring and accessories to be installed in the building.

This Section was first published in 1970 and was subsequently revised in 1983, 2005 and 2016 as a chapter of National Building Code of India. In the first revision in 1983, the main changes made included: inclusion of brief provision regarding importance of architectural treatment and finishes as applicable to prefabricated buildings; addition of a brief clause on the requirements of materials for use in prefabrication; elaboration of the clause on prefabricating systems and structural elements; revision of the clause on testing of components to include testing of structure or part of structure; and addition of a brief clause on the manufacture of cellular concrete.

In the second revision in 2005, this Section, earlier named as 'Prefabrication and systems building', was renamed and restructured as follows:

Section 7 Prefabrication, systems buildings and mixed/composite construction
  Subsection 7A Prefabricated concrete
  Subsection 7B Systems buildings and mixed/composite construction

In the second revision in 2005, several significant changes were introduced to enhance the standard. The modular coordination and modular dimensions of components were revised to allow greater flexibility in planning. Provisions related to tolerances were updated to address various types of prefabricated components. Additionally, a detailed clause on design requirements was incorporated to ensure the safety of prefabricated buildings against progressive collapse. Furthermore, a new clause specifying the sampling procedure for testing components was added.

In the third revision in 2016, in the Subsections 7A and 7B, several significant modifications had been incorporated. Definitions for new terms had been added and existing terminologies had been modified where necessary. Provisions related to prefabricated systems had been updated and detailed guidelines on the diaphragm action of floor systems had been included. The emulative system had been categorized and elaborated on, covering its definition, analysis, design and detailing. Design considerations had been revised to account for accidental impacts due to vehicles. Provisions and testing procedures for the water tightness of joints had been introduced, along with illustrations of typical precast joint details. Fire resistance testing of prototypes under sustained loads had been addressed and reliance solely on frictional resistance for connections between adjacent prefabricated members had been replaced with recommendations for resistance using shear. Updates have also been made to provisions on site prefabrication and vertical stacking guidelines, including restrictions on the number of components stacked on the ground. The time duration for load testing selected components from a lot had been modified. Additionally, new provisions for tolerances during erection and associated design considerations had been added. An annex had been included to address common defects, their causes and remedies, covering issues such as dimensional deviations, cracks, honeycombing, damages, strand slippage and alignment problems.

In this revision, this publication has been renamed as National Building Construction Standards (NBCS).

In this revision, it has been decided to merge subsections 7A and 7B into Section 7, 'Prefabricated Concrete Construction'. The following major modifications have been incorporated in this revision:

a) Definitions of some new terms have been added and existing terminologies modified, wherever required;
b) The emulative design approach has been adopted wherein precast elements are connected at site using wet concrete or grout;
c) Emulative system has been categorized and detailed with respect to its definition, analysis, design, detailing, etc;
d) Provisions relating to prefab systems namely moment resisting frame system, braced frame system, load bearing wall system, cell system and hybrid system are given along with their types and their applications;
e) Provisions relating to the design of corbel, bearing including dapped bearing are given in detail;
f) Provisions relating to quality control and assurance have been included;
g) Provisions for tolerances in erection and associated design considerations have been updated;
h) Provisions and testing procedures for water tightness of joints have been included;
j) A guideline for 3D printed concrete structures has been included in Annex B;
k) A comprehensive guideline on prefabricated prefinished volumetric construction (PPVC) methods, materials, design standards and performance criteria for guidance to building professionals and stakeholders involved in modular construction has been included in Annex C;
m) Guidelines for design for manufacturing and assembly has been included in Annex D;
n) Annex E on common precast connection has been modified based on the current practices in precast industry; and
p) Sustainability in precast concrete construction has been included in Annex G.

This information contained in this section is largely based on IS 15916 : 2026, 'Prefabricated concrete construction — Code of practice (*second revision*)' (*under publication*).

All standards, whether given herein above or cross-referred to in the main text of this Section, are subject to revision. The parties to agreement based on this Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

As the regulation of land development and buildings is a State subject and is dealt by the States and local bodies such as urban local bodies within their jurisdiction through building regulatory documents like building regulations, building byelaws, and fire regulations, this document is voluntary in nature and is non-binding. The implementation depends on adoption by concerned parties or stipulations in a contract or by appropriate adoption by the concerned authorities.

For the purpose of deciding whether a particular requirement of this Section is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 'Rules for rounding off numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this Section.

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Important Explanatory Note for Users of the NBCS

In any Part/Section of this NBCS, where reference is made to **‘good practice’** in relation to design, constructional procedures or other related information, and where reference is made to **‘accepted standard’** in relation to material specification, testing, or other related information, the Indian Standards listed at the end of the Part/Section shall be used as a guide to the interpretation.

At the time of publication, the editions indicated in the standards were valid. All standards are subject to revision and parties to agreements based on any Part/Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

In the list of standards given at the end of a Part/Section, the number appearing within parentheses in the first column indicates the number of the reference of the standard in the Section. For example:

a) Accepted standard [C-7(1)] refers to the Indian Standard(s) give at serial number (1) of the list of standards given at the end of this Part C/Section 7, that is, IS 13920 : 2016 ‘Ductile design and detailing of reinforced concrete structures subjected to seismic forces — Code of practice (*first revision*)’,

b) Accepted standard [C-7(9)] refers to the Indian Standard(s) give at serial number (9) of the list of standards given at the end of this Part C/Section 7, that is, IS 16172 : 2023 ‘Reinforcement couplers for mechanical splices of steel bars in concrete — Specification (*first revision*)’.

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART C STRUCTURAL DESIGN

SECTION 7 PREFABRICATED CONCRETE CONSTRUCTION

1 SCOPE

1.1 This NBCS (Part C/Section 7) covers provisions for prefabricated concrete construction in buildings, including prefabrication systems, design considerations, element tolerances, joints and requirements for manufacture, storage, transportation and erection.

1.2 This Section is limited to the emulative detailing approach, wherein precast elements are connected at site using wet concrete or grout with reinforcement detailing in accordance with this Section and relevant design standards.

1.3 Structural analysis shall consider appropriate computational models, including connections, and the overall performance shall be verified in terms of strength, stiffness, and ductility. The design intent shall be to achieve performance comparable to cast in-situ concrete construction. The design and detailing provisions specified for cast in-situ concrete in good practice [C-7(1)] shall form the basis, and the design engineer shall provide similar detailing to achieve equivalent behaviour compare to cast in situ practice. If required by the contract statement, this can be demonstrated by appropriate testing as specified by the Competent Authority and 12 in agreement with the design team and client.

1.4 Where exact replication of cast in-situ detailing is not feasible, the minimum requirements specified in this Section shall be followed. In cases not covered by this Section, alternative detailing approaches may be adopted, provided their performance is validated through testing (in terms of strength, stiffness, and ductility) as specified and approved by the competent authority in agreement with the design team and client.

2 –

NOTE — This clause is intentionally left blank.

3 TERMINOLOGY

For the purpose of this section, the following definitions shall apply.

3.1 Authority Having Jurisdiction — The authority which has been created by a statute and which, for the purpose of administering the NBCS/part, may authorize a committee or an official or an agency to act on its behalf; hereinafter called the ‘Authority’.

3.2 Basic Module — The fundamental module used in modular coordination, the size of which is selected for general application to building and its components.

NOTE — The value of the basic module has been chosen as 50 mm for the maximum flexibility and convenience. The symbol for the basic module is *M*.

3.3 Cellular Concrete — The material consisting of an inorganic binder (such as lime or cement or both) in combination with a finely ground material containing siliceous material (such as sand), gas generating material (for example, aluminium powder), water and harmless additives (optional); and/or steam cured under high pressure in autoclaves.

3.4 Components — A building product formed as a distinct unit having specified sizes in three dimensions.

3.5 Composite Members — Structural members comprising of prefabricated structural units of steel, prestressed concrete or reinforced concrete and cast in-situ concrete connected together in such a manner that they act monolithically.

3.6 Diaphragm — It is a horizontal or nearly horizontal structural system (for example, reinforced concrete floors and horizontal bracing systems), which transmits lateral forces to vertical elements that resist earthquake-induced inertia effects.

3.7 Increments — Difference between two homologous dimensions of components of successive sizes.

3.8 Light-Weight Concrete — Concrete of substantially lower unit weight (1 400 kg/m^3 to 1 800 kg/m^3) than that made with gravel or crushed stone.

3.9 Module — A unit of size used in dimensional coordination.

3.10 Modular Coordination – Dimensional coordination employing the basic module or a multimodule.

NOTE — The purposes of modular co-ordination are:

a) to reduce the variety of component sizes produced; and

b) to allow the building designer greater flexibility in the arrangement of components.

3.11 Modular Grid — A rectangular coordinate reference system in which the distance between consecutive lines is the basic module or a multimodule. This multimodule may differ for each of the two dimensions of the grid.

3.12 Multimodule — A module whose size is a selected multiple of the basic module.

3.13 Prefabricate — To fabricate concrete components or assembled units prior to erection or installation in a building.

3.14 Prefabricated Building — The partly/fully assembled and erected building, of which the structural parts consist of prefabricated individual units or assemblies using ordinary or controlled materials, including service facilities; and in which the service equipment may be either prefabricated or constructed in-situ.

3.15 Sandwich Concrete Panels — Panels made by sandwiching an insulation material between two layers of reinforced/prestressed concrete to act as insulation for composite or non-composite concrete panels.

3.16 Self Compacting Concrete — Concrete that is able to flow (650 mm in diameter) under its own weight and completely fill the voids within the formwork, even in the presence of dense reinforcement without any vibration, whilst maintaining homogeneity without segregation.

3.17 Shear Connectors — Structural elements, such as anchors, studs, channels, loops and spirals, intended to transmit the shear between the prefabricated member and the cast in-situ concrete and also to prevent separation at the interface (to transmit the interfacial shear).

3.18 System — It is a particular method of construction of buildings with certain order and discipline using the prefabricated components which are inter-related in functions and are produced based on a set of instructions.

3.19 Unit — Building component formed as a simple article with all three dimensions specified, complete in itself but intended to be part of a larger, compound unit or complete building. Examples are brick, block, floor panel, wall panel and other individual components.

3.20 Emulative Detailing System — A connection detailing system for precast concrete structures that provides a similar level of ductility equivalent to that of a conventionally designed, cast in-situ, monolithic concrete structure subjected to earthquake.

3.21 Jointed Detailing System — A connection detailing system for precast concrete structures that has individual precast components separated from each other but connected using special connections such as welded or bolted plates. These connections are not allowed as per this Section, if adopted appropriate testing needs to be carried out as per 10.

3.22 Terminology Relating to 3D Printing

3.22.1 *Extrusion-Based Concrete* 3*D Printing* — Extrusion based printing refers to the delivery of the concrete through a nozzle in the required shape and dimension, in a layer-by-layer deposition process. The nozzle can either be placed on a gantry or attached to a central robot or a rail mounted mechanism.

3.22.2 *Binder Jetting-Based* 3*D Printing* —Binder jetting is a 3D printing technology in which a liquid binding agent (water) is sprayed on the surface of a thin layer of the binder (cement and aggregate) to attain the required shape and dimensions. A new layer of the binder is then placed on the top of the existing layer, and the process of spraying the water is repeated. This process is continued until reaching the required height of the object. The formed object is allowed to harden before removing the excess unreacted binder.

3.22.3 *Print Plane* — The plane on which the material is deposited.

3.22.4 *Directions in the Printed Specimens* — The performance of the printed specimen varies with the principal directions of the printed concrete. The directions of the printed concrete are designated as X, Y and Z with reference to the print pathway, where:

a) X direction is parallel to the print direction and in the print plane;

b) Y direction is perpendicular to the print direction in the print plane and could cross different layers; and

c) Z direction is perpendicular to the print direction and print plane, crossing many printed layers.

3.22.5 *Concrete for* 3*D Printing* — Concrete is a composite material with cement (ordinary Portland cement blended with or without supplementary cementitious materials), water, fine aggregate, coarse aggregate and admixtures. Fine aggregates and coarse aggregate need to comply with the requirements of good practices [C- 7(2)] and [C-7(3)]. Aggregates can be used in the mix subjected to testing and validation, confirming to the required printable properties like pumpability, buildability and extrudability.

3.22.6 *Printable Concrete* — Printable concrete is a mixture of cement (with or without supplementary cementitious materials), water, aggregates and admixtures that can be extruded through the nozzle of the printer and attain the designed dimension within certain tolerance zone on placing additional layers.

3.22.7 *Buildability* — Buildability is the ability of the printed layers to develop adequate green strength to withstand the self-weight as well as load due to subsequent layers without significant geometrical deformation or collapse of the freshly printed component.

3.22.8 *Extrudability* — Extrudability is the ability of the mixture to pass through the nozzle under pressure and attain the designed shape after the extrusion.

3.22.9 *Pumpability* — Pumpability is the ease of transporting concrete mixture from the pump to the nozzle.

3.22.10 *Printability* — The printability of the mixture is a combination of the pumpability and extrudability.

3.22.11 *Open Time* — Open time represents the time over which the 3D printing mixture remains printable. This defines the time period in which the mixture can be delivered through the pumping system and dispensed through the nozzle without clogging of the extrusion system.

3.22.12 *Filament* — The extruded shape is termed as the filament. The cross section of the filament can be circular, rectangular, or square, depending on the shape of the nozzle. The filament is characterised by its diameter (for circular nozzle) or by its orthogonal dimensions – width and thickness. However, it can be of any shape.

3.22.13 *Layer* — A layer is the object formed with a single pass of the printer. Multiple layers are stacked one over the other to build up the full object. Each layer is characterized by the height or thickness, for rectangular or square nozzles.

3.22.14 *Bond* — Bond is an interface between successive layers or filaments of a 3D printed concrete specimen. The interface between layers can be called as 'horizontal' bond, while the interface between filaments side by side can be called as 'vertical' bond.

3.22.15 *Shape Stability* — Shape stability is the ability of the printed component to maintain the dimension as subsequent layers are placed.

3.22.16 *Base Layer* — A base layer is the first printed layer on which all following layers are built on.

3.22.17 *Dead Zone Length* — The dead zone length is defined as the length of static deposition of concrete or where the material flow stops such as near the nozzle with rapid change in cross section.

3.22.18 *Extracted Specimen* — Specimen of the required dimension which is extracted (cored/sawn) from the 3D printed concrete elements in any orientation.

3.22.19 *Speed of Extrusion* (*Extrusion Speed*) — The rate at which the extrusion system moves while extruding the concrete. Generally expressed in length/unit time, volume/unit time, or mass/unit time.

3.22.20 *Admixtures*

3.22.20.1 *Superplasticizers* — Superplasticizers are required in 3D printed mixes in order to control the workability of concrete and make it suitable for pumping and extrusion.

3.22.20.2 *Accelerators* — Accelerators are admixtures added to the concrete to decrease the initial setting time and increase the early-age strength.

3.22.21 *Viscosity Modifier* — An admixture that when added to the concrete, modifies the viscosity of the mix.

3.22.22 *Out-of-Plane Deformation* — Distortion/bending of the printed layers from the predefined (vertical) plane of the specimen. Intentional cantilevering or offset shall be allowed and is not considered as out-of-plane deformation.

4 NOTATIONS AND SYMBOLS

The notations used in this section are given at Annex A.

5 MATERIALS

The relevant materials for precast structures shall satisfy the requirements given in the following sections. For addressing sustainability aspects in selecting materials, a reference may be made to Annex G (*see* **G-2** and **G-5**).

5.1 Concrete Ingredients

5.1.1 *Cement*

The cement shall be selected in accordance with good practices [C-7(2)] to provide minimum required strength for lifting, transportation and durability. Each shipment of cement shall be referenced to a certified mill test report that indicates compliance with the specified type of cement. However, accelerated tests shall be carried out before application.

5.1.2 *Mineral Admixtures*

For mineral admixtures, the provisions of Part C 'Structural Design, Section 5 Structural Concrete' of this NBCS shall apply, unless otherwise specified by the client or the design.

5.1.3 *Aggregates*

Aggregates used in concrete shall comply with accepted standard [C-7(4)]. All aggregates must be sourced from approved suppliers, with representative samples tested according to the requirements specified in the governing standards. The desired concrete properties must be demonstrated through trial mixes to ensure compliance and satisfactory performance.

The provisions of good practice [C-7(2)] shall apply while deciding the maximum and minimum size of coarse aggregate.

For stitch joints between precast elements with thickness less than 75 mm, the maximum size of aggregate shall be limited to 10 mm.

5.1.4 *Water*

Water used for concrete mixtures shall conform to Part C ‘Structural Design, Section 5 Structural Concrete’ of this NBCS. In addition, mixing water shall be free from deleterious matter that may interfere with the setting or strength development of the concrete. Water shall be tested based on the batching requirements at least once a month.

5.1.5 *Chemical Admixtures*

5.1.5.1 All chemical admixtures such as accelerating admixtures, retarding admixtures, water-reducing admixtures, air-entraining admixtures and super-plasticizing admixtures shall comply with accepted standards [C-7(5)].

5.1.5.2 Admixtures containing chloride ions shall not be used.

5.1.5.3 Admixtures must be checked for compatibility with cement and other admixtures to ensure proper performance. A trial mix program shall evaluate slump, stability, workability, air content and strength under typical conditions, including temperature and humidity. The effect of dosage variations and the order of admixture addition shall be determined from supplier recommendations or trial.

5.1.5.4 Synthetic or natural pigments may be used in precast facade or decorative elements to achieve desired colours. The pigments must be insoluble in water, free of soluble salts, acids, calcium sulphate and resistant to sunlight, alkalis and weak acids. The pigment type and amount must not affect concrete setting time or strength.

5.2 Concrete Mix Design

Qualification of a concrete mix for use in precast concrete production shall be through laboratory testing, production trials and quality control testing. The minimum grades of concrete shall be as per good practices [C-7(2)].

5.2.1 *Mix Development*

5.2.1.1 Concrete mixes for precast elements shall be determined through laboratory methods, complying with Part C ‘Structural Design, Section 5 Structural Concrete’ of this NBCS exposure class requirements. The mix shall meet project needs, service conditions and desired surface finish (colour and texture), with adequate workability for proper placement and consolidation. Water use shall be minimized to the amount necessary for proper placing and vibration consolidation.

5.2.1.2 For standard concrete, the mix design procedure shall be as per good practice [C-7(6)]. The good practices [C-7(2)] shall be used for the correlation between compressive strength and tensile strength, modulus of elasticity, shrinkage, creep coefficient, co-efficient of thermal expansion, etc.

5.2.1.3 Special concretes (for example, high-performance, ultra-high performance) shall be designed based on specialized literature and approved by the competent authority. The literature shall also correlate compressive strength with other properties such as tensile strength, modulus of elasticity, shrinkage, creep and thermal expansion.

5.2.1.4 Steel fibre reinforced concrete, specified in structural elements to enhance mechanical and durability properties, shall be designed using hooked, crimped or straight steel fibres as per specialized literature and with appropriate approvals from competent authority. Any construction joint in precast steel fibre reinforced concrete elements shall have reinforcement bar across the joint to transfer stresses.

5.2.1.5 Lightweight concrete may be used for non-structural precast elements (such as wall panels, facade units, and sandwich panels) to reduce the self-weight, enhance ease of handling and transportation, thermal insulation, and sound absorption. For lightweight concrete, adjustments are required during mix design to account for the lower density and altered workability. Specialized literature shall be referred and appropriate approvals from competent authority shall be obtained.

5.2.2 *Miscellaneous*

5.2.2.1 All the concrete mixes to be used in the production of precast elements shall be evaluated as trial batches, prepared in accordance with good practice [C-7(7)] under conditions that simulate the actual production and finishing as closely as possible.

5.2.2.2 If the source/manufacturer of cement, source/gradation of aggregates or source/manufacturer of admixture are changed after mix finalization, the proportions of the mix shall be validated and re-designed, if required.

5.2.2.3 When accelerated curing is to be used, the mix proportions shall be based on similarly cured test specimens.

5.2.2.4 When self-compacting concrete is used, the mix proportion shall meet the requirement of good practices [C-7(8)].

5.3 Reinforcement

5.3.1 Reinforcing bars and prestressing strands shall be in accordance with the provisions of Part C 'Structural Design, Section 5 Structural Concrete' of this NBCS, respectively. Reinforcing steel deliveries shall be identified with a heat number least that can be correlated with a mill certificate.

5.3.2 For welding of reinforcement, the good practice [C-7(9)] and Part C 'Structural Design, Section 5 Structural Concrete' of this NBCS shall be referred.

5.3.3 Reinforcement couplers shall comply with the accepted standard [C-7(10)].

5.3.4 If glass fibre reinforced polymer (GFRP) bars are used, the material shall conform to the requirements of accepted standard [C-7(11)]. Such bars shall be used only in precast elements with low risk, based on the decision of engineer-in-charge and client.

5.3.5 Welded wire reinforcement shall conform to accepted standard [C-7(12)].

5.3.6 Welding shall not be performed near any prestressing strand, whether tensioned or not tensioned. The prestressing strand shall not be exposed to spatter, direct heat, or short-circuited current flow.

5.3.7 Prestressing accessories shall comply with the requirements of good practice [C-7(3)].

5.3.8 Plastics for welded wire and bar supports shall be composed of polyethylene, styrene copolymer rubber-resin blends, polyvinyl chlorides and polytetrafluoroethylene. Plastics shall be alkali-resistant and have thermal properties compatible with concrete.

5.4 Grout

5.4.1 *Cementitious Grout*

5.4.1.1 Cementitious grout used in the precast application shall be as per good practice [C-7(2)].

5.4.1.2 Non-shrink non-metallic high-strength and flowable cementitious grouts shall be used for all structural joints between two precast elements having gap less than 50 mm. The grout strength shall exceed the strength of the joining member by at least 5 MPa. If the strength of the members varies, the cementitious grout with the highest required strength shall be used. For special connection, strength of the grout shall be as per 8.

5.4.1.3 For joint width more than that recommended in the grout manufacturer's guidelines or 50 mm, the grout shall be mixed with 10 mm down aggregate or self-compacting concrete or micro concrete shall be used.

5.4.2 *Chemical Grouts*

Chemical grouts shall be used as per manufacturer's guidelines and its properties shall comply with accepted standard [C-7(13)].

5.5 Mould

5.5.1 All moulds, regardless of material, shall conform to the profiles, dimensions and tolerances of precast concrete product indicated by the contract documents and the approved shop drawings.

5.5.2 Repeated use of moulds shall not cause any dimensional or planar changes that exceed allowable tolerances of the member. When exposed to temperature fluctuations or moisture, the warping or buckling of moulds shall not exceed to allowable tolerance limits.

5.5.3 Moulds exposed to external vibrations must be capable of transmitting these vibrations evenly across a sufficient area, without flexing, warping or causing plate flutter.

5.5.4 If it is planned to apply a prestressing force by jacking against the mould, the mould shall be sufficiently strong to withstand the force without buckling or wrinkling and maintain the required dimensional tolerances.

5.5.5 When different materials are used to construct the mould, they shall not affect the colour and texture of the precast concrete product intended to be installed unrendered. The mould materials shall be non-absorbent or properly sealed to prevent excessive moisture absorption to minimize variations in finish.

5.5.6 Wooden moulds shall be sealed with suitable materials to prevent moisture absorption.

5.5.7 Steel moulds shall be visually inspected before each use for rust, distortion and tightness of steel sheet joints.

5.5.8 Fibre reinforced polymer moulds shall be used for achieving localized architectural finishes.

5.5.9 Moulds shall be coated with mould release agents that permit its release without damaging or staining the concrete and without affecting subsequent coating, painting, or caulking operations. Debonding agents or wax shall be used during match casting.

5.5.10 Whenever concrete is to be painted or stained, only mould release agents compatible with the coating shall be permitted, unless surface preparation is performed to ensure good adhesion between the coating/stain and the concrete.

5.6 Hardware, Lifting Devices and Miscellaneous Materials

5.6.1 *Hardware*

5.6.1.1 Hardware refers to items:

a) To be placed on or in the structure to receive the precast concrete units (anchor bolts, angles, or plates with suitable anchors);

b) To be embedded in the concrete units for connection or for other mechanical, plumbing, glazing, miscellaneous iron, masonry, roofing works, etc; and

c) Necessary for the installation of the precast concrete units.

5.6.1.2 Hardware shall be made from ductile materials or as specified in the design. For high-strength materials, the design must ensure elastic behaviour. For testing, 12 shall be referred.

5.6.1.3 Welding of steel plates, angles, and other shapes shall be carried out by certified welders in conformance with standard procedures. The size, length, type and location of all welds shall conform to the approved shop drawings, and no unspecified welds shall be added without the approval of the designer.

5.6.1.4 Electrodes used for welding operations shall be bought in sealed (airtight) containers. The selection of a suitable electrode shall be made based on the material to be welded, intricacies based on the geometry of the job, thickness, weld profile and weld position. The maintenance of any electrode used shall be as prescribed by the manufacturer.

5.6.1.5 All metallic hardware surfaces that are exposed to or within 12 mm of concrete surfaces that are exposed to the weather, corrosive conditions, or condensation preferably be protected against corrosion or be made of non-corrosive materials. Hardware shall be properly cleaned before application of protective treatment. Corrosion protection shall be done as required. Care shall be taken to prevent chemicals, such as acids, from coming in contact with the hardware and causing corrosion.

5.6.1.6 Supplier of hardware shall furnish records of compliance to specification requirements and mill certificates for the material used. Review of hardware fabrication shall be performed by quality control personnel.

5.6.2 *Lifting Devices*

5.6.2.1 Lifting devices shall be capable of supporting the element in all positions planned during manufacture, storage, delivery and erection. Safe loads for lifting inserts or hooks or devices shall be supplied by the manufacturer of proprietary devices. Information on the use and installation of the devices to ensure proper performance shall be supplied by the manufacturer. For factor of safety and capacity of lifting inserts or hooks, 7 and 8 shall be referred, respectively. For testing, 12 shall be referred.

5.6.2.2 If the lifting device is subjected to dynamic loads, it shall preferably be fabricated using ductile materials or shall be designed to remain elastic.

5.6.2.3 Reinforcing bars provided as main reinforcement in the members shall not be used as lifting hooks. Separate reinforcing bars of required grade, bent to the correct size and shape, may be used exclusively as lifting hooks, with adequate embedment or anchorage whining the precast member. Where necessary, smooth rebars with adequate embedment length shall be used as lifting hooks. Lifting hooks made of reinforcing bars shall not be used for multiple handling applications.

5.6.2.4 Each bar size and configuration shall be considered such that it meets load and handling requirements.

5.6.2.5 Coil rods and bolts shall not be welded when used in lifting operations.

5.6.2.6 Connection hardware shall not be used for lifting or handling unless carefully reviewed and approved by the site engineer/designer.

5.6.2.7 Shop drawings shall clearly define insert dimensions and locations for fabrication and placement or refer to standard details.

5.6.2.8 Members incorporating embedded hardware shall be provided with corrosion protection during long-term storage.

5.6.3 *Surface Finishes and Coating*

5.6.3.1 All surface finishes and coating on precast concrete units shall be as stated in the shop drawing.

5.6.3.2 When specified in the project requirements, for finishing processes such as sandblasting, acid etching, surface retardation, the use of mould liners, or the application of veneer facing materials may be employed to achieve the desired surface appearance. These methods shall help control form joints, form blemishes and air voids within acceptable limits.

5.6.3.3 Based on project requirements and client specifications, curing compounds for precast elements shall be chosen for compatibility with coatings, moisture retention, and ease of removal. Only membrane-forming compounds that meet standards for water retention and curing efficiency shall be used. Application should occur immediately after demoulding to prevent moisture loss and ensure proper strength. The surface must be free of dust or laitance, and curing must be uniform to avoid streaking. Curing compounds shall be non-residual or removable when subsequent coatings are applied.

5.6.3.4 Based on project requirements and client specifications, anti-carbonation coatings shall be selected for CO_2 diffusion resistance, breathability and UV stability, conforming to durability standards. They must be tested for permeability and adhesion on precast surfaces. Application should occur on clean, dry, fully cured concrete, free from laitance, dust and form oil. Coatings must be applied evenly to avoid streaks and ensure effective protection.

5.6.3.5 Based on project requirements and client specifications, paints used on precast elements shall be alkali-resistant, weatherproof, and compatible with the concrete substrate. Selection shall be based on exposure conditions, including moisture, UV and chemical resistance requirements. Before application, the surface must be properly primed and any efflorescence or moisture-related defects must be addressed to prevent peeling or discoloration. Roller or spray application shall ensure uniform coverage and multiple coats shall be applied as required to achieve the desired opacity and aesthetic consistency.

5.6.3.6 Based on project requirements and client specifications, epoxy coatings, selected for chemical resistance, adhesion, impact resistance and fire rating, are used for flooring, structural connections and corrosion protection. Surfaces must be clean and dry, with a primer applied for better bonding. Curing conditions should be controlled, and components must be mixed correctly and applied evenly to avoid uneven gloss or discoloration.

5.6.3.7 Based on project requirements and client specifications, polyurethane or hybrid sealants for external precast joints shall be compatible with concrete, offer high elongation (for grouted joint 200 percent or more, for non-grouted joints 400 percent or more) and resist UV and environmental degradation. Selection should consider joint movement, exposure and adhesion. Joints must be clean, dry and free of contaminants before application, with a primer used if needed. Proper tooling is essential to ensure seamless finishes and prevent air pockets. Sealants in grouted joints act as moisture barriers, so their lifespan shall be verified.

5.6.4 *Insulation Material*

5.6.4.1 Rigid foam insulation for precast elements shall be selected based on thermal resistance, compressive strength and moisture resistance. Expanded polystyrene, extruded polystyrene, polyurethane or polyisocyanurate, etc, are preferred for long-term efficiency. Panels must conform to accepted standard [C-7(14)] or relevant manufacturer guidelines for density, strength and thermal conductivity. Panels shall be precisely cut for a snug fit to minimize thermal bridging. Exposed foam surfaces must be protected with coatings for durability and UV resistance. Foam with strength more than 10 MPa or as per design may be used in flooring to reduce concrete weight and thickness.

5.6.4.2 Mineral wool insulation shall be selected for its fire resistance, acoustic properties, and vapour permeability. Rigid or semi-rigid panels shall be used to withstand the casting process without compression. Mineral wool products conforming to accepted standard [C-7(15)] or any relevant manufacturer's guidelines shall possess thermal conductivity, density, moisture absorption and fire resistance requirements. Before placement, mineral wool boards shall be dry, securely positioned and properly supported to prevent displacement when concrete is poured. Special care shall be taken to prevent fibre shedding, which can affect worker safety and surface finish. If exposed, mineral wool shall be coated or encased to prevent moisture absorption and fibre degradation over time.

5.6.4.3 Lightweight concrete used for insulation layers in precast elements shall be selected based on its density, thermal performance and compatibility with structural concrete. Autoclaved aerated concrete and non-autoclaved cellular concrete conforming to accepted standard [C-7(16)] shall be used or relevant manufacturer's guidelines shall be followed. Proper mix design and curing conditions shall be maintained to achieve uniform density and minimize shrinkage or cracking. During production, the interface between lightweight and normal concrete layers shall be well bonded to prevent delamination. Surface smoothness and uniformity shall be checked, as inconsistencies may affect finishing and overall insulation performance.

5.7 Connections

In addition to the requirements in 5.6.1, the materials of a connection shall be selected such that embrittlement of any part of the assembled connection do not occur. Non-ferrous inserts shall be resistant to electrolytic action and alkali attack. If more than one material is used in a connection, abutting materials shall be selected such that corrosion is not induced. Dissimilar metals shall not be embedded near or in direct contact in moist or saturated concrete unless it is ensured that detrimental chemical or electrochemical (galvanic) reactions do not occur. For continuity of rebar, grouted coupler, grout filled tube or lapping of rebar shall be used. However, depending on seismic requirements the type of continuity method shall be selected. For testing and performance evaluation 12 shall be referred.

5.7.1 *Wire Loop System — Loop Box*

5.7.1.1 The wire loop system (proprietary product) is a load-transferring, cast-in element consisting of a box and a U-shaped wire loop for connecting prefabricated concrete elements. Generally, the joint with wire loop boxes is considered non-structural and should only be used for durability and gravity load requirements.

5.7.1.2 Relevant manufacturer's guidelines shall be used for selecting the appropriate product. In addition to that, the following points shall be considered:

a) The box and the two flexible wire loops shall be made of carbon steel sheet and high strength wire ropes, respectively. The surface of the box shall be equipped with a profiled surface to ensure sufficient bonding with the surrounding concrete;

b) Proper selection involves ensuring compliance with tensile strength requirements and alignment accuracy to prevent misfits. High-strength, non-shrink non-metallic cementitious grout is recommended to encapsulate loops fully. Care shall be taken in application to maintain uniform joint appearance, especially in exposed architectural elements;

c) The looped wire ropes shall not react with grout and form corrosion. Also, shall not be used if found having corrosion; and

d) The manufacturer shall furnish the detailed technical datasheet along with the test results corroborating the values noted in the technical datasheet. Also, the same shall be verified by the engineer-in-charge by conducting appropriate testing per batch.

5.7.2 *Grouted Coupler*

5.7.2.1 Grouted couplers (proprietary product) provide mechanical splicing of rebars between precast elements, ensuring structural continuity.

5.7.2.2 Their selection shall consider compatibility with reinforcing bar sizes and compliance with applicable standards.

5.7.2.3 Reinforcing bar ends and coupler interiors shall be clean before grouting to ensure proper bonding. A high-performance cementitious grout, characterized by non-shrink non-metallic high strength properties, high early strength shall be used to ensure effective load transfer. The grout shall meet the specified compressive strength and flowability requirements for complete void filling. Misalignment or incomplete grouting shall be addressed through inspection to maintain both functionality and appearance.

5.7.2.4 Class H coupler as per accepted standard [C-7(10)] shall be used with appropriate testing as per 12.3.1.

5.7.3 *Grout Filled Tubes* (*Dowel Tube*)

5.7.3.1 The tubes shall be corrugated to have proper bond with concrete and grout.

5.7.3.2 The length of the tube shall be as per development length or design requirements as per 7 and 8.

5.7.3.3 The tube shall be free from oil, grease or loose particles prior to installation and grouting. A high-performance cementitious grout, characterized by non-shrink non-metallic high strength properties, high early strength shall be used to ensure effective load transfer. The grout shall meet the specified compressive strength and flowability requirements for complete void filling. Adequate curing time shall be allowed for strength development. Grout shall be placed using gravity feed to ensure complete filling and venting shall ensure proper air escape. Misalignment or incomplete grouting shall be addressed through inspection to maintain both functionality and appearance.

5.7.4 *Terminators* (*Headed Bars*)

5.7.4.1 Headed bars are used in precast concrete elements to enhance anchorage efficiency by providing an enlarged head at the end of the reinforcement bar, reducing the required development length.

5.7.4.2 These bars shall be manufactured from high-strength reinforcement steel to ensure adequate ductility and mechanical performance. The heads shall be formed through welding, forging, or mechanical attachment and shall comply with the specified geometric and strength requirements. The selection of headed bars shall be based on design specifications, including grade of bar, head dimensions and load transfer capacity.

5.7.5 *Metal Inserts*

5.7.5.1 Steel plates shall be cast into precast elements to facilitate connections with other structural components for non-structural or gravity load transfer. Plates shall be made from structural-grade steel with appropriate thickness, positioned accurately during casting and securely anchored to prevent displacement.

5.7.5.2 Welded studs shall provide reliable load transfer by creating strong mechanical bonds between steel inserts and concrete. Studs shall be manufactured from high-strength steel and shall conform to applicable material and welding standards. Proper fusion and alignment shall be ensured and weld quality shall be verified through inspection to prevent structural deficiencies.

5.7.5.3 Corrosion protection, such as galvanization or stainless-steel alternatives, shall be applied based on environmental exposure conditions. Protective measures shall not interfere with mechanical performance or bonding with concrete. In exposed applications, surface finishes shall be such as to maintain aesthetic quality. Fire safety requirements shall also be verified for exposed applications.

5.7.6 *Shims*

5.7.6.1 Plastic shims shall be composed of materials that provide sufficient compressive strength (not less than 10 MPa or as required by the design) and demonstrate resistance to moisture, UV exposure, and temperature variations. They shall be dimensionally stable, free from warping or defects and sized to ensure a precise and secure fit for their intended application. Plastic shims shall be used for thicknesses up to 40 mm or less.

5.7.6.2 Metal shims shall be used for any shim thickness; however, use is preferable for thicker shims (typically greater than 40 mm). These shims shall be having higher strength and load-bearing capacity, particularly where greater stability and structural support are needed. For multi-layer shims, tack welding shall be performed between the layers to ensure a strong bond and prevent shifting or separation of the individual layers. Metal shims that are exposed to the environment or are in contact with moisture or corrosive elements shall be provided with appropriate corrosion protection. Care must be taken during installation to ensure that the corrosion protection is intact and not compromised by any mechanical processes.

6 PRECAST CONCRETE SYSTEMS

6.1 General

In precast concrete construction, the design shall address additional requirements including selection of component types, appropriate connection detailing, structural continuity, flexibility and restraint. Structural connections between elements shall be explicitly classified and designed as pinned, rigid, or ductile based on seismic performance criteria. Horizontal elements such as slabs, beams and staircases shall be detailed as simply supported or made continuous using in-situ topping, integrity reinforcement and collector elements to provide diaphragm action for lateral load transfer to the lateral force resisting system (LFRS). Vertical elements (for example, columns and walls) shall be designed as continuous members unless specifically excluded from LFRS. Beam-to-column joints not forming part of LFRS shall be designed to resist gravity loads with compatible displacements, moments based on design requirements and erection eccentricity. Such frames shall incorporate structural bracing to resist lateral forces. For selection of precast concrete system 6.2 to 6.5 shall be referred.

6.2 System Considerations

6.2.1 *Structural Concept*

Precast concrete structural systems shall be explicitly designed to ensure continuity between elements and robustness of the overall system. The selected system shall be robust and shall be designed to withstand the following:

a) Stability against progressive collapse;

b) Prevention of structural failure under all design load combinations;
c) Fire resistance as per applicable regulations;
d) Adequate ductility and energy dissipation capacity;
e) Redundancy and continuity in load paths;
f) Control of cracking within serviceability limits;
g) Acceptable deformation within serviceability limits; and
h) Durability against environmental exposure.

6.2.1.1 The structural system and each of its components shall maintain stability during all stages, including transportation, erection and service life. The following factors shall be considered for the selection of precast system:

a) Grid distances;
b) Spanning direction of slab and beam;
c) Position of columns and walls;
d) Position of load bearing walls and/or facade and/or facade at stilt;
e) Position and approximate requirements for stabilizing elements; and
f) Position of expansion joints.

6.2.1.2 The appropriate precast structural system shall be selected based on Table 1, considering building usage, architectural constraints, seismic performance requirements and constructability. The response reduction factor (R) shall be considered as per **5** of Part C 'Structural Design, Section 1 Loads and Load Effects' of this NBCS.

6.2.2 *Standardization of Precast Components/Elements*

The precast components/elements shall preferably be standardized based on the structural, architectural and/or aesthetic requirements. The precast components/elements given below but not limited to, shall be used in accordance with relevant Indian Standards (*see* Part B 'Building Materials' of this NBCS) and the accepted standards, where available:

a) Reinforced/prestressed concrete channel unit;
b) Reinforced/prestressed concrete slab unit;
c) Reinforced/prestressed concrete beams;
d) Reinforced/prestressed concrete columns;
e) Reinforced/prestressed concrete hollow core slab;
f) Reinforced concrete waffle slab/shells;
g) Reinforced/prestressed concrete wall elements;
h) Hollow/solid concrete blocks and battens;
j) Precast planks and joists for flooring and roofing;
k) Precast joists and trussed girders;
m) Light weight/cellular concrete slabs/wall panels;
n) Precast lintels and *Chajjas*;
p) Large panel prefabricates;
q) Reinforced/prestressed concrete trusses;
r) Reinforced/prestressed roof purlins;
s) Precast concrete L-panel units;
t) Prefabricated concrete double-T units;

u) Prefabricated sandwich concrete panels;

v) Precast concrete foundations; and

y) Precast concrete staircases.

Any other type of components shall be used with approval of the Competent Authority and appropriate testing.

Table 1 Precast Concrete (PC) Buildings with Different Structural Systems

(*Clause* 6.2.1.2)

Sl No. (1)	Structural System (2)
i)	*Building with Precast Concrete Moment Frames*:
	a) Buildings with single or multi-storey cantilever columns with simply supported beams (*see* Note 1)
	b) Building with ordinary moment resisting frames (OMRFs) (*see* Note 2)
	c) Buildings with special moment resisting frames (SMRFs)
ii)	*Buildings with Precast Concrete Structural Walls*:
	a) Ordinary structural walls (*see* Note 2)
	b) Ductile structural walls
iii)	*Buildings with Precast Concrete Moment Frames and Precast/RC Structural Walls* (*Dual System*) (*see* Note 3):
	a) Buildings with ordinary structural walls with OMRFs (*see* Note 2)
	b) Buildings with ordinary structural walls with SMRFs (*see* Note 2)
	c) Buildings with ductile structural walls with OMRFs (*see* Note 2)
	d) Buildings with ductile structural walls with SMRFs
iv)	*Precast Cell System*:
	a) Ordinary precast/RC structural wall system (*see* Note 2)
	b) Ductile precast/RC structural wall system

NOTES

1 Precast single-storey or multi-storey columns with simply supported beams shall be designed using a response reduction factor (R) of 2, as this system permits only one mode of plastic hinge formation.

2 Precast/RC emulative structures in Seismic Zones III and above shall be designed to be ductile. Hence, precast ordinary moment resisting frame system (OMRF) is not allowed in these seismic zones.

3 Buildings with precast RC structural walls also include buildings having precast RC structural walls and precast RC moment frames, but where:

a) frames are not designed to carry design lateral loads, or
b) frames are designed to carry design lateral loads, but do not fulfil the requirements of 'dual systems'.

4 Various types of moment resisting frame systems are explained in **6.3.4**, the structural designer shall select the appropriate system based on the requirements of the structure.

5 For all structures, precautions shall be taken to ensure continuity of load path, adequacy of connections, and compliance with drift limitations.

6 For shear walls with coupling beams, CIS coupling beams shall be used.

7 For elements designed to transfer gravity loads and not part of LFRS, assemblage testing shall be carried out to verify the failure mode of gravity frame elements and to ensure compliance with displacement requirements (equivalent to 'R' times the design storey drift), also the performance criteria with an approval from institute of repute may be verified.

8 The use of precast structural systems in Seismic Zone IV and above shall be permitted subject to approval by institute of repute. The adequacy of such systems shall be established through testing and/or appropriate structural analysis, as deemed appropriate.

6.3 Basic Precast Concrete Systems

Precast concrete building systems are composed of some basic types of structural systems. These systems shall be combined in various ways to obtain a suitable and effective structural concept that meets the needs of specific buildings. The most common systems are:

a) Precast concrete buildings with moment frames;

b) Precast concrete buildings with structural walls;

c) Precast concrete buildings with moment frames and structural walls (or dual system);

d) Precast concrete buildings with precast or cast-in-situ flat slab and precast concrete moment frames and precast concrete structural walls; and

e) Cell/3D system.

6.3.1 The above list is not unique as many combinations are possible to achieve the same objectives, such as the use of arches and rigid portal frames.

6.3.2 When facade systems act as load-bearing walls, their design shall explicitly consider lateral stability. For non-load-bearing facades, beam deflection and frame movement shall be accommodated in the connection detailing to avoid unintended cracking or overstressing of facade panels.

6.3.3 Where partial fixity is introduced by structural topping or dowels, the resulting flexural stiffness (EI) may be considered in serviceability limit state checks. The contribution of topping shall be analytically substantiated.

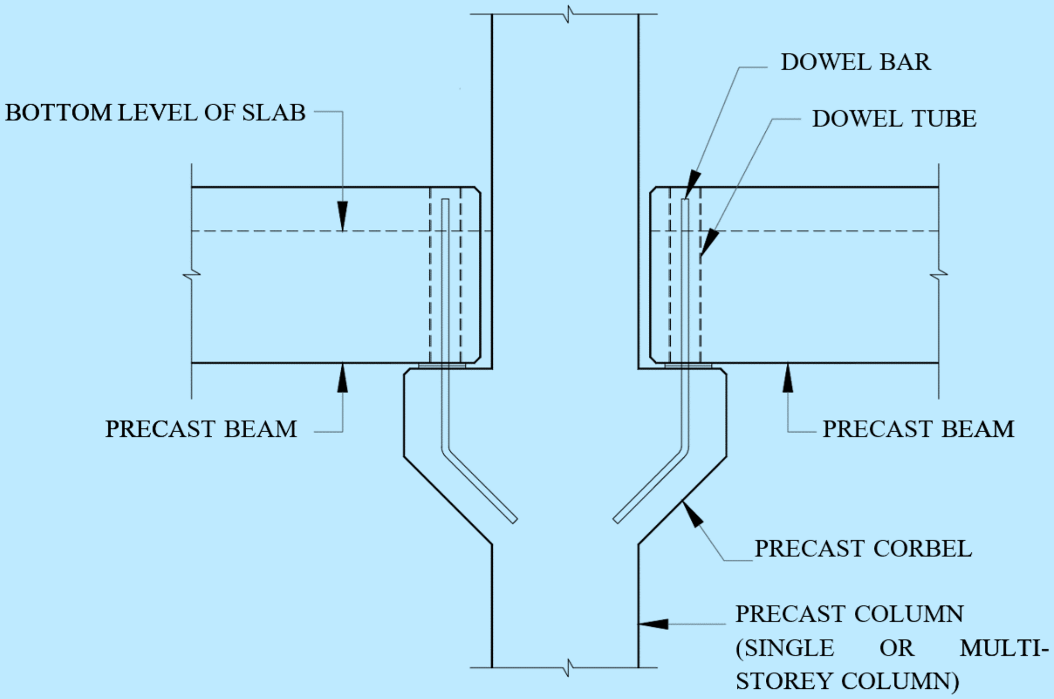
6.3.4 *Skeletal Frame Systems*

Skeletal frame systems composed of beams and columns shall be used where architectural flexibility, large spans, or column-free space is required, including in commercial, educational, healthcare and industrial facilities. The following skeletal systems shall be permitted:

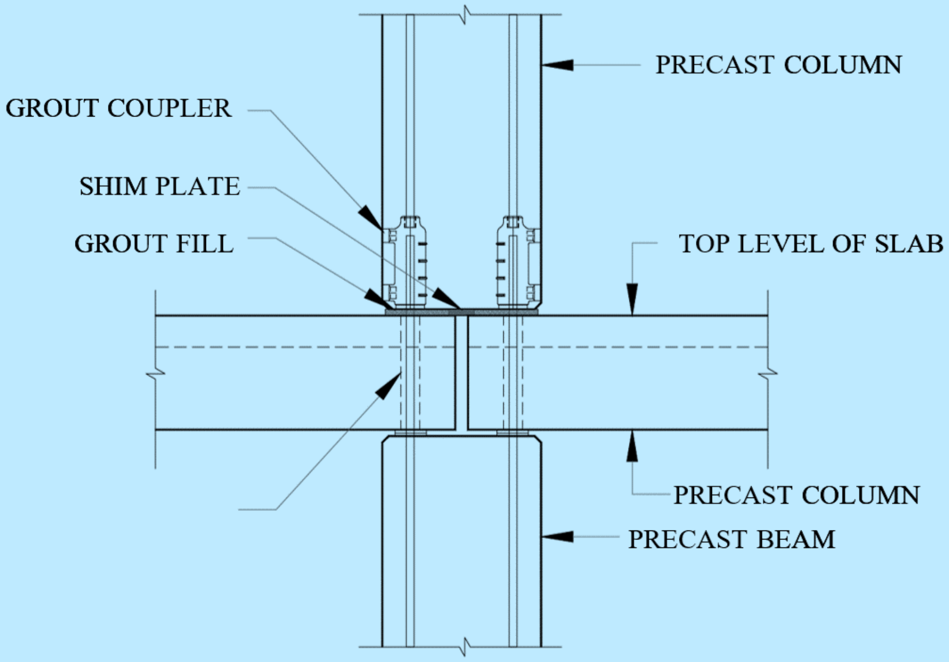
a) Moment resisting frames; and

b) Moment frames with stabilizing cores (with precast structural walls).

Depending on the importance of the structure, structural framing system, connection detailing requirement and the level of ductility demanded by the building, the precast beam to column or beam to beam connection shall be selected from the five types as shown in Fig. 1. Type 1 and Type 2 (with minor fixity) shall be adopted with cantilever with single or multi-storey columns with simply supported beam. Types 2, 3 and 4 with detailing as per the good practice [C-7(2)] shall be adopted with OMRF. Types 2, 3, and 4 with detailing as per the good practice [C-7(1)] and detailing of connection as per this NBCS shall be adopted with SMRF. In the case of Type 3 and Type 4, the location of beam-to-beam connection shall be selected such that plastic hinge formation zones are avoided (at least more than 0.15 L_{beam}). In the case of secondary beams or short length beams, the location of the connection can be at the mid span with appropriate detailing.

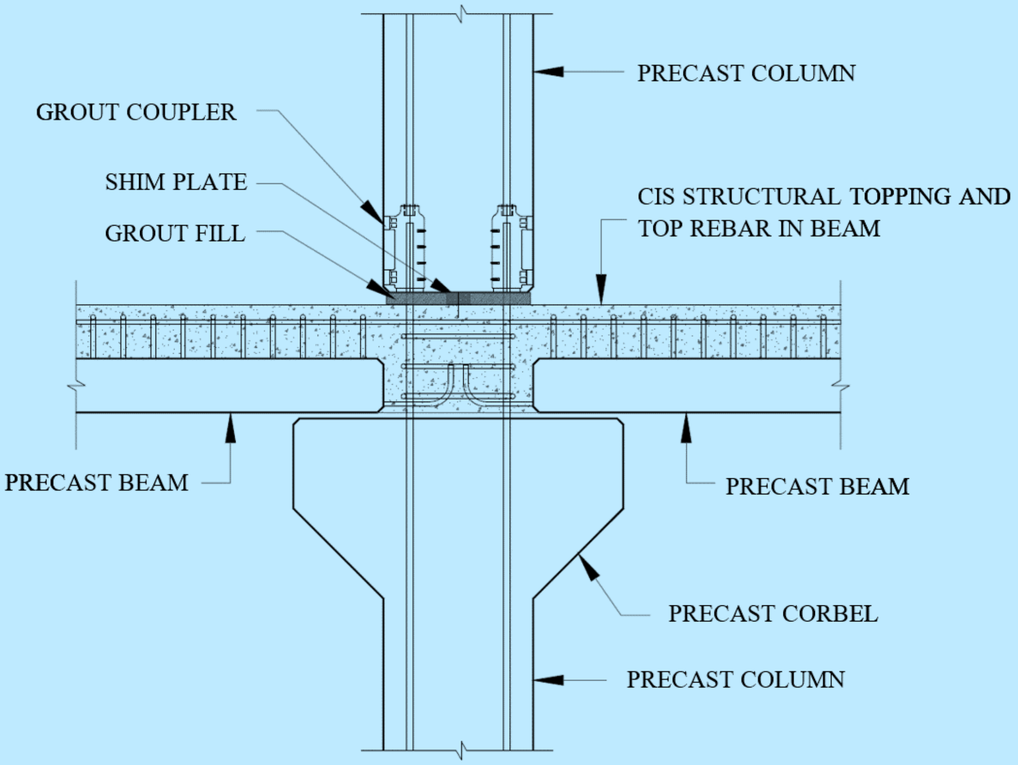

BOTTOM LEVEL OF SLAB
DOWEL BAR
DOWEL TUBE
PRECAST BEAM
PRECAST BEAM
PRECAST CORBEL
PRECAST COLUMN (SINGLE OR MULTI-STOREY COLUMN)

1A) TYPE 1

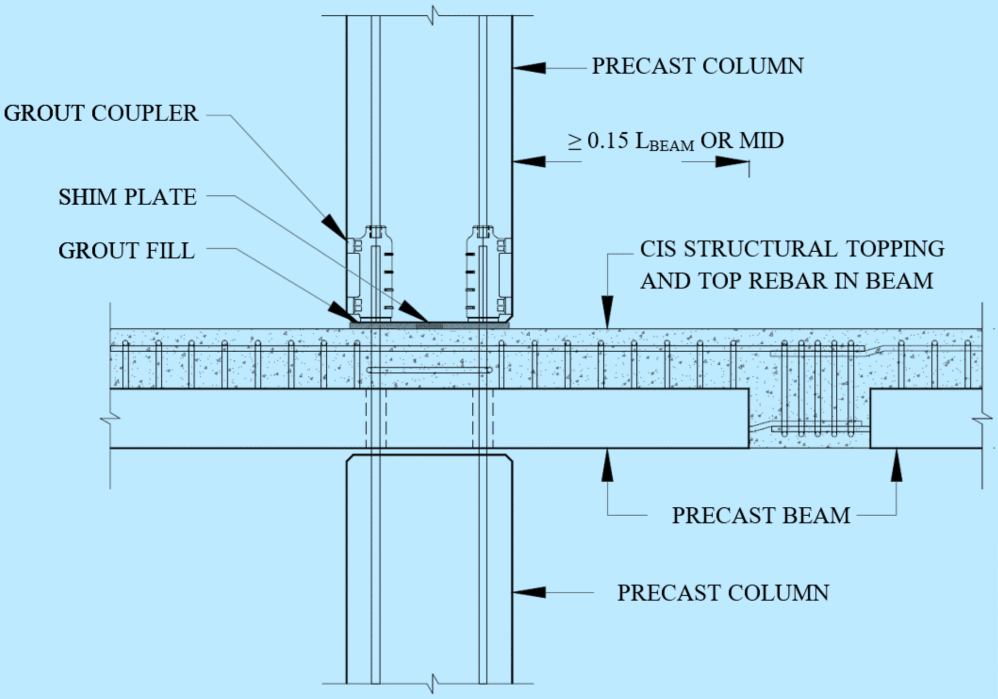

PRECAST COLUMN
GROUT COUPLER
SHIM PLATE
GROUT FILL
TOP LEVEL OF SLAB
PRECAST COLUMN
PRECAST BEAM

1B) TYPE 2

FIG. 1 PRECAST BEAM-COLUMN CONNECTION (CONTINUED)

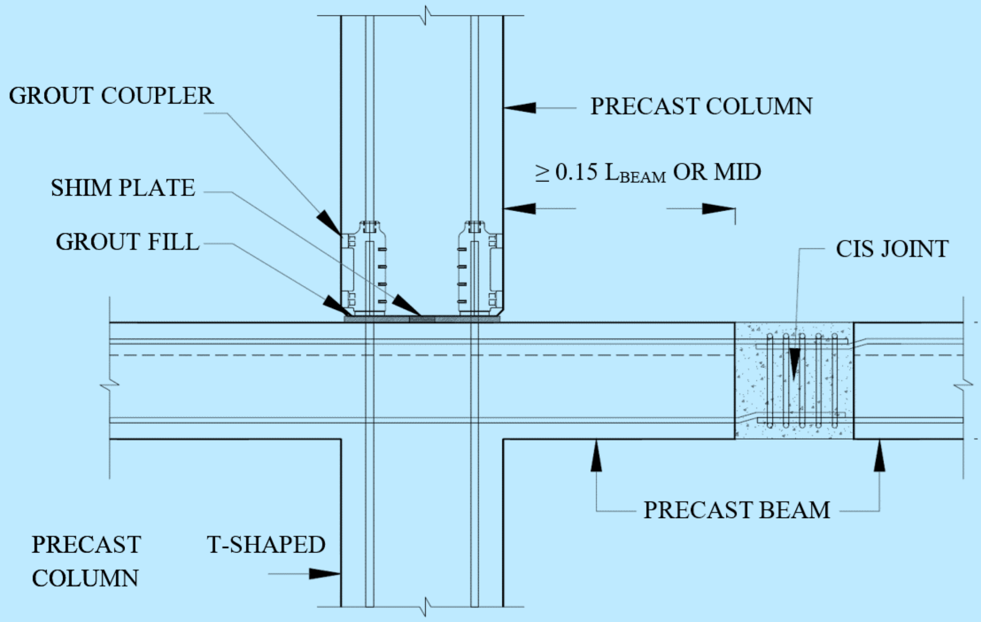

PRECAST COLUMN
GROUT COUPLER
SHIM PLATE
GROUT FILL
CIS STRUCTURAL TOPPING AND
TOP REBAR IN BEAM
PRECAST BEAM
PRECAST BEAM
PRECAST CORBEL
PRECAST COLUMN

1C) TYPE 3


PRECAST COLUMN
GROUT COUPLER
≥ 0.15 L_{BEAM} OR MID
SHIM PLATE
GROUT FILL
CIS STRUCTURAL TOPPING
AND TOP REBAR IN BEAM
PRECAST BEAM
PRECAST COLUMN

1D) TYPE 4

FIG. 1 PRECAST BEAM-COLUMN CONNECTION (CONTINUED)



1E) TYPE 5

FIG. 1 PRECAST BEAM-COLUMN CONNECTION

6.3.4.1 *Moment resisting frames*

Rigid beam-column connections shall be formed using Type A, Type B, or Type C systems, depending on the required ductility level and building importance. All systems shall include structural topping for diaphragm action in accordance with 6.3.6:

a) *Type-A frames* — Type A frames shall consist of precast beam units between columns/column corbels, where columns can be cast-in-place or precast (*see* Fig. 2). These shall be achieved by adopting either one or a combination of the following arrangements:

  1) System A1 — This system consists of single or multi-storey columns fixed at the base, supporting simply supported beams on corbels or directly above the columns. The slab units shall be simply supported between the ledges or above the beams;

  2) System A2 — This system consists of single storey columns fixed at the base with provision of seating notch or temporary supports or permanent corbels for beams. Depending on design requirements, beams and slabs shall be designed as simply supported for temporary loading and made continuous for permanent loading;

  3) System A3 — This system consists of single or multi-storey columns fixed at the base and staggered joints between the columns at other grid levels with corbels to support the beams. Staggering of columns shall be arranged such that only 50 percent of all columns are spliced at any given storey level. Depending on design requirements, beams and slabs shall be designed as simply supported for temporary loading and made continuous for permanent loading; and

  4) System A4 — This system consists of 3 or 4 storeys columns fixed at the base with corbels to support the beams. Depending on design requirements, beams and slabs shall be designed as simply supported for temporary loading and made continuous for permanent loading.

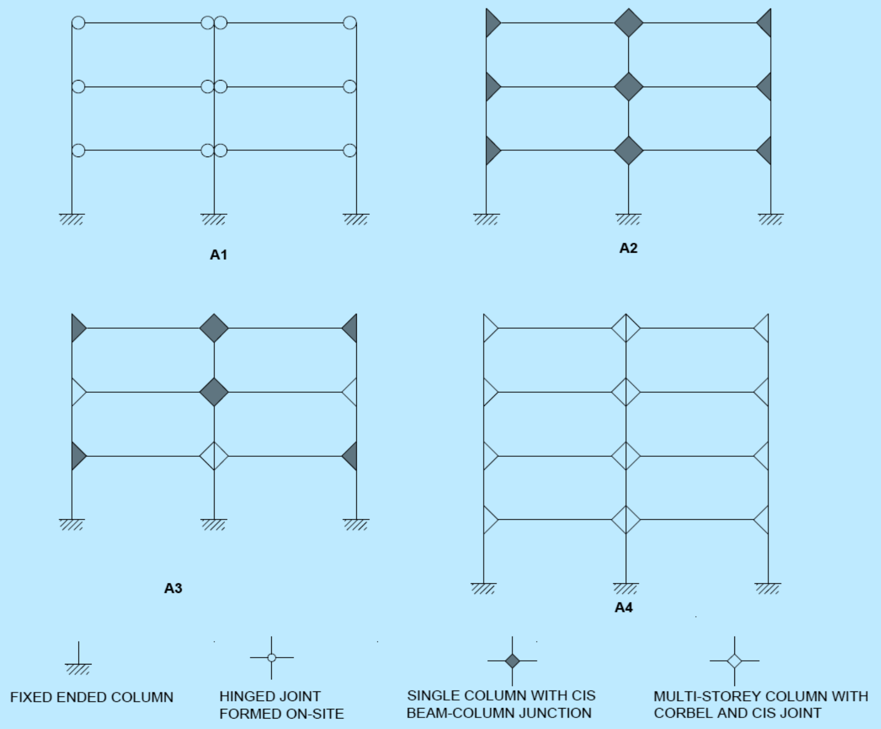

A1
A2
A3
A4
FIXED ENDED COLUMN
HINGED JOINT FORMED ON-SITE
SINGLE COLUMN WITH CIS BEAM-COLUMN JUNCTION
MULTI-STOREY COLUMN WITH CORBEL AND CIS JOINT

FIG. 2 TYPE A FRAMES

b) *Type-B frames* — Type B frames shall consist of precast beam units passing through columns (*see* Fig. 3). These shall be achieved by adopting the following arrangement:

   1) System B1 — Columns shall be 1 storey high and spliced at each floor level. Precast beams run through the columns and are spliced at point of contraflexure. It shall be ensured that beam splices are avoided at end spans. Slab units shall be designed as simply supported.

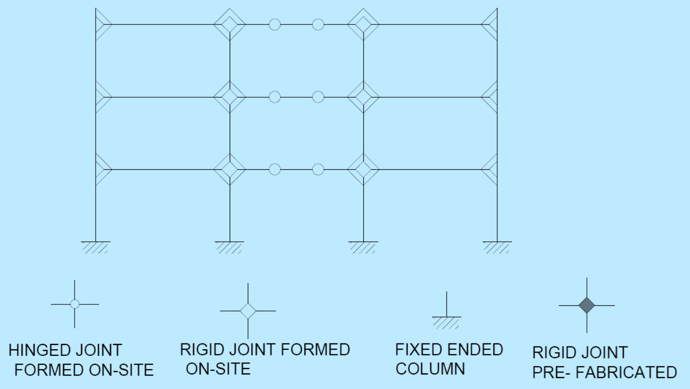

HINGED JOINT FORMED ON-SITE
RIGID JOINT FORMED ON-SITE
FIXED ENDED COLUMN
RIGID JOINT PRE- FABRICATED

FIG. 3 TYPE B FRAME

c) *Type-C frames* — Type C frames (*see* Fig. 4) shall consist of monolithically fabricated beam column units such as cruciform, T/L-units, H-frames, portal frames, etc. These shall be achieved by adopting either one or a combination of the following arrangements:

   1) System C1 — Single storey portal frames shall be placed alternately and simply supported at floor levels. Orthogonal beams and beams connecting the portal shall be simply supported or continuous based on the design requirements. Slab units shall be designed as simply supported; and

   2) System C2 — L-shaped and T-shaped frame units shall be placed simply supported on the base and on top of each other. Hinged or moment resisting connections shall be made between frame units at the mid-span of beams. Slab units shall be designed as simply supported.

3) System C3 — H-shaped frames with a cantilever beam shall be provided with rigid connection at the junction of beam and column. Hinge or moment resisting connections shall be provided at the mid-height of columns and centre of beams. Slab units shall be designed as simply supported.

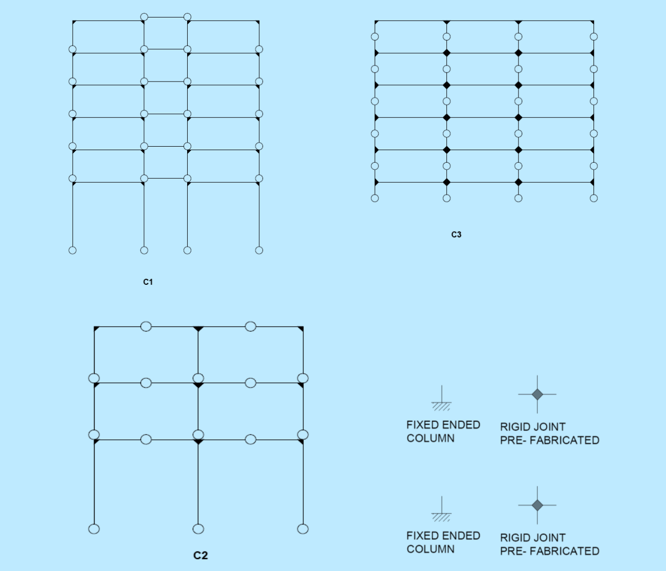


FIG. 4 TYPE C SYSTEMS

6.3.4.2 *Moment frames with structural wall*

In this system, lateral stability shall be achieved through structural walls, structural cores, or bracing. Beam-column and column-base connections shall be designed as pinned or rigid in accordance with the required ductility and seismic performance level (*see* Fig. 5).

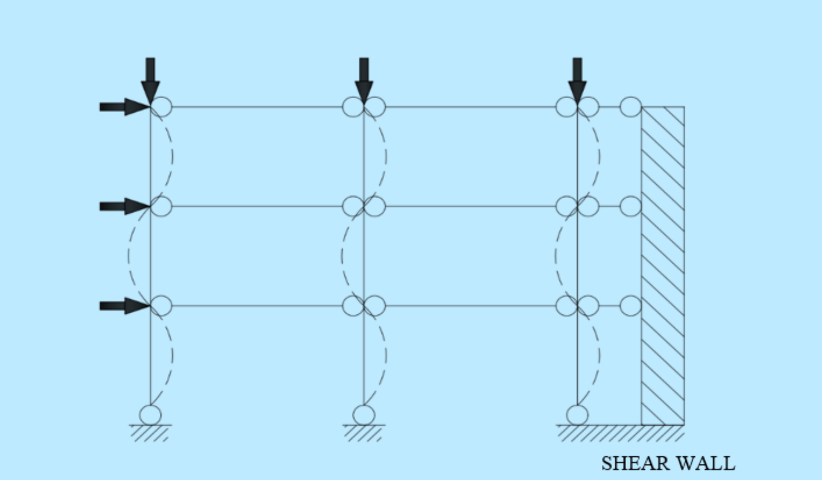


FIG. 5 DUAL SYSTEM

6.3.5 *Wall Systems*

Wall systems in precast construction shall be classified on the basis of the design of connections between individual concrete panels, which when joined together form the structural wall (*see* Fig. 6). The types of emulative wall systems shall be as follows:

a) Wall systems without shear transferring vertical joints; and

b) Monolithic wall systems.

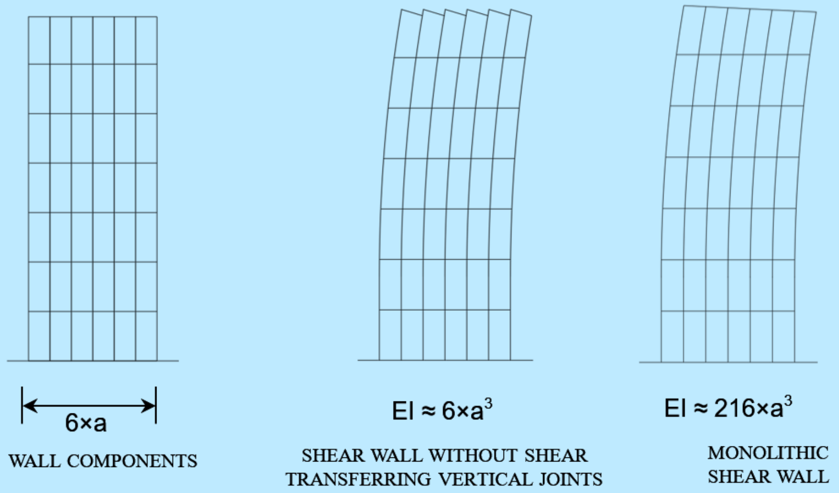
These classifications shall guide the detailing of connections and the overall performance of the system under gravity and lateral loads.

6.3.5.1 For systems without shear transferring vertical joints, the horizontal joints shall be designed to exhibit ductile behaviour. Vertical joints shall not be relied upon for structural continuity and shall be detailed to allow for movement or minimal shear capacity to be provided. Each panel shall be designed as an independent unit for gravity and lateral loads.

6.3.5.2 For monolithic wall systems, horizontal joints shall be detailed to permit ductile behaviour. Vertical joints shall be designed as strong connections with sufficient capacity to remain elastic under design-level lateral loads, preserving global ductility.

6.3.5.3 For jointed wall systems, both vertical and horizontal joints shall be detailed to provide ductile behaviour. Connections shall be capable of undergoing inelastic deformation with energy dissipation, contributing to system-level ductility.

6.3.5.4 Combination of monolithic and systems without shear transferring vertical joints shall be adopted based on the performance requirements of the building.



$6 \times a$
WALL COMPONENTS
$EI \approx 6 \times a^3$
SHEAR WALL WITHOUT SHEAR TRANSFERRING VERTICAL JOINTS
$EI \approx 216 \times a^3$
MONOLITHIC SHEAR WALL

FIG. 6 SHEAR WALL BEHAVIOUR DUE TO CONNECTIONS

6.3.6 *Floor/Roof Systems*

Precast floor and roof systems shall be designed to function as horizontal diaphragms capable of transferring in-plane shear and distributing lateral loads to the lateral force resisting system (LFRS) under all applicable load combinations.

6.3.6.1 A minimum structural topping of 75 mm with reinforcing mesh or welded wire mesh shall be used in Seismic Zones III and above which can be reduced to 50 mm in Seismic Zone II. The diameter of re-bars used in both reinforcing mesh and welded wire mesh shall not be less than 6 mm. Welded wire mesh shall be avoided in Seismic Zones III and above. The minimum structural topping thickness shall be measured above the slab top level even at the highest camber location. Where service conduits of larger diameter are provided, the thickness of structural topping shall be such that a minimum cover of 25 mm is maintained above the conduit. The structural topping shall be provided on the entire floor.

6.3.6.2 Precast floor and roof systems shall be selected from the types defined in **6.3.6.3** to **6.3.6.6**, based on span length, loading and diaphragm requirements**.**

6.3.6.3 *Hollow-core slab* (*HCS*) *system*

This system is made up of prestressed precast concrete slabs with hollow cores (*see* Fig. 7). These systems may be used for multi-story buildings with moderate spans. Structural topping shall be provided to ensure diaphragm action. The top surface of the slab shall be intentionally roughened to amplitude more than 6 mm. The individual HCS units shall not be considered for diaphragm force transfer:

a) The thickness of hollow core slabs varies depending on the span and load requirements, but typically range from 150 mm to 500 mm;

b) Standard width of hollow core slab may be 1 200 mm or 2 400 mm; and

c) Standard dimensions of hollow core slabs shall conform to good practice [C-7(17)].

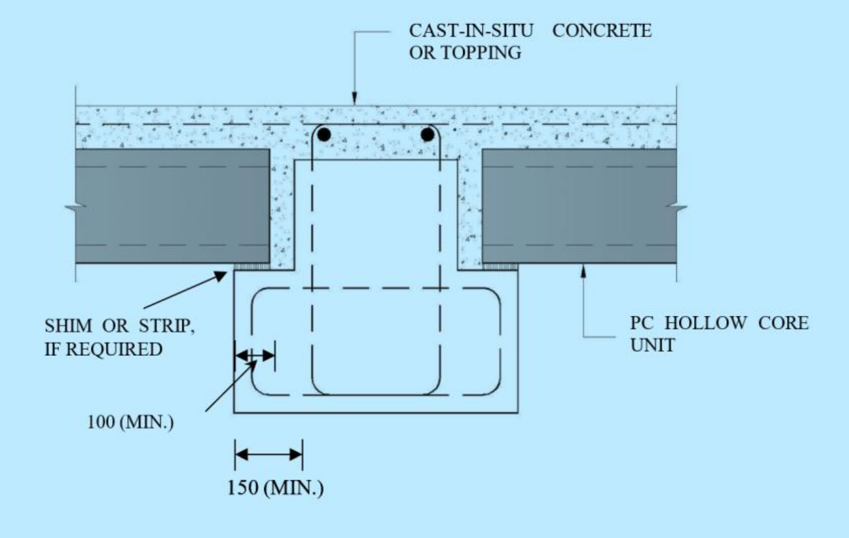


FIG. 7 HOLLOW CORE SLAB

6.3.6.4 *Double tee slab system*

This system is made up of precast concrete slabs with a double tee cross-section. The double tee shape provides greater strength and stiffness than a flat slab, making it suitable for larger spans and higher loads. These shall conform to good practice [C-7(17)]. Structural topping shall be provided to ensure diaphragm action. The double tee units shall not be considered in diaphragm action if the units are not connected for required force transfer, structural continuity and overall stability of the system.

6.3.6.5 *Solid slab system*

Solid precast concrete slab systems shall comprise precast elements that are thinner than equivalent hollow-core slabs. These slabs shall be used in residential or commercial buildings, where individual slab units are intended to span shorter distances.

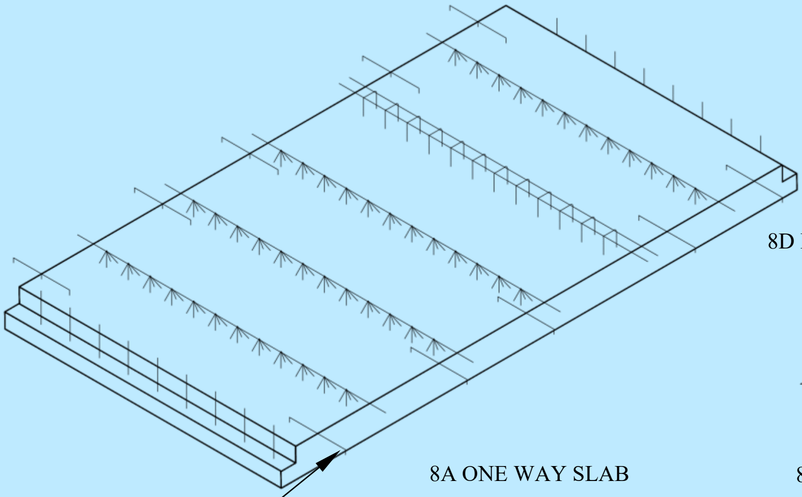
The slab system shall be considered to act as a structural diaphragm when adequate connections are provided between the slab units and the supporting structural elements and when a structural topping concrete is placed and properly bonded.

In cases where no structural topping is provided, the slab system may still be designed to act as a diaphragm, provided that the connection details ensure adequate transfer of in-plane forces, structural continuity and overall stability of the system.

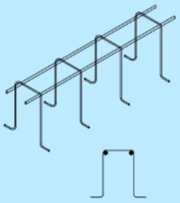
6.3.6.6 *One-way/two-way composite slab system*

6.3.6.6.1 Composite slab (*see* Fig. 8), also termed as half slab is a precast slab system cast in two stages. The first stage is to manufacture thin precast concrete panels, typically of about 60 mm to 85 mm thick, with the slab's bottom reinforcement and projected shear reinforcement in the form of truss. The projected reinforcement facilitates for multiple point lifting/handling as well as acts as shear connectors for in-situ deck concreting.

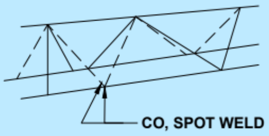
6.3.6.6.2 The slab panels shall be designed for overall thickness (precast and in-situ deck) as one-way or two-way in accordance with provisions of **5** of Part C 'Structural Design, Section 1 Loads and Load Effects' of this NBCS, and Part C 'Structural Design, Section 5 Structural Concrete' of this NBCS.


AS PER DEVELOPMENT LENGTH REQUIREMENTS

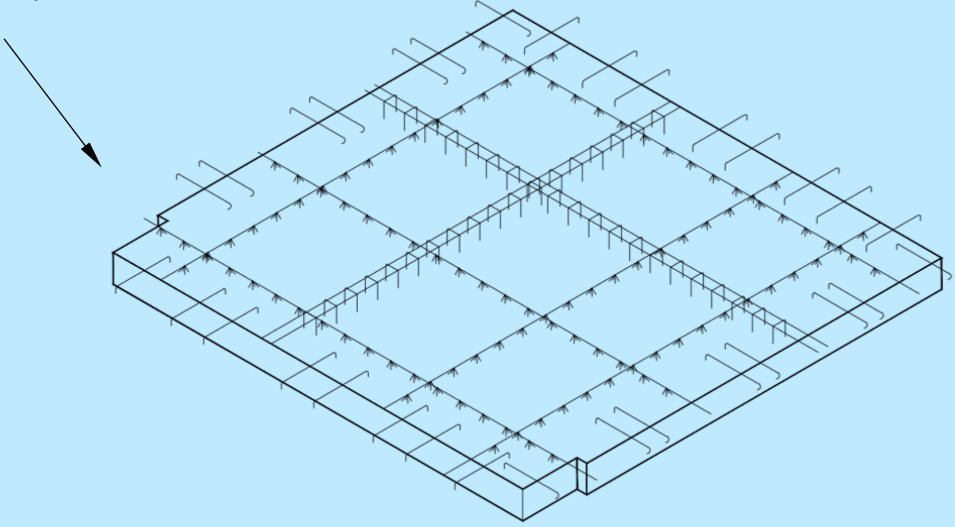
8A ONE WAY SLAB



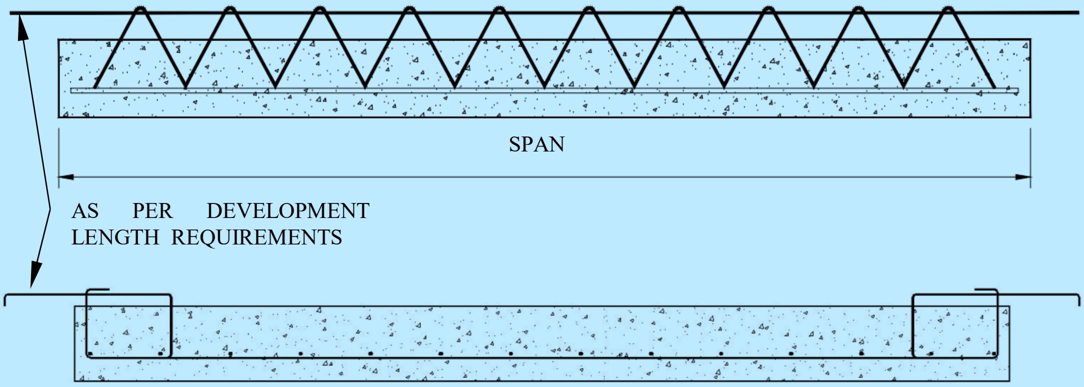
8D RECTANGULAR TRUSS


CO, SPOT WELD

8E TRIANGULAR TRUSS



8B TWO-WAY SLAB


SPAN
AS PER DEVELOPMENT LENGTH REQUIREMENTS

8C TYPICAL SECTIONAL VIEW

FIG. 8 PRECAST COMPOSITE SLAB PANELS

6.3.7 *Facade Systems*

Precast facade system shall be made up of following types of non-load bearing cladding panels:

a) Precast insulated concrete panels;

b) Precast solid cladding panels;

c) Architectural precast decorative facade panels; and

d) Precast concrete fins.

All façade connections shall comply with the requirements of the good practice [C-7(18)] and 6.3.2. Design shall account for differential movement, panel dead load and seismic restraint.

6.4 Hybrid System

The following systems are considered in precast hybrid system:

a) Precast concrete seismic structural system (PRESSS) (utilization of bonded or non-bonded prestressing tendons); and

b) Mixed system (utilization of cast-in-situ along with prestressed concrete (PC) members or steel members).

6.4.1 *Precast Concrete Seismic Structural System* (*PRESSS*)

Precast concrete seismic structural system (PRESSS) shall be implemented as an equivalent monolithic system, consisting of precast elements with grouted joints and bonded post-tensioned tendons. The main advantages of post-tensioning are deflection recovery and immediate occupancy of the structure. Two different system of PRESSS are explained in 6.4.1.1 and 6.4.1.2 and application of this system shall be carried out by conducting successful full-scale testing, verification through nonlinear analysis and approvals from competent authorities or institutes of repute.

6.4.1.1 *System* 1 *precast beam elements post-tensioned between columns*

System 1 shall use precast beams post-tensioned between multi-storey columns. Beam length shall be shorter than clear span (20 mm or tolerance requirements, whichever is greater). Post-tensioning and joint grouting shall occur after beam placement (*see* Fig. 9).

6.4.1.1.1 The beams shall be temporarily seated on steel brackets or props. Grout shall then be placed in the gap between beam ends and column faces, followed by post-tensioning operation and grouting of tendons.

6.4.1.1.2 The temporary supports shall be removed once the grout has achieved the required design strength.

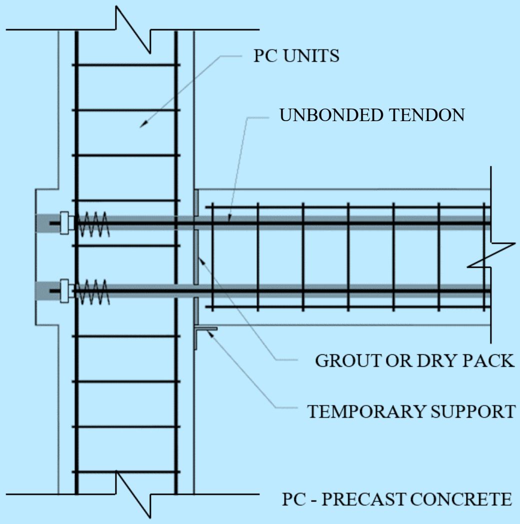


FIG. 9 SYSTEM 1 PRECAST BEAM ELEMENTS POST-TENSIONED BETWEEN COLUMNS

6.4.1.2 *System* 2 *supported precast beam elements post-tensioned between columns*

In this system, the beams shall be seated on corbels that transfer gravity loads to the adjacent columns. The beams shall be either built prismatic or with dapped ends, depending on the position of the corbel (*see* Fig. 10) and then post-tensioned.

6.4.1.2.1 The columns in this system shall normally be one-storey in height.

6.4.1.2.2 Columns shall be connected through a mechanical coupler or a grouted steel sleeve.

6.4.1.2.3 This system shall be adopted for buildings designed to demonstrate elastic response, with couplers giving continuity between the column elements, this is utilized for ductile moment resisting frames.

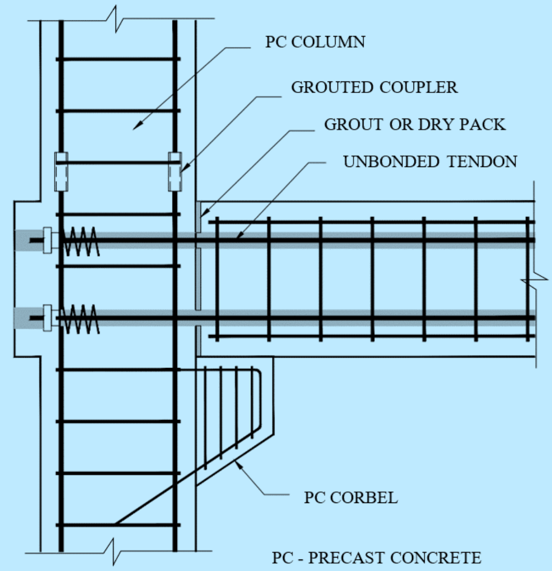


FIG. 10 SYSTEM 2 SUPPORTED PRECAST BEAM ELEMENTS POST-TENSIONED BETWEEN COLUMNS

6.4.2 *Mixed System* (*Cast In-Situ Precast or Structural Steel-Precast*)

This system shall use pretensioned prestressed concrete or reinforced concrete beam shell units or prestressed concrete beams as permanent formwork for cast in-situ beams or structural steel beams (as shown in Fig. 11). Application of this system shall be carried out by conducting successful full-scale testing, nonlinear analysis and approvals from competent authorities or institutes of repute.

6.4.2.1 The precast shells shall typically be left permanently in position after the cast-in-place reinforced concrete core has been cast. The shells can be made from fibre reinforced concrete or reinforced concrete, depending on the design requirements.

6.4.2.2 The precast U-beams or structural steel beams shall be designed to carry self-weight and construction loads and act compositely with the reinforced concrete core when subjected to other loading in the completed structure.

6.4.2.3 Precast U-beams may not be connected by reinforcement to the cast-in-place concrete of the beam or column. If the interfacial shear is found to be not sufficient then shear connector (protruding stirrups or ties) shall be provided between the interfaces.

6.4.2.4 The design shall ensure that the composite beams shall develop plastic hinges during major earthquakes.

6.4.2.5 All precast shell units shall be free of laitance, oil, dust and loose debris before placement of cast in-situ concrete. Construction sequences shall ensure adequate bond between interfaces.

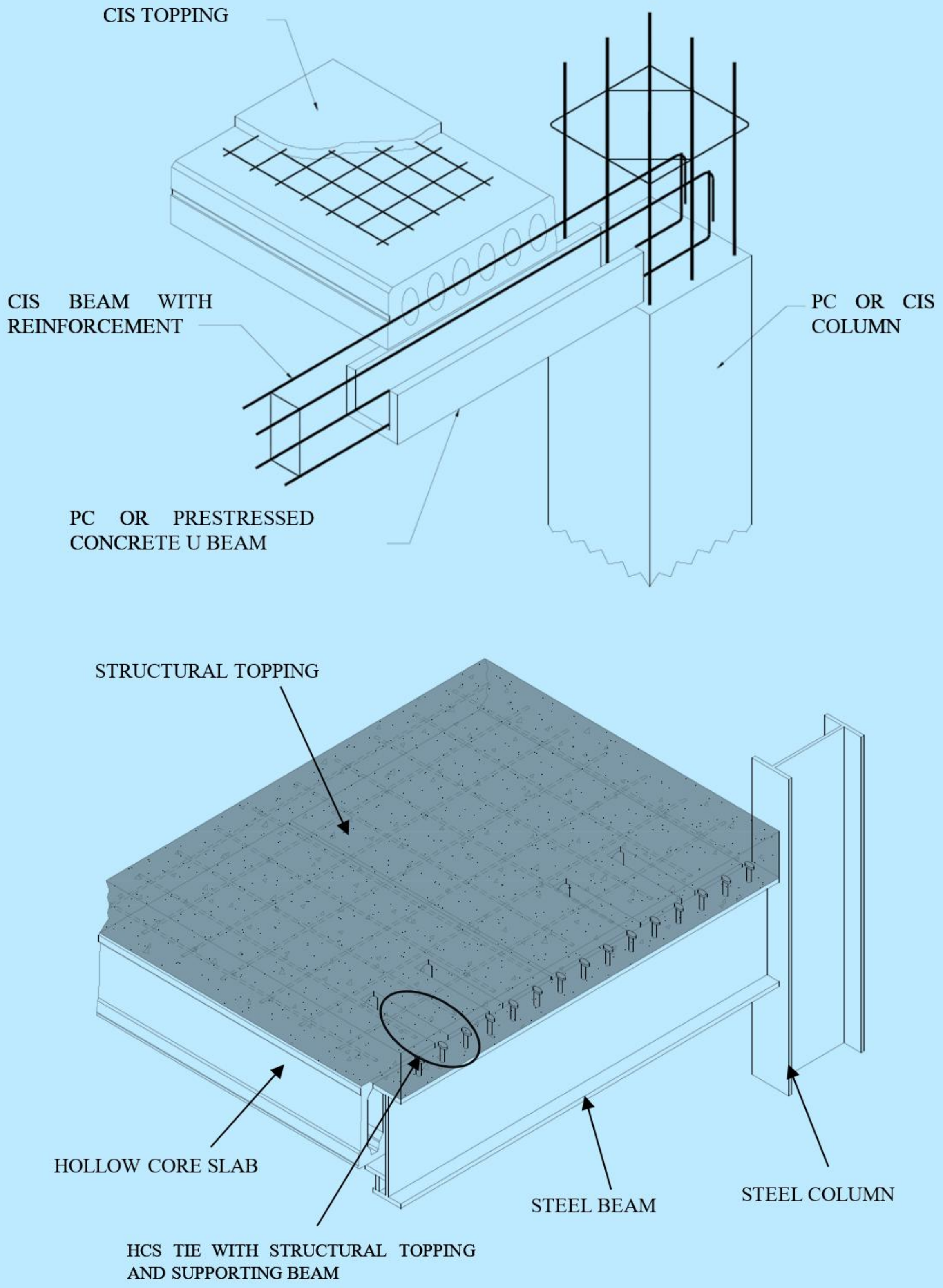

CIS TOPPING
CIS BEAM WITH REINFORCEMENT
PC OR CIS COLUMN
PC OR PRESTRESSED CONCRETE U BEAM
STRUCTURAL TOPPING
HOLLOW CORE SLAB
STEEL BEAM
STEEL COLUMN
HCS TIE WITH STRUCTURAL TOPPING AND SUPPORTING BEAM

FIG. 11 MIXED SYSTEM

6.5 Advanced Precast Systems

Advanced precast systems shall include modular 3D precast elements, digitally fabricated units and prefabricated structural modules integrated via design for manufacturing and assembly (DFMA) principles.

6.5.1 *3D Printed System*

3D printed precast systems shall only be used upon approval from the competent authority and shall follow Annex B for design, durability and testing criteria.

6.5.2 *Cell Systems*

Cell systems shall consist of volumetric precast units fabricated as open or closed modules. Connections to surrounding walls and floors shall be verified for strength and serviceability. Annex C shall be referred for further details.

Cell elements for specific area of a structure, such as wet zones (for example, toilets and kitchens), shall be used and integrated with wall and floor systems with appropriate connections.

6.6 Design for Manufacturing and Assembly (DFMA) Method

DFMA-based methods shall conform to Annex D. Designers shall ensure that precast elements are standardized, repeatable and modular to reduce rework and improve assembly efficiency.

7 STRUCTURAL ANALYSIS

7.1 General

Structural analysis shall be carried out to evaluate internal forces and deformations in members and the structural system. The analysis shall verify compliance with strength, serviceability, stability and robustness criteria. These effects include the distribution of forces and moments as well as the calculation of stresses, strains, curvatures, rotations and displacements under both static and dynamic conditions. Advanced analysis methods, such as nonlinear pushover analysis and time history analysis, may be adopted based on project requirements. However, these methods shall be mandatory for irregular structures, critical facilities and structures located in high seismic regions. For sustainable design aspects refer to **G-6**.

7.1.1 All the members and structural system shall be analysed to determine the critical load effects as per methods given in Part C 'Structural Design, Section 5 Structural Concrete' and relevant clauses of this Section.

7.1.2 To carry out analysis, the geometry, boundary conditions and behaviour of the structure need to be idealized both for global and local behaviour. The structure is idealized by considering it as made up of elements/ components which can be linear, two dimensional or three dimensional.

7.1.3 Structural analysis shall use methods capable of capturing action effects with sufficient accuracy. These may include classical mechanics or numerical methods such as finite element analysis, provided the model appropriately represents the actual structure.

7.1.4 Precast structures shall be analysed as either emulative systems, where precast performance matches that of monolithic CIS structures, or jointed systems with discrete joint behaviour. Emulative models shall assume monolithic behaviour with joints designed for equivalent force transfer. Lateral force resistance shall be achieved through moment-resisting joints or orthogonally placed structural walls or as per the design requirements.

7.1.5 For precast bearing wall buildings, rotational stiffness of floor-wall and floor-beam joints shall be neglected in structural design. Each component shall be independently designed considering the applicable end conditions, structural loads as specified in **7.2** and the various stages of construction.

7.1.6 Members shall also be designed to resist handling, erection and impact loads expected during the transportation and erection phases 7.14.

NOTES

1 Jointed construction using welded and bolted connections is not covered in this NBCS. This may be adopted with approval from competent authority and appropriate testing.

2 Rotational stiffness may be accounted for long/short term deflection and serviceability calculations as per 6.3.4, provided that the approach is mutually agreed by the design team and approved by the Authority.

3 Horizontal precast members that transfer gravity loads but are not part of the lateral force resisting system (LFRS) shall be designed assuming pinned end conditions, unless justified otherwise through analysis.

4 Linear model, non-linear model and P-Delta analyses may be used for design, provided the analysis method, assumptions and modelling parameters are clearly defined and justified and approved by the Competent Authority.

7.2 Loads and Forces

The design shall consider all the loading requirements as specified in Part C 'Structural Design, Section 1 Loads and Load Effects' of this NBCS. Consideration shall also be given to construction loads, any special requirements, such as for plant loads or storage loads and the loading condition should be modified accordingly.

7.2.1 Structural design shall take into consideration the dead loads, live or imposed loads, wind loads, forces such as those caused by earthquake effects, prestressing effects, crane loads, vibration, impact, natural disasters (flood, landslide, etc), blast and effects due to shrinkage, creep, temperature, etc, where applicable.

7.2.1.1 *Dead load*

Dead loads shall be calculated based on unit weights which shall be established taking into consideration the materials specified for construction or **2** of Part C 'Structural Design, Section 1 Loads and Load Effects' of this NBCS.

7.2.1.2 *Imposed load*

Imposed loads shall be considered as per **3** of Part C 'Structural Design, Section 1 Loads and Load Effects' of this NBCS. A minimum construction load (as per design requirement) of 1.0 kN/m^2 or construction traffic load shall be adopted for design, if not specified in the contract document. However, due consideration shall be given to actual possible construction loads.

7.2.1.3 *Wind load*

Wind load shall be considered as per **4** of Part C 'Structural Design, Section 1 Loads and Load Effects' of this NBCS.

7.2.1.4 *Construction traffic load*

Construction traffic load shall be assumed in accordance with the project requirements. A minimum traffic load (as per design requirement) of 1.0 kN/m^2 or imposed load shall be adopted for design, if not specified in the contract document.

7.2.1.5 *Seismic load*

The seismic forces shall be calculated in accordance with **5** of Part C 'Structural Design, Section 1 Loads and Load Effects' of this NBCS.

7.2.1.6 *Notional horizontal load*

Notional horizontal load (as shown in Fig. 12) shall be taken as not less than 1.5 percent of the characteristic dead load and accidental loads such as from earth movement, impact of construction vehicles, etc.

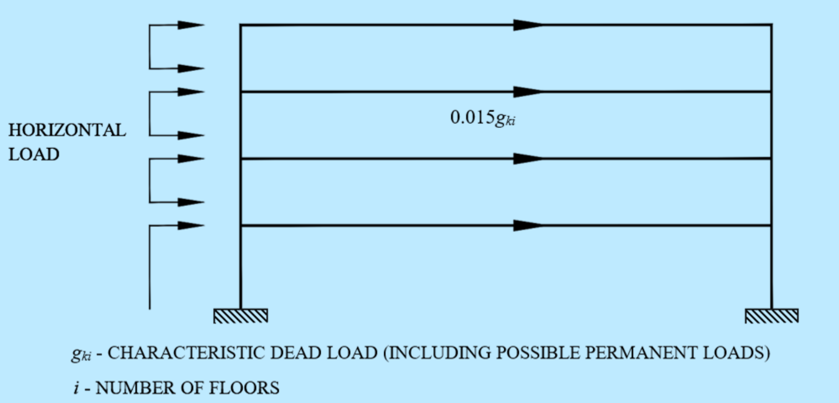

HORIZONTAL LOAD
$0.015g_{ki}$
g_{ki} - CHARACTERISTIC DEAD LOAD (INCLUDING POSSIBLE PERMANENT LOADS)
i - NUMBER OF FLOORS

Fig. 12 Notional Horizontal Load Floor Levels

7.2.1.7 *Shrinkage, creep and temperature effects*

The effects of shrinkage, creep and temperature shall be considered according to the good practice [C-7(2)]. Special literature can be referred to for critical structures.

7.2.1.8 *Environmental loading*

The effects of thermal loading and changes in values of creep and shrinkage due to environmental exposure shall be considered according to the good practice [C-7(2)] or as defined in design basis report.

7.2.1.9 *Other forces and effects*

Relevant clauses of Part C 'Structural Design, Section 1 Loads and Load Effects' of this NBCS shall be followed for additional forces such as snow load, liquid retaining loads, impact due to equipment, cranes, etc.

7.2.2 *Load Combinations*

Basic load combination shall be as per the good practice [C-7(2)] and Part C 'Structural Design, Section 1 Loads and Load Effects' of this NBCS. In addition, precast specific load combinations specified by the competent authority or given in this NBCS shall be adopted.

7.2.2.1 *Factor of safety/partial safety factor for load combinations*

Load and material safety factors shall be as per the good practice [C-7(2)]. Precast specific partial safety factors given at various sections of this NBCS shall be adopted accordingly.

7.3 Effective Span

7.3.1 Except for the purely simply supported spans, the effective spans for all elements shall be estimated as per the relevant clauses of the good practice [C-7(2)].

7.3.2 Effective span for all elements during the temporary erection stage are to be considered based on the temporary support condition.

7.3.3 The effective span for simply supported elements shall be considered as the centre-to-centre distance between the bearing pads or shims at each end. If the multiple shims are used, only the shims or pads close to the end of the elements shall be considered as governing case.

7.4 Stiffness

7.4.1 *Relative Stiffness*

The relative stiffness of the member shall be calculated based on the moment of inertia of the section considering gross section, transformed section and cracked section as provided in the good practice [C-7(2)].

7.4.2 *Stiffness Modifiers*

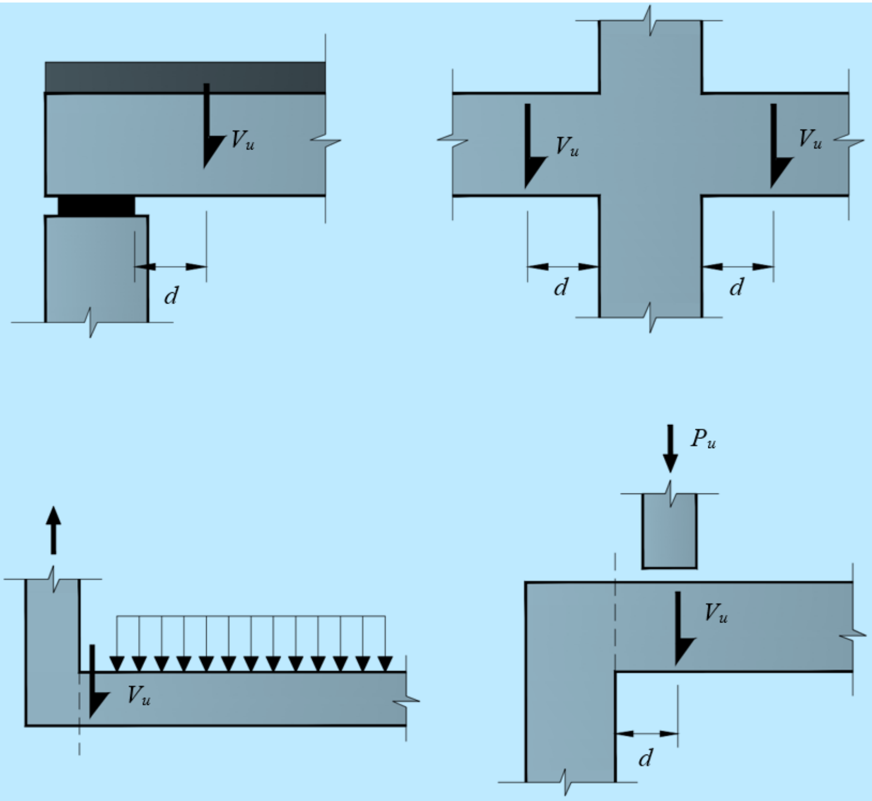
Stiffness reduction factors for members and connections shall be applied as per **5** of Part C 'Structural Design, Section 1 Loads and Load Effects' of this NBCS, considering structural system type and ductility requirements.

7.4.3 *Critical Sections for Moment and Shear*

The critical sections for moment and shear shall be identified as per the good practice [C-7(2)] and additionally as per **7.4.3.1** and **7.4.3.2**.

7.4.3.1 Critical section for shear as per the good practice [C-7(2)] is shown in Fig. 13.

7.4.3.2 For L-beams and inverted T-beams carrying loads within the bottom 30 percent of section depth (*refer* Fig. 13), the critical section for shear shall be taken at the face of support, unless a monolithic or emulative beam-column joint is specifically detailed to resist shear.



d – effective depth of beam

FIG. 13 CRITICAL SECTION FOR SHEAR

7.5 Concentrated Loads on Floor Slabs

7.5.1 Concentrated loads shall be applied as per Part C 'Structural Design, Section 1 Loads and Load Effects' of this NBCS. Effective width for slabs carrying concentrated loads shall be calculated as per the good practice [C-7(2)] along with **7.5.2** and **7.5.3**.

7.5.2 The load distribution for hollow core slab depends on the one-way action of the plank and the cast in place structural topping. The effective width for hollow core slabs shall be calculated as per **7.5.3**.

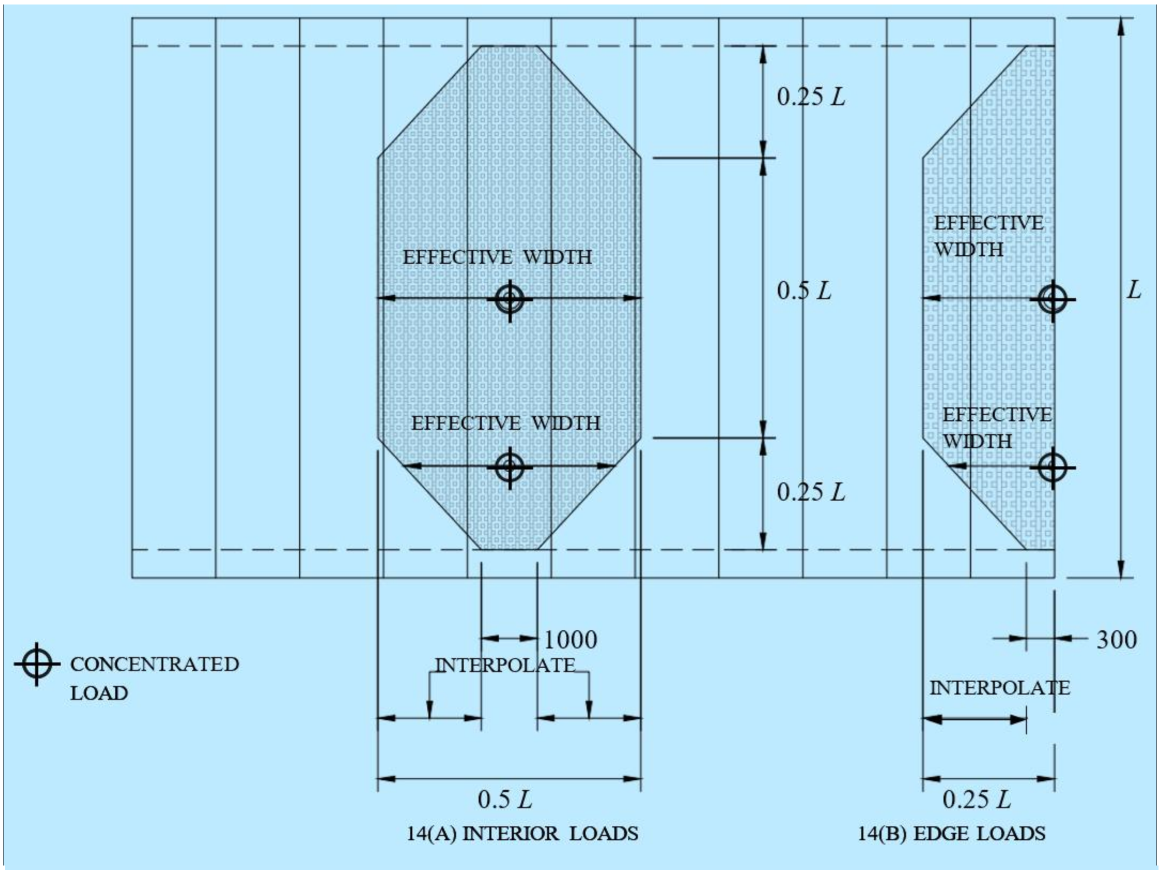
7.5.3 Moments and shears induced by line and concentrated loads shall be resisted by an effective section as described in Fig. 14. If the total deck width, perpendicular to the span, is less than the span, modification may be required. In addition, the following limitations would apply:

a) As the width of the system becomes narrower than the span length, the effective resisting widths will become narrower;

b) For extremely high span-depth ratios (more than approximately 50), the effective section at mid-span shall be reduced by 10 percent to 20 percent;

c) For spans less than about 3 m, the effective width at the support may become narrower; and

d) Local load concentrations can cause longitudinal splitting failures due to transverse bending in the system and punching shear failure. The magnitude of concentrated loads shall be limited to minimise such failures.


0.25 L
EFFECTIVE WIDTH
0.5 L
EFFECTIVE WIDTH
0.25 L
EFFECTIVE WIDTH
EFFECTIVE WIDTH
L
CONCENTRATED LOAD
1000
INTERPOLATE
300
INTERPOLATE
0.5 L
14(A) INTERIOR LOADS
0.25 L
14(B) EDGE LOADS

All dimensions in millimetres.

FIG. 14 MOMENT AND SHEAR DISTRIBUTION WIDTHS FOR HCS

7.6 Stability Design

7.6.1 *Design Philosophy*

The following factors shall be considered in designing for stability of a precast structure:

a) The overall structural system shall be checked for global and local stability under all applicable loading conditions including temporary and final stages;

b) Precast structural systems shall be designed to resist wind and all applicable lateral loads;

c) Cross walls or sway frames shall be so arranged to provide lateral stability;

d) When lateral loads are low, stability shall be verified using a notional horizontal force equal to 1.5 percent of total vertical load, as shown in Fig. 12;

e) Lateral stability shall be maintained during all construction and erection stages. Temporary bracing, shoring, or props shall be detailed and installed to match the staged loading conditions. A temporary works scheme including propping layout, sequencing and dismantling plan shall be submitted and approved before execution;

f) Inverted T and L-beams shall be analysed for asymmetric loading during both construction and service stages, using all applicable load combinations;

g) The strength of grout shall be at least 50 percent of the design strength or as per design requirement before application of any other loads (temporary or permanent) on the element. Stress and cracking shall be evaluated and verified before proceeding;

h) Long-span and high-rise precast structures shall include engineered bracing and verified stability measures during all construction and service stages; and

j) Temporary anchors shall be designed for proper alignment and safety of the elements. Appropriate washers shall be used.

7.6.1.1 *Overturning*

Stability against overturning shall be checked in accordance with the requirements in Part C/Section 5 of this NBCS. For L and inverted T beams, lateral support shall be provided during construction to avoid stability related failures.

7.6.1.2 *Sliding*

Stability against sliding shall be checked in accordance with the requirements in the good practice [C-7(2)]. All the precast members during construction shall be propped or anchored to prevent sliding from the supporting structure. Minimum bearing as per 7.11 shall be followed.

7.6.1.3 *Probable variation in dead load*

Probable variations in dead load during casting of in-situ components shall be accounted for in the design. Pouring of structural topping above the long span elements (such as HCS) shall be monitored to have the required pouring depth measured from top of the highest point of the element (camber point) instead of global level.

7.6.1.4 *Moment connection*

Moment connection shall be used for lateral force resistance system frames. Where frames are pin-jointed, transverse stability shall be ensured through structural walls or bracing system. Integrity ties shall be provided to maintain system continuity.

7.6.1.5 *Lateral sway*

Stability against lateral sway shall be evaluated using the good practice [C-7(2)] and **5** of Part C 'Structural Design, Section 1 Loads and Load Effects' of this NBCS, including during temporary construction stages and final occupancy.

7.6.1.6 *Lateral force resistance system design*

The lateral force resistance system design shall be in accordance with the relevant provisions of Part C 'Structural Design, Section 1 Loads and Load Effects', Part C 'Structural Design, Section 5 Structural Concrete' and Part C 'Structural Design, Section 6 Steel and Steel-Concrete Composite Construction, Subsection A Steel' of this NBCS with the guidelines stipulated in **6**. Additional impact of lateral loads such as earth fill, or liquid/snow retention shall be analysed as per the project requirements.

7.7 Durability Design

7.7.1 *Design Philosophy*

The following factors shall be considered for achieving the design life and durability of a precast structure:

a) Geometry and detailing of precast elements;

b) Concrete mix design, including constituent materials;

c) Nominal and minimum cover as per environmental class;

d) Environmental exposure classification in accordance with the good practice [C-7(2)];

e) Fire resistance rating based on intended use;

f) Access provisions for inspection and maintenance;

g) Controlled production quality;

h) Handling, transport and erection constraints; and

j) Watertight and durable joint detailing.

In addition to above requirements, the recommendations specified in the good practice [C-7(2)] and relevant accepted standards shall be followed.

7.7.2 *Service Life*

7.7.2.1 The service life of any structure shall be specified in the design basis report (DBR) or considered based on the good practice [C-7(2)].

7.7.2.2 For temporary structure, the service life shall be considered as the period the structure is required to satisfy the intended function, or as mentioned in the contract document.

7.7.2.3 The service life specified for a structure does not apply to architectural finishes, replaceable materials such as sealants, paints, non-structural grout. The service life of such items shall be considered as per the manufacturer's guidelines and mutually agreed upon by all the stakeholders.

7.7.3 *Shape of Precast Units*

7.7.3.1 Sharp corners or sudden changes in geometry, re-entrant corners, or grooves in a section causes stress concentrations that may lead to cracking or spalling of concrete and therefore shall be avoided. For sections with practical constraints, stress concentrations shall be checked and strengthening or local detailing shall be provided, as necessary.

7.7.3.2 Extra reinforcements shall be provided around the cut-outs or opening, if any, present in an element. Larger cut-outs shall be considered in the analysis to characterize the stress concentration and its effects on the design as per the good practice [C-7(2)].

7.7.3.3 Buckling and instability must be prevented during the lifting and erection of long, slender precast units, as per the good practice [C-7(2)]. For thin sections (thickness less than 75 mm), the positioning of lifting inserts should be such that it prevents buckling of the compression flange, especially during the handling and manoeuvring of the elements.

7.7.3.4 The precast unit shall be designed and detailed to have sufficient drainage to avoid standing water or excessive moisture.

7.7.4 *Concrete Cover*

Concrete cover for precast concrete elements shall comply with the requirements of the good practice [C-7(2)], unless reduced values from Table 2 are adopted. Reduced cover values shall only be permitted if the elements are produced in a controlled environment.

7.7.4.1 The minimum concrete cover for reinforcement to ensure durability against fire and corrosion shall comply with the provision of the good practice [C-7(2)]. Fire resistance of joint fillers and other components shall meet or exceed the fire resistance rating of the connected precast members, or as prescribed in **7.8**.

7.7.4.2 The cover to all brackets, fixings, etc shall comply with the minimum cover requirements specified for reinforcement as per the above table or the good practice [C-7(2)].

Table 2 Nominal Cover in Precast Elements

(*Clause* 7.7.4)

Sl No.	**Exposure**	**Elements**	**Nominal Concrete Cover,** (mm, *Min*)
(1)	(2)	(3)	(4)
i)	Mild	All	20
ii)	Moderate	Slabs and walls	25
		For the ties/stirrups of beams and columns exposed to weather	25
		For ties/stirrups of beams and columns non-exposed to weather	Greater of d_b or 20
iii)	Severe	All	40
iv)	Very Severe	All	45
v)	Extreme	All	70

NOTES

1 The prescribed covers for precast elements are lesser than the covers noted in the good practice [C-7(2)] to account for the greater control for proportioning, placing and curing inherent to precast concrete produced in a controlled environment.

2 Controlled environment does not imply that the precast members shall be manufactured in a factory. Elements manufactured at the jobsite or in a temporary factory also qualify under these requirements, if the controls are equal to that normally adopted in a factory. The client and engineer-in-charge shall verify the temporary factory and certify the same, if the cover requirements of this Table are adopted.

3 d_b is bar diameter.

7.7.5 *Protection and Maintenance of Joints and Connections*

7.7.5.1 The connection between the precast element shall be properly filled with high strength, non-shrink, non-metallic cementitious grout (minimum 50 MPa or 5 MPa more than the strength of the element, whichever higher) to prevent corrosion, cracking and spalling of concrete. Where the joint gap between the precast elements is more than 50 mm, the provisions of **5.4.1.3** shall apply.

7.7.5.2 Steel plates or inserts used in permanent connections shall be provided with adequate concrete cover or protected with corrosion-resistant coatings. Inserts for temporary use shall be removed or treated to prevent corrosion.

7.7.5.3 Where minimum cover cannot be ensured due to geometric or project constraints, only corrosion-resistant materials (such as stainless steel or galvanized steel) shall be used for connectors and fixings.

7.7.6 *Other Effects*

7.7.6.1 Joint spacing and width shall account for cumulative movements including production tolerances, creep, shrinkage, settlement and thermal expansion to prevent cracking and spalling.

7.7.6.2 In addition to satisfying general requirements for durability, strength, stability, control of cracking and limitation of deformation, the following provisions shall be met:

a) Structural components shall be designed to limit cracking and deformation from early thermal movements, creep and shrinkage; and

b) Bearings or movement joints shall be provided to minimize structural restraints. Where restraint is unavoidable, the design shall include measures to resist resulting stresses, with reinforcement provided as per as per the good practice [C-7(2)].

7.8 Fire Resistance

7.8.1 *Fire Resistance Requirement*

7.8.1.1 The fire resistance of a structural element shall be expressed in terms of time in hours in accordance with good practices [C-7(19)]. General requirements for fire protection are given in good practice Part F 'Fire and Life Safety' of this NBCS.

7.8.1.2 Elements and joints wider than 50 mm shall comply with fire resistance provisions of the good practice [C-7(2)], except where otherwise specified in this section.

7.8.1.3 All joints in fire-prone structures shall be filled with mortar, grout, or concrete in accordance with the design requirements.

7.8.1.4 The joints between slab elements or hollow core elements with structural topping of more than 50 mm (minimum thickness of structural topping concrete) may not require any additional treatment for fire rating.

7.8.1.5 For joints between structural wall elements with a width less than or equal to 50 mm shall be filled with grout of strength minimum 50 MPa or 5 MPa more than the strength of the element, whichever higher. For non-structural wall elements, the grout strength shall be at least equal to that of the element. For joints with a width exceeding 50 mm, the provisions of **5.4.1.3** shall apply.

7.9 Structural Design of Precast Concrete Components

7.9.1 *Footings*

7.9.1.1 All the design and detailing requirements of the good practice [C-7(2)] shall be followed for members/elements along with any specific criteria given in this Section.

7.9.1.2 Precast footing with multiple elements stitched using appropriate connection arrangement shall be adopted, wherever required. However, footing subjected to vibration shall be without any joints, preferably a single unit or cast in-situ or the system shall be tested prior to application for the required level of vibration.

7.9.1.3 The minimum thickness at the edge of a precast footing shall be as per the good practice [C-7(2)].

7.9.1.4 The connections shall be detailed as per **8** to ensure effective force transfer between elements.

7.9.1.5 Detailing of column, pedestal and wall connections to the footing elements shall be as per **8**.

7.9.2 *Walls*

7.9.2.1 Design and detailing of wall elements shall comply with the good practice [C-7(2)], in addition to the specific requirements of this Section.

7.9.2.2 As the elements are manufactured in controlled environment, walls subjected to marginal shear forces, minimum longitudinal and transverse reinforcement shall be 0.1 percent of gross area. For other cases, reinforcement shall be as per the good practice [C-7(2)].

7.9.2.3 The connections shall be detailed as per **8** and shall ensure proper force transfer between the elements.

7.9.2.4 Walls shall be tied to intersecting elements such as floors, columns, other walls and footings using appropriate ties or mechanical connections that ensure force transfer and structural continuity.

7.9.3 *Shear Wall*

7.9.3.1 All the design and detailing requirements of the good practice [C-7(2)] shall be followed for members/elements along with any specific criteria given in this Section.

7.9.3.2 Minimum reinforcement for structural wall shall be as per the good practice [C-7(2)] and as per good practice [C-7(18)].

7.9.3.3 At least one continuous vertical tie of 12 mm diameter or higher shall be provided from foundation to terrace at each end of the structural wall using Class H coupler as per [C-7(9)] or any other connection with appropriate lapping or welding as per the design requirements.

7.9.3.4 The connections shall be detailed as per **8** and to ensure adequate transfer of axial, shear and bending forces between connected elements.

7.9.3.5 Shear walls shall be structurally tied to intersecting elements, including floors, columns, other walls and footings, using mechanical ties, dowels, or other engineered connections capable of transferring expected design loads.

7.9.4 *Floors/Slabs*

7.9.4.1 All the design and detailing requirements of the good practice of [C-7(1)] shall be followed for members/ elements along with any specific criteria given in this Section.

7.9.4.2 Minimum reinforcement for slab elements and structural topping the minimum reinforcement shall be as per good practice [C-7(1)].

7.9.4.3 The thickness of structural topping shall be considered if the maximum shear stress at any location is less than 0.4 MPa. Also, the top surface of the slab shall be roughened to a minimum amplitude of 6 mm. Where the shear stress exceeds 0.4 MPa, adequate shear reinforcement or studs shall be provided to ensures the composite action between the topping and the floor slab elements.

7.9.4.4 The minimum grade of concrete for the structural topping shall be equal to M30 or as per design (whichever is higher).

7.9.4.5 The connections shall be detailed as per **8** and shall ensure proper force transfer between the elements.

7.9.4.6 For pre-tensioned and post-tensioned members, stress limits shall be as per good practice [C-7(3)].

7.9.4.7 For simply supported slab at least one third of the maximum positive reinforcement shall be extended till the centre of the bearing. For other cases, at least one fourth of the reinforcement shall extend into the support for a length of 150 mm. Adequate development length shall be provided to the bottom reinforcement as per good practice [C-7(2)]

7.9.4.8 For requirements relating to design and detailing for precast structures with hollow core slabs, Annex H may be referred.

7.9.5 *Columns*

7.9.5.1 All the design and detailing requirements of the good practice [C-7(1)] shall be followed for members/elements along with any specific criteria given in this NBCS.

7.9.5.2 Minimum reinforcement requirements shall be as per the good practice [C-7(2)].

7.9.5.3 The connections shall be detailed as per **8** and shall ensure proper force transfer between the elements.

7.9.5.4 At least four continuous vertical ties of 12 mm diameter or higher shall be provided from foundation till the roof using Class H coupler as per accepted standard [C-7(9)] or any other connection, with appropriate lapping or welding.

7.9.5.5 Transverse reinforcement as per the good practice [C-7(2)] shall be provided in the members as well as the splice locations (grouted coupler, grouted duct, mechanical connections, etc).

7.9.5.6 For connection using grouted coupler of height less than 250 mm, minimum cover to the confinement reinforcement shall be 25 mm at the location of coupler. For all other cases cover shall be as per the good practice [C-7(2)].

7.9.5.6 For connection using grouted duct/tube or any other, minimum cover shall be as per the good practice [C-7(2)].

7.9.6 *Beams*

7.9.6.1 All the design and detailing requirements of good practice [C-7(1)], [C-7 (2)] and [C-7(3)] shall be followed for members/elements along with any specific criteria given in this Section.

7.9.6.2 Minimum reinforcement requirements shall be as per the good practice [C-7(2)].

7.9.6.3 The connections shall be detailed as per **8** and shall ensure proper force transfer between the elements.

7.9.6.4 Transverse reinforcement as per good practice [C-7(2)] shall be provided in the members as well as the splice locations (grouted coupler, grouted duct, mechanical connections, etc).

7.9.6.5 For connection using mechanical coupler of length less than 500 mm, minimum cover of 20 mm shall be maintained to the transverse reinforcement at the coupler location. In all other cases the cover shall be as per the good practice [C-7(2)].

7.9.6.6 For beam made composite to the cast in-situ topping (T-action or L-action, in compression), the thickness of cast in-situ shall be considered in the height of the beam and the width of flange shall be calculated according to the good practice [C-7(2)].

7.9.6.7 Stress limits for pre-tensioned and post-tensioned beams shall be as per good practice [C-7(3)].

7.9.6.8 For simply supported beam at least one third of the maximum positive reinforcement shall be extended till the centre of the bearing. For other cases, the reinforcement shall extend to the other member or to the support and shall develop f_y at the tension face of the support.

7.9.7 *Staircase/Landing*

7.9.7.1 All the design and detailing requirements of Part C 'Structural Design, Section 5 Structural Concrete' of this NBCS shall be followed for members along with any specific criteria given in this Section.

7.9.7.2 Minimum reinforcement requirements shall be as per Part C 'Structural Design, Section 5 Structural Concrete' of this NBCS and shall ensure proper force transfer between the elements.

7.9.7.3 The connections shall be detailed as per **8**.

7.9.8 *Composite Concrete Construction*

7.9.8.1 All the design and detailing requirements of Part C 'Structural Design, Section 5 Structural Concrete' of this NBCS shall be followed for members along with any specific criteria given in this Section.

7.9.8.2 The connections shall be detailed as per **8** and shall ensure proper force transfer between the elements.

7.9.9 *Insulated Panels/Thermal Comfort*

7.9.9.1 All the design and detailing requirements of Part C 'Structural Design, Section 5 Structural Concrete' of this NBCS shall be followed for members along with any specific criteria given in this Section.

7.9.9.2 Minimum thickness of the concrete wythe shall be 50 mm.

7.9.9.3 Individual wythe shall be connected to each using wythe connectors by providing solid zones or special reinforcements.

7.9.9.4 Maximum spacing between the reinforcements in the wythe shall be 250 mm or as per design.

7.9.9.5 For walls made from composite wythe, the solid zone shall be designed to transfer the shear demand on the wall and for moment transfer complete composite wythe section shall be considered.

7.9.9.6 Insulation material if provided shall have adequate bond with the concrete wythes to avoid splitting of junction during handling.

7.9.9.7 The connections with other elements shall be detailed as per **8** and shall ensure proper force transfer between the elements.

7.9.10 *Composite Floors*

7.9.10.1 All the design and detailing requirements of Part C 'Structural Design, Section 5 Structural Concrete' of this NBCS shall be followed for members along with any specific criteria given in this Section.

7.9.10.2 No shear reinforcement/studs shall be provided if the maximum shear stress at any location is less than or equal to 0.4 MPa.

7.9.10.3 The minimum grade of concrete for the structural topping shall be equal to M30 or as per design (whichever is higher).

7.9.10.4 The connections shall be detailed as per **8** and shall ensure proper force transfer between the elements.

7.9.11 *Others Structural Elements*

7.9.11.1 Any structural element shall be designed and detailed as per Part C 'Structural Design, Section 5 Structural Concrete' of this NBCS.

7.9.11.2 The connections shall be detailed as per **8** and shall ensure proper force transfer between the elements.

7.9.11.3 Any connection scheme found effective in force transfer shall be used, subjected to approval of competent authority.

7.10 *Design of Diaphragm*

For the stability of the precast concrete building horizontal loads due to wind and earthquake shall be transmitted to the lateral force resistance system through the floor acting as horizontal deep beam. However, in a precast slab system, the floor comprises individual units generally not connected to each other. A structural topping concrete is provided to act as the diaphragm, or the individual elements are connected. In this system, the diaphragm action shall ensure the following:

a) Collect and transfer lateral forces at each level to the lateral force resisting elements such as shear walls, moment frames, etc; and

b) Tie individual lateral force resisting elements into a single lateral force resisting system.

7.10.1 Diaphragm action arises from the in-plane stiffness inherent to the floor system. As a result, substantial in-plane forces can develop in the diaphragm during lateral loading. In the context of precast concrete construction, the panelled nature of floor systems can pose challenges in the seismic design of diaphragms. These challenges may involve ensuring sufficient strength, stiffness, and in some cases, ductility in both the diaphragm and its connections.

7.10.2 In case of buildings whose floors can provide rigid horizontal diaphragm action, the total shear in any horizontal plane shall be distributed to the various vertical elements of lateral forces resisting system, assuming the floors to be infinitely rigid in the horizontal plane.

7.10.3 In case of building whose floor diaphragms cannot be treated as infinitely rigid in their own plane, the lateral shear at each floor shall be distributed to the vertical elements resisting the lateral forces, considering the in-plane flexibility of the diaphragms.

> NOTE — Reinforced concrete monolithic slab-beam floors or those consisting of prefabricated/precast elements such as solid slabs, hollow core slabs or double tees with reinforced topping shall satisfy the requirements of 7.10.10. In all cases, the precast elements need not be considered as part of the diaphragm except solid slabs with proper connectivity. The gravity load design, however, shall be composite including the structural topping as well as the precast element provided the interface shear at the topping and element face is analysed and designed for the same.

7.10.4 *Rigid Diaphragms*

A diaphragm is classified as rigid if it can distribute the horizontal forces to the vertical components in proportion to their relative stiffness. Diaphragms of concrete slabs of concrete-filled metal deck with span-to-depth ratios of 3 or less in structures that have no horizontal irregularities are permitted to be idealized as rigid. The minimum thickness of structural topping concrete shall be as per 7.10.10.

Where the diaphragm is very stiff compared to the vertical elements, as in a low aspect ratio, cast-in-place diaphragm supported by moment frames, it is acceptable to model the diaphragm as a completely rigid element.

7.10.5 *Flexible Diaphragms*

A floor diaphragm shall be considered to be flexible, if it deforms such that the maximum lateral displacement measured from the chord of the deformed shape at any point of the diaphragm is more than 1.5 times the average displacement of the entire diaphragm or as per good practice [C-7(18)] and **5** of Part C 'Structural Design, Section 1 Loads and Load Effects' of this NBCS. Flexible diaphragm can be adopted in modular structures having frequent openings such as substation, electrical rooms, industrial structures, etc.

7.10.5.1 Where the diaphragm is flexible compared with the vertical elements, as in some jointed precast systems supported by structural walls, it may be acceptable to model the diaphragm as a flexible beam spanning between rigid supports.

7.10.5.2 In other cases, it may be advisable to adopt a more detailed analytical model to account for the effects of diaphragm flexibility on the distribution of displacements and forces. Examples include buildings in which diaphragm and vertical element stiffness have approximately the same value, buildings with large force transfers, and parking structures in which ramps connect between floors and act essentially as bracing elements within the building.

7.10.6 *Topped Diaphragms*

Topped floor and roof diaphragms include systems with in-situ concrete slab over precast RC planks and joists. The in-situ concrete slab is considered to act composite with the precast RC planks with sufficient surface roughness to transfer horizontal shear, so that the flexural strength of the precast component is enhanced by the added structural depth of the in-situ slab.

> NOTE — In the computational model of the structure, the diaphragm shall be modelled considering the thickness of the topping/structural topping with extra dead load applied on top of the diaphragm to consider the precast planks or elements.

7.10.7 *In-plane Diaphragm Design Loads and Forces*

Topped floor and roof diaphragms shall be designed to resist design in-plane inertial forces due to earthquake forces and wind loads from the structural analysis. Earthquake forces shall be calculated in accordance with good practices [C-7(1)] and [C-7(20)] and **5** of Part C 'Structural design/Section 1 Loads and load effects' of this NBCS. Wind loads shall be estimated in accordance with Part C 'Structural design/Section 1 Loads and load effects' of this NBCS.

7.10.8 *Standard Analysis Methods for Diaphragm Design*

7.10.8.1 The magnitude of the inertia force at each floor level is estimated using a capacity design approach or a diaphragm design force distribution based on equivalent lateral loads. A key design step is to transform the diaphragm design forces into internal actions. For regular floor plans, a 'horizontal plate girder' analogy is typically used in design. In this approach, diaphragm design forces are typically applied at each level as a distributed in-plane load along the length of the diaphragm. The resulting girder internal forces are used to determine the amount of flexural reinforcement (chord steel), shear (web) reinforcement, and lateral system reaction load path reinforcement (collector steel). An irregular mass distribution in plan may require the design forces to take on a smeared load configuration as the mass distribution with respect to diaphragm depth has relevance in determining the proper web reinforcement. For more complex diaphragm configurations, a strut-and-tie method can be used. The strut-and-tie method accurately predicts the behaviour of floor diaphragms, in general, and may become the preferred method of diaphragm analysis (*see* Fig. 15 and Fig. 16).

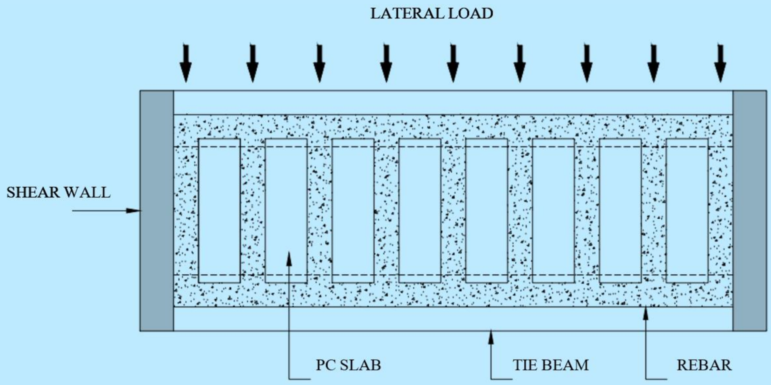
7.10.8.2 Calculation of diaphragm in-plane design moments, shears and axial forces shall be consistent with requirements of equilibrium and with design boundary conditions. It shall be permitted to calculate design moments, shears, and axial forces in accordance with one of (a) through (d):

a) A rigid diaphragm model if the diaphragm can be idealized as rigid;

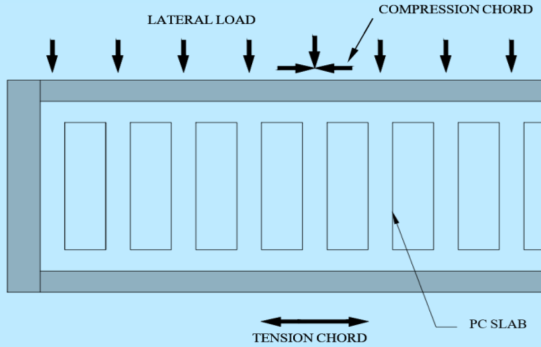
b) A flexible diaphragm model if the diaphragm can be idealized as flexible;

c) A bounding analysis in which the design values are the envelope of values obtained by assuming upper bound and lower bound in-plane stiffness for the diaphragm in two or more separate analyses; and

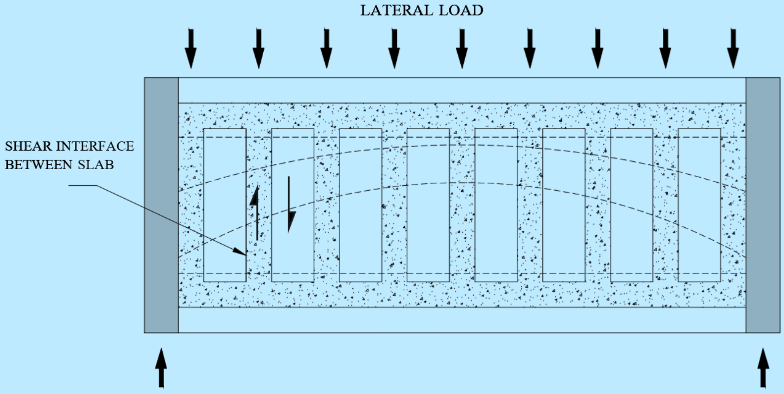
d) A finite element model considering diaphragm flexibility (semi rigid).



15A DIAGONAL TRUSS



15B VIERENDEEL GIRDER



15C DEEP HORIZONTAL BEAM

FIG. 15 STRUCTURAL MODELS FOR FLOOR DIAPHRAGMS

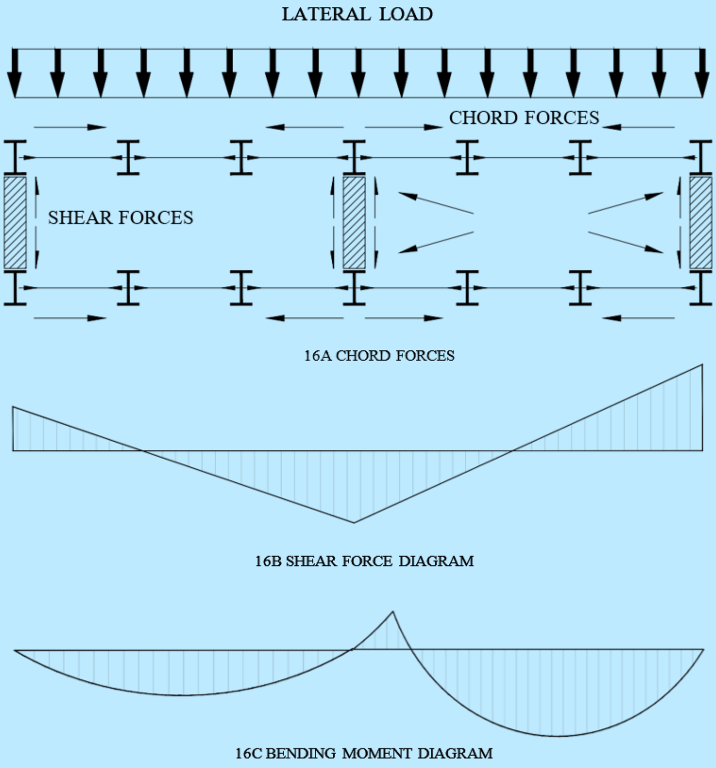


FIG. 16 DESIGN FORCES ON A DIAPHRAGM

7.10.9 *Materials*

7.10.9.1 Design properties of in-situ concrete for the topped diaphragms and diaphragm reinforcement shall be considered as per Part C 'Structural Design, Section 5 Structural Concrete' of this NBCS.

7.10.9.2 Minimum grade of structural topping concrete shall be 40 MPa or as per design (whichever is higher).

7.10.10 *Minimum thickness of topped diaphragms*

7.10.10.1 Topped floor and roof diaphragms shall have thickness as required for stability, strength and stiffness under factored load combinations.

7.10.10.2 Topped floor and roof diaphragms that comprises RC planks composite with in-situ concrete slabs, the full thickness of the entire diaphragm must be sufficient to resist the design actions. In system with special precast slab elements such as hollow core slabs or double tees, the diaphragm thickness shall be limited to the in-situ structural topping concrete.

7.10.10.3 The minimum thickness of in-situ structural topping concrete shall be as per 6.3.6.1.

7.10.11 *Diaphragm Connections*

Connections between individual precast RC planks shall not be designed for any diaphragm forces in a topped diaphragm where the diaphragm thickness is limited to cast-in-place structural topping only. Nominal connections required to facilitate the vertical alignment of the RC planks and flanges shall be provided.

7.10.12 *Opening and Voids in the In-situ Concrete Topping Slab*

The effects of openings and voids in the in-situ concrete topping slab shall be considered in the diaphragm design. Detailing around the openings and voids must be done in accordance with Part C 'Structural Design, Section 5 Structural Concrete' of this NBCS.

7.10.13 *Collectors*

7.10.13.1 Collectors shall extend from the vertical elements of the lateral-force-resisting system across all or part of the diaphragm depth as required to transfer shear from the diaphragm to the vertical element (as shown in Fig. 17). It shall be permitted to discontinue a collector along lengths of vertical elements of the lateral-force-resisting system where transfer of design collector forces is not required.

7.10.13.2 Collectors shall be designed as tension members, compression members, or both, in accordance with the criteria for axial member in Part C 'Structural Design, Section 5 Structural Concrete' of this NBCS.

7.10.13.3 Where a collector is designed to transfer forces to a vertical element, collector reinforcement shall extend along the vertical element to at least the greater of (a) and (b):

a) The length required to develop the reinforcement in tension; and

b) The length required to transmit the design forces to the vertical element through shear-friction in accordance with 7.12, through mechanical connectors, or through other force transfer mechanisms.

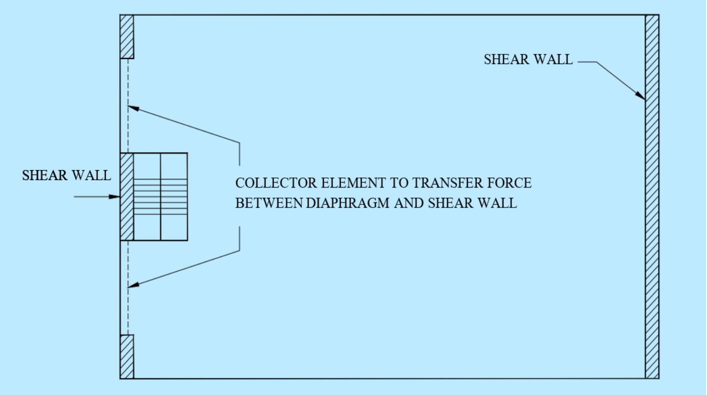

SHEAR WALL
SHEAR WALL
COLLECTOR ELEMENT TO TRANSFER FORCE
BETWEEN DIAPHRAGM AND SHEAR WALL

FIG. 17 COLLECTORS BETWEEN FRAMING ELEMENTS

7.10.14 *Reinforcement Limits*

7.10.14.1 Reinforcement to resist shrinkage and temperature stresses shall be estimated according to relevant clauses of Part C 'Structural Design, Section 5 Structural Concrete' of this NBCS.

7.10.14.2 Reinforcement designed to resist diaphragm in-plane forces shall be in addition to reinforcement designed to resist other load effects, except that reinforcement designed to resist shrinkage and temperature effects shall be permitted to also resist the diaphragm in-plane forces.

7.10.15 *Reinforcement Detailing*

7.10.15.1 Concrete cover for reinforcement shall be in accordance with good practice [C-7(2)].

7.10.15.2 Development lengths of deformed and prestressed reinforcement shall be in accordance with good practice [C-7(2)] and [C-7(3)], respectively, unless longer lengths are required by high seismic zone requirements.

7.10.15.3 Splices of deformed reinforcement shall be in accordance with Part C 'Structural Design, Section 5 Structural Concrete' of this NBCS.

7.10.15.4 Bundled bars shall be in accordance with Part C 'Structural Design, Section 5 Structural Concrete' of this NBCS.

7.10.16 *Reinforcement Spacing*

7.10.16.1 Minimum spacing of reinforcement shall be in accordance with Part C 'Structural Design, Section 5 Structural Concrete' of this NBCS.

7.10.16.2 Maximum spacing of deformed reinforcement shall be the lesser of five times the diaphragm thickness and 450 mm.

7.10.17 *Diaphragm and Collector Reinforcement*

7.10.17.1 Tensile or compressive force in reinforcement at each section of the diaphragm or collector shall be developed on each side of that section.

7.10.17.2 Reinforcement provided to resist tension shall extend beyond the point at which it is no longer required to resist tension for at least a length of L_d, except at diaphragm edges and at expansion joints.

7.10.17.3 Welded wire mesh of diameter 6 mm or higher shall be used in the structural topping concrete to achieve the diaphragm reinforcement.

7.10.18 *Other Parameters*

7.10.18.1 Heavy duty PVC or metal conduits with diameter up to 20 mm are preferable. Larger diameter conduits (25 mm or 32 mm or higher) may be permitted as per project requirements with proportionately higher thickness of structural topping.

7.10.18.2 Single junction box shall be used to conduct the conduits.

7.11 Designing of Bearing Region

7.11.1 *General*

The bearing region shall ensure structural integrity through the following measures:

a) Overlapping reinforcement in reinforced bearing zones;

b) Physical restraint to prevent loss of bearing due to movement; and

c) Tolerance provisions to accommodate cumulative deviations due to production and erection.

7.11.2 *Net Bearing Width of Non-Isolated Members*

The net bearing width of a member shall not be less than 40 mm and shall be determined by:

$$\text{Net bearing width} = \frac{\text{ultimate support reaction}}{\text{effective bearing length} \times \text{ultimate bearing stress}}$$

The net bearing width should be increased to cater for any free movement permitted or rotation of the bearing about the support.

7.11.3 *Effective Bearing Length*

The effective bearing length of a member shall be taken as the least of:

a) Actual bearing length;

b) One-half of bearing length plus 100 mm; or

c) 600 mm.

7.11.4 *Design Ultimate Bearing Stress*

The design ultimate bearing stress shall be based on the weaker bearing surface and shall be:

a) $0.4f_{ck}$ for dry concrete bearings;

b) $0.6f_{ck}$ for mortar-bedded concrete bearings; or

c) $0.8f_{ck}$ for steel bearing plates embedded in concrete, provided the plate dimensions do not exceed 40 percent of the supporting concrete dimension.

An intermediate value of bearing stress between dry and bedded bearings may be used for flexible bedding.

7.11.5 *Net Bearing Width of Isolated Members*

For isolated members, the net bearing width shall be increased by 20 mm over that required for non-isolated members.

7.11.6 *Minimum Dimensions of Bearing*

The minimum requirement for bearing length shall be as per Fig. 18.

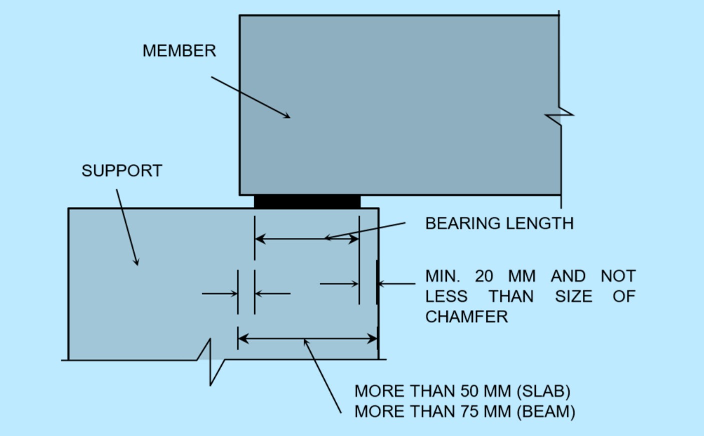
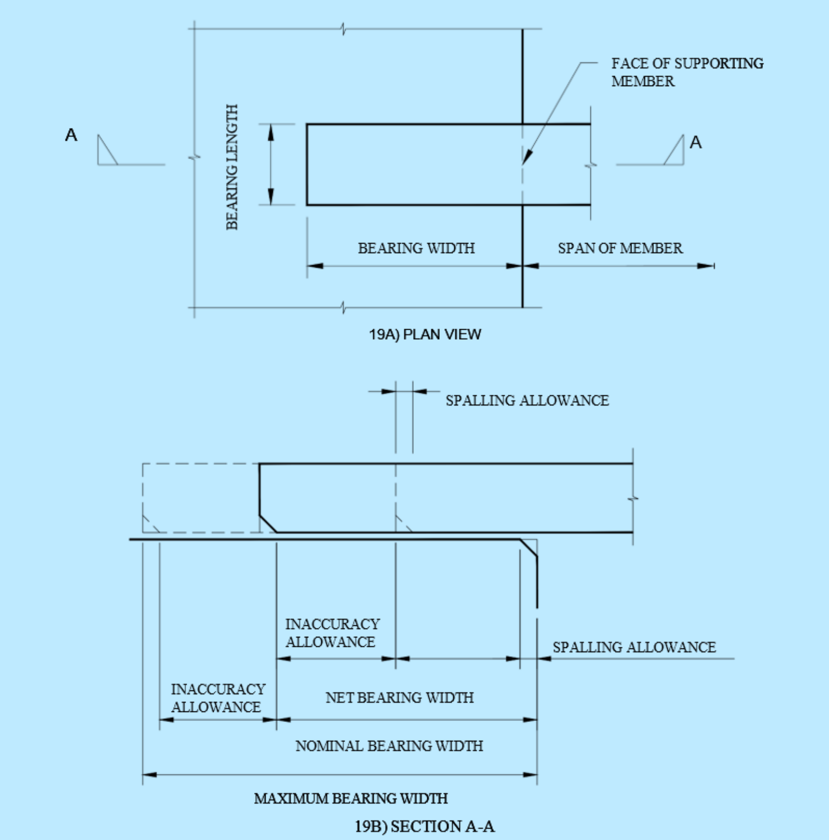

MEMBER
SUPPORT
BEARING LENGTH
MIN. 20 MM AND NOT LESS THAN SIZE OF CHAMFER
MORE THAN 50 MM (SLAB)
MORE THAN 75 MM (BEAM)

FIG. 18 BEARING LENGTH ON SUPPORT

7.11.7 *Detailing for Simple Bearing*

Over and above the net bearing width calculated above, allowances for spalling and constructional inaccuracies should be made in the nominal width selected (*see* Fig. 19). The effects of accidental displacement of a supported member during erection shall also be considered. Minimum anchorage lengths shall comply with requirements specified in **9**.


FACE OF SUPPORTING MEMBER
A
A
BEARING LENGTH
BEARING WIDTH
SPAN OF MEMBER
SPALLING ALLOWANCE
INACCURACY ALLOWANCE
SPALLING ALLOWANCE
INACCURACY ALLOWANCE
NET BEARING WIDTH
NOMINAL BEARING WIDTH
MAXIMUM BEARING WIDTH

19A) PLAN VIEW

19B) SECTION A-A

FIG. 19 SCHEMATIC ARRANGEMENT OF ALLOWANCES FOR BEARING

7.11.8 *Allowances for Spalling at Supports*

The design shall account for reduction in effective bearing area due to potential spalling, in accordance with Table 3 and Table 4. When determining the outer edge of a support or the end of a supported member, chamfers occurring within the areas subjected to spalling may be excluded.

Table 3 Allowances for Effects of Spalling at Supports

(*Clause* 7.11.8)

Sl No. (1)	**Material of Support** (2)	**Ineffective Distance, Measured from Outer Edge of Support** mm (3)
i)	Steel	0
ii)	Concrete ≥ M30	15
iii)	Concrete < M30	25
iv)	RC with outer edge less than 300 mm deep and vertical loop bar not greater than 12 mm	Nominal cover to reinforcement on outer face of support
v)	RC with outer edge less than 300 mm deep and vertical loop bar is 16 mm or above	Nominal cover plus inner radius of bend of bars

Table 4 Allowances for Effects of Spalling at Supported Members

(*Clause* 7.11.8)

Sl No. (1)	**Reinforcement at Bearing of Support Member** (2)	**Ineffective Distance, Measured from Outer Edge of Support** mm (3)
i)	Straight bar, horizontal loops or vertical loops of 12 mm diameter or less	Greater of nominal cover or 10 mm
ii)	Tendons or straight bars exposed at end of member	0
iii)	Vertical loops of 16 mm diameter or above	Nominal end cover plus inner radius of bend of bars

7.11.9 *Shims*

Plastic or metal shims shall be used as per structural and durability requirements and shall be specified as per design requirements.

7.11.9.1 Steel shims shall not be used at areas susceptible to spalling. Load transfer through shims shall be included in the structural design.

7.11.9.2 The total thickness of individual shims shall not exceed 40 mm.

7.11.9.3 For joint gaps exceeding 40 mm, steel shims shall be used and shall be tack welded when shim thickness exceeds 40 mm to ensure load transfer and stability. Minimum thickness of shim plates shall be 5 mm.

7.11.10 *Allowance for Construction Inaccuracies*

The design shall include allowances for construction inaccuracies due to deviations in layout, manufacturing and erection. In absence of statistical deviation data, the minimum allowances shall be:

a) 15 mm or 3 mm/m for steel or precast concrete supports;

b) 20 mm or 4 mm/m for masonry supports; and

c) 25 mm or 5 mm/m for in-situ concrete supports.

7.11.11 *Bearings Transmitting Compressive Forces*

The horizontal joints between load-bearing walls or columns shall be designed to resist all the forces and moments implicit in the assumptions made in analysing the structure as a whole and in designing the individual member to be joined. In the absence of more accurate information derived from a comprehensive programme of suitable tests, the area of concrete to be considered in calculating the strength of the joint in a wall or column shall be as per 8.3.2. Joints and joint reinforcement shall be detailed to prevent premature splitting or spalling at member ends.

7.11.12 *Other Forces at Bearings*

a) *Horizontal forces at bearing* — The horizontal forces at bearings may be induced by creep, shrinkage, temperature effects, misalignment, lack of plumb or other causes. When these forces are significant, the structural capacity of the supporting member may be impaired. A minimal force of 0.2 V_u (vertical or shear force on the bearing) shall be used in design. Allowances should be made by the provision of:

   1) Sliding bearings which allow longitudinal and lateral movement;

   2) Additional lateral reinforcement at the top of the supporting member; or

   3) Continuity reinforcement which ties the ends of the supported members together.

b) *Rotation at bearing* — Suitable bearings should be used to accommodate the rotations at end supports in particular for flexural members. Allowances should be made for any consequential increases in bending moments or bearing stresses due to rotations.

7.11.13 *Design of Bearing on Plain Concrete*

7.11.13.1 Plain concrete bearing (*see* Fig. 20) shall be used in situations where the bearing is uniform and the bearing stresses are low.

7.11.13.2 In other situations, and in thin-stemmed components where the bearing area is less than 12 500 mm^2, a minimum reinforcement equal to $N_u/0.65f_y$ (but not less than one bar of 10 mm diameter) is recommended. If horizontal load is not present, a minimum recommended value of $N_u = 0.2\ V_u$ shall be used.

where

N_u = factored axial force (minimum shall be 0.2 V_u); and

V_u = factored shear force.

7.11.13.3 The design bearing strength of plain concrete shall be calculated based on the following equation as given below:

Supporting area is wider in all sides than the loaded area (lesser of)

$$V_{uR} = (0.45 f_{ck} A_1)\sqrt{\frac{A_2}{A_1}}$$

$\sqrt{\frac{A_2}{A_1}}$ shall not exceed 2,

$$V_{uR} = 2(0.45 f_{ck} A_1)$$

Other cases

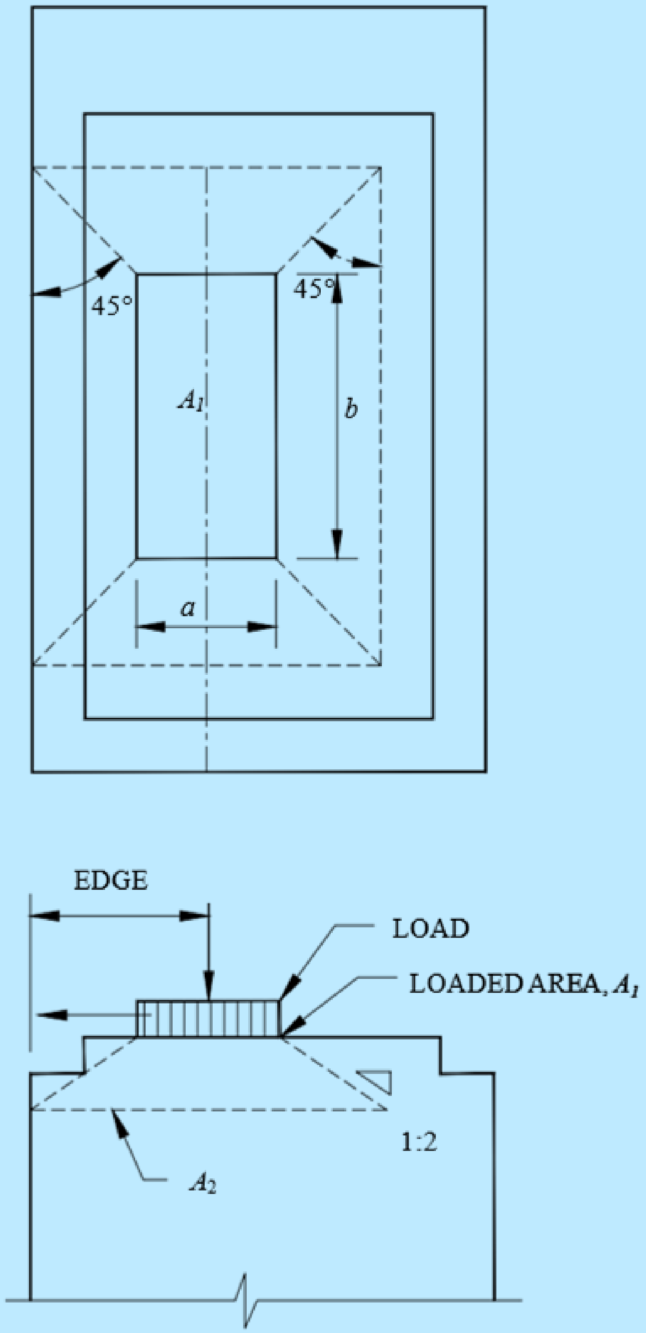
$$V_{uR} = 0.45 f_{ck} A_1$$

where

V_{uR} = design shear resistance;

A_1 = loaded area (bearing constant area) (*see* Fig. 20); and

A_2 = area of the lower base of pyramid, cone or tapered wedge (*see* Fig. 20).



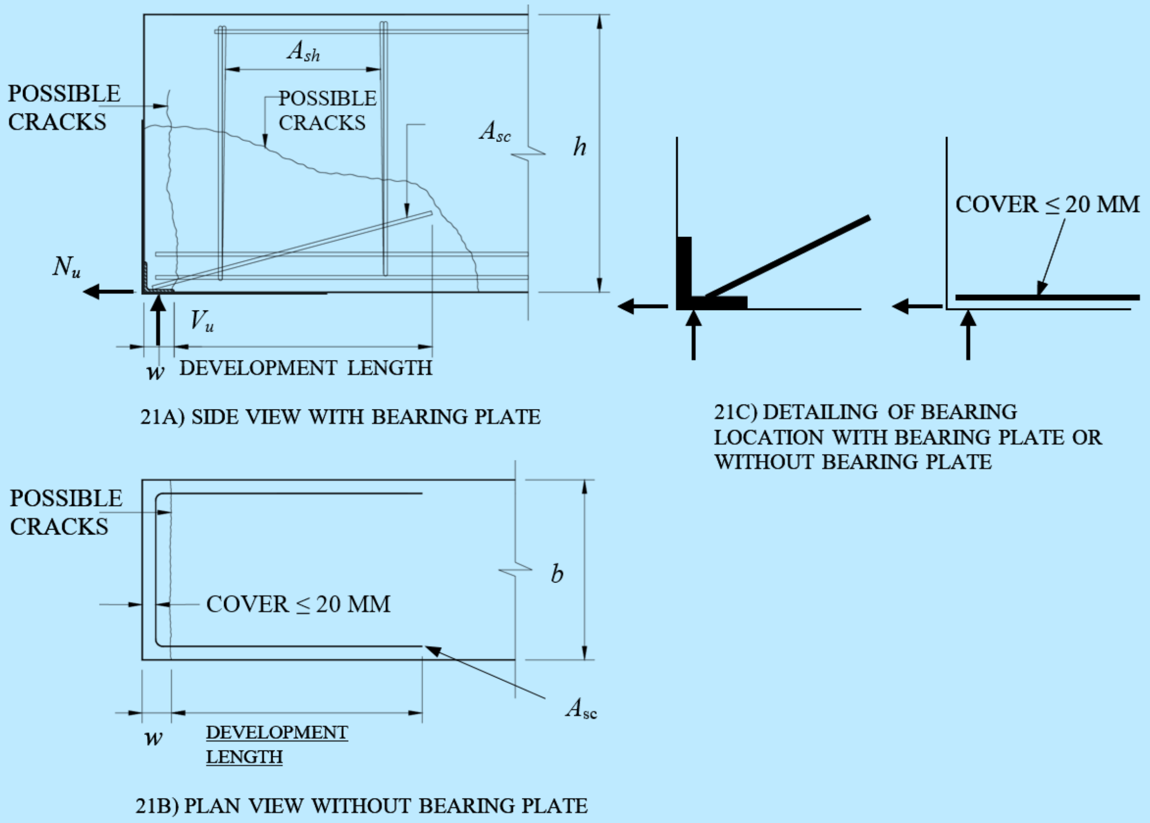
A_1 = LOADED AREA (BEARING CONTACT AREA)
A_2 = AREA OF THE LOWER BASE OF PYRAMID, CONE OR TAPERED WEDGE

FIG. 20 BEARING ON PLAIN CONCRETE

7.11.14 *Design of Reinforced Concrete Bearing* (*for thin Stem Elements and Rectangular Beams*)

7.11.14.1 If the applied load V_u, exceeds the design bearing strength V_{uR}, as calculated by equation in 7.11.13.3, reinforcement shall be provided in the bearing area as per Fig. 21.

7.11.14.2 The area of reinforcement $A_{vf} + A_n$ shall be calculated as per 7.12 and 7.11.16. This reinforcement shall be appropriately developed on each side of the vertical crack by development length, hooks, or welding to an anchor bar, bearing plate, or angle.



21A) SIDE VIEW WITH BEARING PLATE

21C) DETAILING OF BEARING LOCATION WITH BEARING PLATE OR WITHOUT BEARING PLATE

21B) PLAN VIEW WITHOUT BEARING PLATE

FIG. 21 REINFORCED CONCRETE BEARING

7.11.14.3 The area of vertical shear reinforcement shall be calculated as follows:

$$A_{sh} = \frac{(A_{vf} + A_n)f_y}{\mu f_{ys}}$$

where

A_{vf} = area of shear friction reinforcement;

A_n = area of tension reinforcement;

f_y = yield strength of tension reinforcement;

μ = coefficient of friction as per Table 6; and

f_{ys} = yield strength of shear reinforcement.

7.11.14.4 Diagonal tension reinforcement such as stirrups or welded-wire mesh may be counted as A_{sh} but shall not be added to separately designed shear reinforcement.

7.11.14.5 When components are subjected to bearing force more than $0.45f_{ck}A_1$ confinement reinforcement in all directions shall be provided. A_1 shall be considered as per Fig. 20.

7.11.15 *Dapped End Bearing* (*Thin Stem and Regular Beams*)

7.11.15.1 Dapped end members shall be designed for the potential failure modes shown in Fig. 22 to Fig. 24 with the reinforcement required for each consideration.

7.11.15.2 Dap reinforcement shall be provided in all cases where one or more of the following conditions:

a) The depth of the recess exceeds the lesser of 0.2 H or 200 mm;

b) The length of the recess (L_p in Fig. 22) exceeds 300 mm for non-thin-stemmed components and the nib (the concrete section above the dap) is not designed for the full flexural and shear capacity; and

c) For non-thin-stemmed components, less than 1/3 of the main flexural reinforcement extends to the end of the component above the dap.

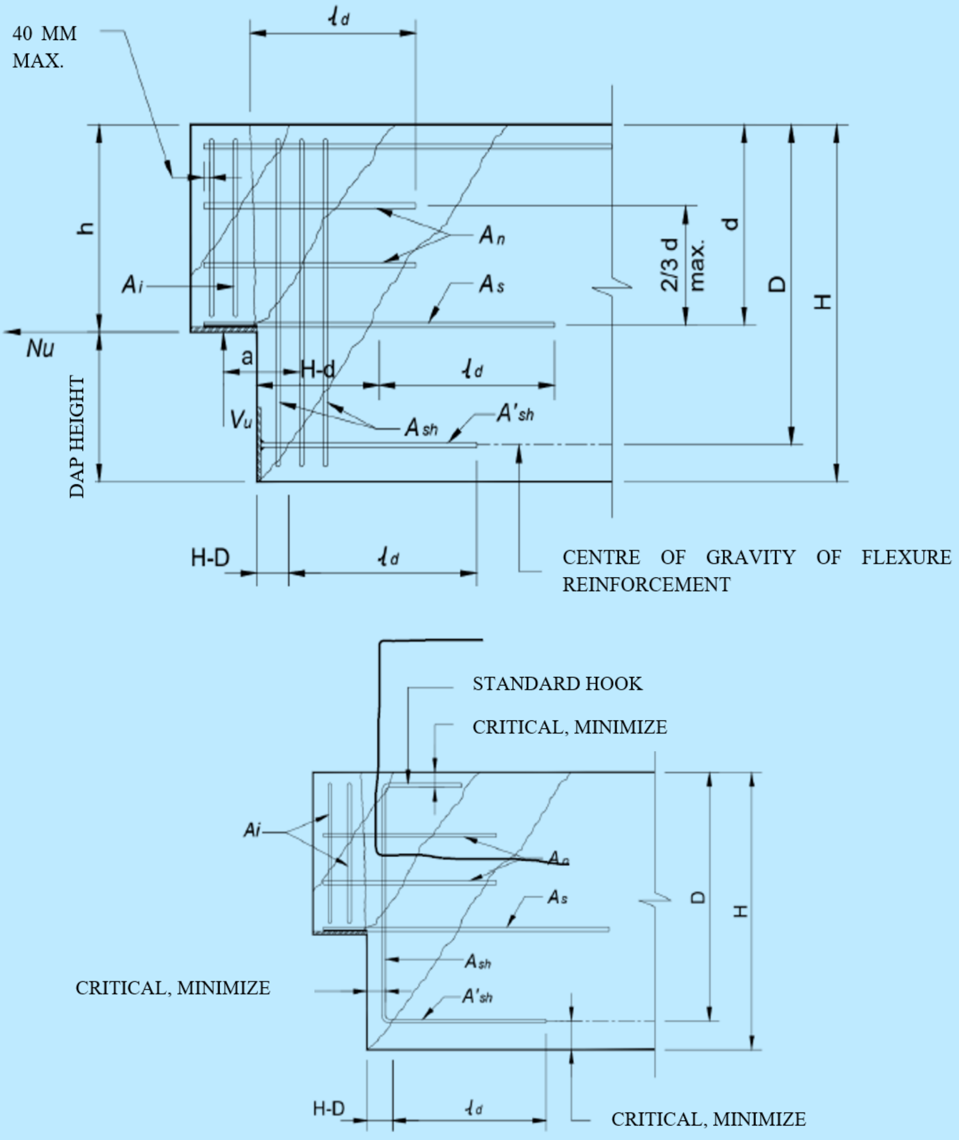
7.11.15.3 Thin-stemmed components such as double tees, T beam, etc, shall be designed with the following additional consideration:

a) Stem width is 125 mm or less;

b) Vertical hanger reinforcement or inclined reinforcement at an angle greater than 90° measured from horizontal; and

c) Dap height ≤ 0.5 h.

7.11.15.4 The design equations given in this section shall be considered for cases where shear span-to-depth ratio (a_v/d) do not exceed 1.0.



40 MM
MAX.
ℓ_d
h
A_i
A_n
A_s
2/3 d
max.
d
D
H
N_u
a
H-d
ℓ_d
V_u
A_{sh}
A'_{sh}
DAP HEIGHT
H-D
ℓ_d
CENTRE OF GRAVITY OF FLEXURE REINFORCEMENT
STANDARD HOOK
CRITICAL, MINIMIZE
Ai
A_n
A_s
D
H
A_{sh}
CRITICAL, MINIMIZE
A'_{sh}
H-D
ℓ_d
CRITICAL, MINIMIZE

Fig. 22 Potential Failure Modes and Required Reinforcement in Non-Thin Stemmed Dapped Ends

7.11.15.5 High strength rebars may be used, however, the yield strength of reinforcement shall be restricted to 415 MPa.

7.11.15.6 For short, shallow recesses, the hanger reinforcement A_{sh}, and A'_{sh}, shall not be necessary. Confinement reinforcement A_v and flexural reinforcement $A_{vf} + A_n$, in accordance with 7.11.14 shall be provided.

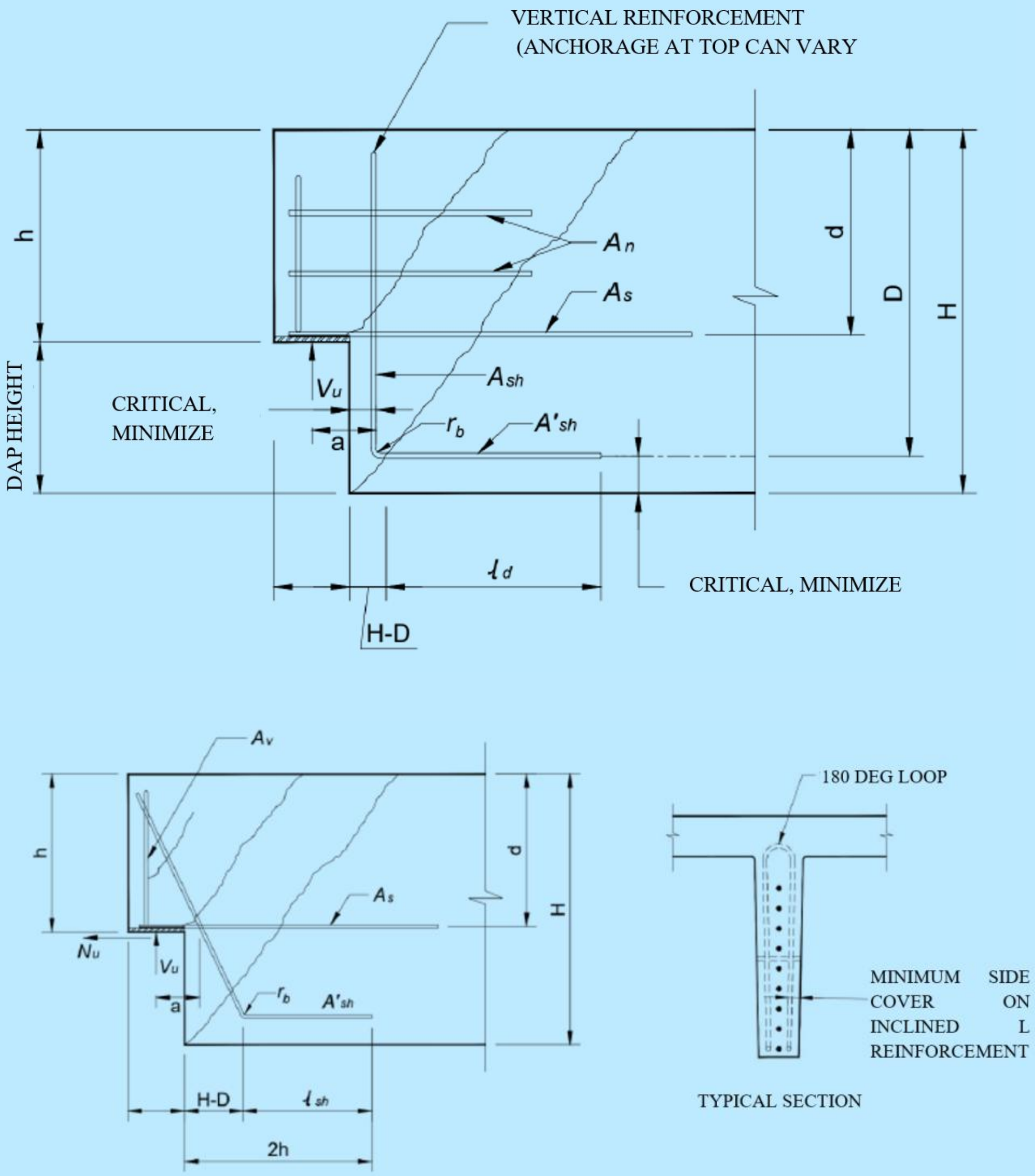
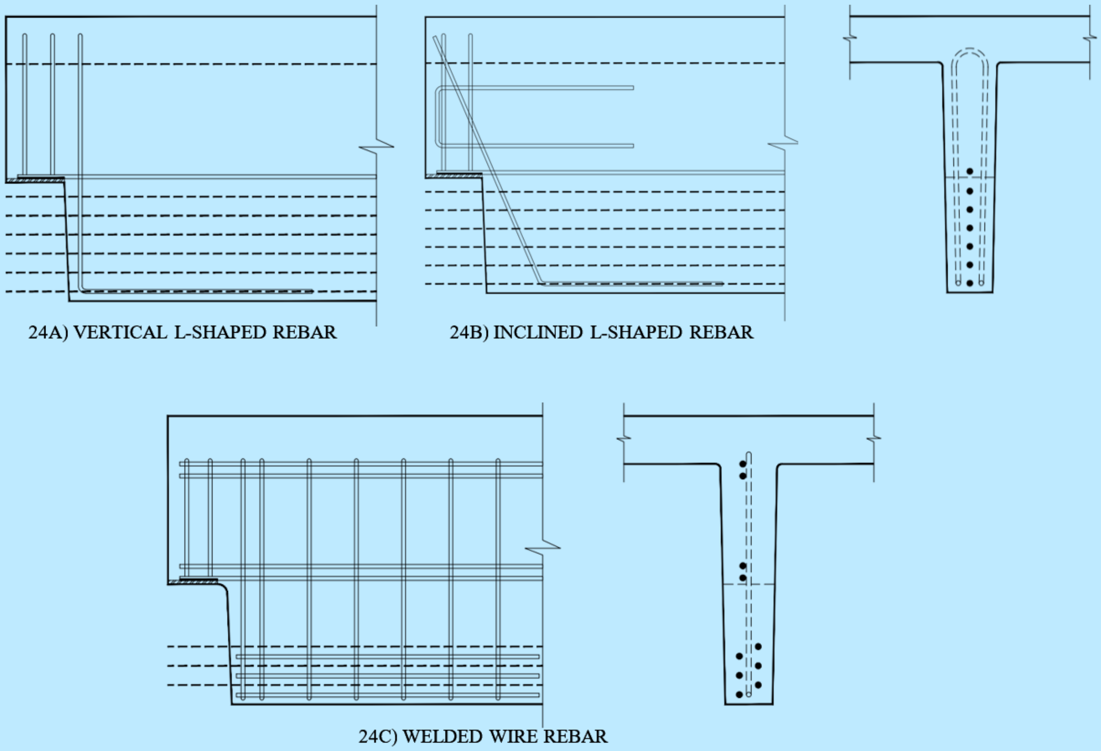

VERTICAL REINFORCEMENT
(ANCHORAGE AT TOP CAN VARY
h
DAP HEIGHT
CRITICAL,
MINIMIZE
An
As
Ash
A'sh
rb
Vu
a
d
D
H
ld
H-D
CRITICAL, MINIMIZE
Av
As
Nu
Vu
a
rb
A'sh
h
d
H
H-D
lsh
2h
180 DEG LOOP
MINIMUM SIDE COVER ON INCLINED L REINFORCEMENT
TYPICAL SECTION

FIG. 23 POTENTIAL FAILURE MODES AND REQUIRED REINFORCEMENT IN THIN-STEMMED DAPPED ENDS



24A) VERTICAL L-SHAPED REBAR

24B) INCLINED L-SHAPED REBAR

24C) WELDED WIRE REBAR

FIG. 24 CONFIGURATION OF DAP REINFORCEMENT FOR THIN-STEMMED DAPPED ENDS

7.11.15.7 The area of horizontal reinforcement A_s (area of reinforcement for flexure and axial tension in the extended end) shall be the larger of the two values calculated using the equations given below. The values of A_f, A_n shall be calculated as per 7.11.17 and A_{vf} is as defined under 7.12:

$$A_s = A_f + A_n \text{ , or}$$

$$A_s = \frac{2}{3} A_{vf} + A_n$$

7.11.15.8 The area of horizontal reinforcement A_h (area of direct shear reinforcement) shall be provided in the nib to arrest Crack 2 as per the following and shall be distributed within 2/3 d measured from the primary tension reinforcement A_s:

$$A_h = 0.5(A_s - A_n)$$

7.11.15.9 The area of hanger reinforcement A_{sh} shall be provided to arrest Crack 3, shall be as per the following:

$$A_{sh} = \frac{V_u}{0.75 f_y}$$

7.11.15.10 The area of vertical shear reinforcement A_v shall be provided to arrest Crack 4 as per the following:

$$V_{uR} = 0.75(A_v f_y + A_h f_y + 0.15\sqrt{f_{ck}} bd)$$

$$\text{Minimum } A_v = \frac{1}{2f_y}(1.34V_u - 0.15\sqrt{f_{ck}} bd)$$

7.11.15.11 The anchorage of reinforcement shall be as per the following:

a) Horizontal bars A_s shall be extended a minimum of L_d beyond Crack 5 and anchored at the end of the component by welding to cross bars, plates, or angles;

b) Horizontal bars A_h shall be extended a minimum of L_d, beyond Crack 2 and anchored at the end of the component by hooks or other suitable means;

c) To ensure development of hanger reinforcement A_{sh}, the rebar shall be bent and continued parallel to the bottom of the component, or a separate horizontal anchored reinforcement with $A'_{sh} \geq A_{sh}$ shall be provided. The extension of reinforcement (A'_{sh}) at bottom of the component must be at least L_d beyond Crack 5. The A'_{sh}, reinforcement may be anchored on the dap side by welding it to a plate, angle, or cross bar;

d) The beam flexure reinforcement may also be used to ensure development of A_{sh} reinforcement, provided that the flexural reinforcement is adequately anchored on the dap side and the A_{sh} reinforcement is wrapped around the flexural reinforcement;

e) In thin-stemmed components, it is recommended that the extension of the hanger reinforcement be greater than L_d. A'_{sh} shall extend a distance that is the greater of 1.5 L_d of the strand past the face of the dap or 2.0 L_d of A'_{sh} beyond the diagonal Crack 5;

f) Vertical reinforcement A_v should be properly anchored by hooks, as required by Part C/Section 5 of this NBCS;

g) Thin-stemmed components, except for the vertical 'Z' configuration, which has the bar welded to the plate, should have at least one 12 mm diameter rebar welded to the bearing plate or have equivalent development length (L-rebar); and

h) Welded-wire reinforcement in place of bars may be used for reinforcement. It should be anchored in accordance with Part C 'Structural Design, Section 5 Structural Concrete' of this NBCS. In thin-stemmed components the use of welded-wire reinforcement should be limited to situations where it is placed symmetrically in the width of the stem.

7.11.15.12 *Other considerations*

In addition to the reinforcement for the dapped end, it is important that the following be considered:

a) The depth of the extended end should not be less than about one half the depth of the beam, unless the beam is deeper than necessary for other than structural reasons;

b) The hanger reinforcement A_{sh} should be placed as close as practical to the re-entrant corner and as symmetrically as possible around the centroid of the section being considered. This reinforcement requirement is not additive to other shear-reinforcement requirements but should be in addition to torsion reinforcement;

c) The shear strength of the full-depth beam behind the dap must be verified;

d) For thin-stemmed components, for a distance of $2H$ beyond the dap the concrete contribution to shear strength should be limited to:

$$V_c = 0.15\sqrt{f_{ck}}b_w d_p$$

or

$$V_c = 0.23\sqrt{f_{ck}}b_w d_p, \text{ where at least two bonded strands in the extended end are present}$$

where

b_w = average width of the stem for the full depth of the section; and

d_p = distance from the top to the centroid of the prestressing strand for the full depth section and shall not be less than 0.8 H.

e) For thin-stemmed components, for a distance 2 H beyond the dap, the reinforcement contribution to shear strength V_s shall be limited as per the following:

$$V_s = 0.15\sqrt{f_{ck}}\, b_w d_p$$

7.11.16 *Ledges*

7.11.16.1 *General*

Beam and wall ledges (as shown in Fig. 25) shall be designed as per the following guidelines. Hanger steel requirements for the ledge in a wall need not be satisfied except where penetrations occur just below ledges. The design procedure explained in this section shall be applicable for the following cases:

a) $N_u \leq V_u$;

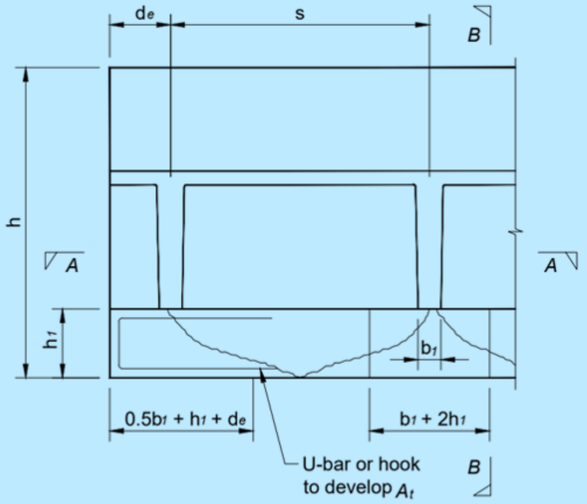
b) Ledges with heights of 200 mm to 450 mm;

c) Ledge projections of 150 mm to 250 mm;

d) Bearing widths of components on the ledge ranging from 100 mm to 300 mm;

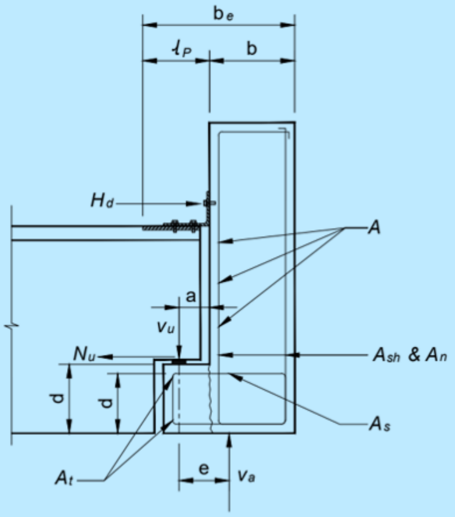
e) Distances of end load to end of ledge ranging from 100 mm to 900 mm; and

f) Design concrete compressive strengths f_{ck} of 30 MPa to 80 MPa.



ELEVATION

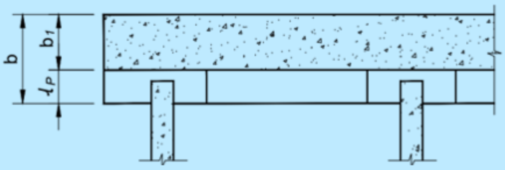
POTENTIAL SHEAR FAILURE SURFACE IN BEAM LEDGES (NOTE: FAILURE PLANE MAY OVERLAP)



SECTION B-B

EQUILIBRIUM AND CONNECTION REINFORCEMENT OF LEDGER BEAM

(NOTE: REINFORCEMENT REQUIRED FOR FLEXURE AND INTERNAL TENSIONS NOT SHOWN)



ASYMMETRIC SYMMETRIC

SECTION A-A

FIG. 25 DESIGN OF BEAM LEDGES

7.11.16.2 For shear strength of ledge for concentrated loads, not near the ends, where $d_e \geq 0.5\ b_t + h_l + l_p$, a symmetric failure controls the design punching shear strength of the ledge shall be determined as the lesser of following two equations:

$$V_{uR} = 0.056\gamma\beta\sqrt{f_{ck}}h_l(b_t + 2h_l + 2l_p)$$

or

$$V_{uR} = 0.028\gamma\beta\sqrt{f_{ck}}h_l(b_t + 2h_l + s + 2l_p)$$

For concentrated loads that are near ends, where $d_e \leq 0.5\ b_t + h_l + l_p$, an asymmetric failure controls the design punching shear strength of the ledge and shall be as per the following:

$$V_{uR} = 0.056\gamma\beta\sqrt{f_{ck}}h_l(0.5b_t + h_l + d_e + l_p)$$

or

$$V_{uR} = 0.56\gamma\beta\sqrt{f_{ck}}h_l(0.5b_t + h_l + d_e + l_p)$$

where

γ = $\sqrt{1 + 12.5\frac{f_{pc}}{f_{ck}}}$, a factor for the effect of prestressing, 1 for precast beams;

β = coefficient of shear strength based on R (as per Fig. 26);

h_l = height of beam ledge;

b_t = bearing width;

l_p = length of ledge projection;

s = minimum spacing of concentrated loads;

d_e = distance from centre of load to the end of the ledge; and

f_{pc} = average prestress force after losses divided by gross concrete area of beam.

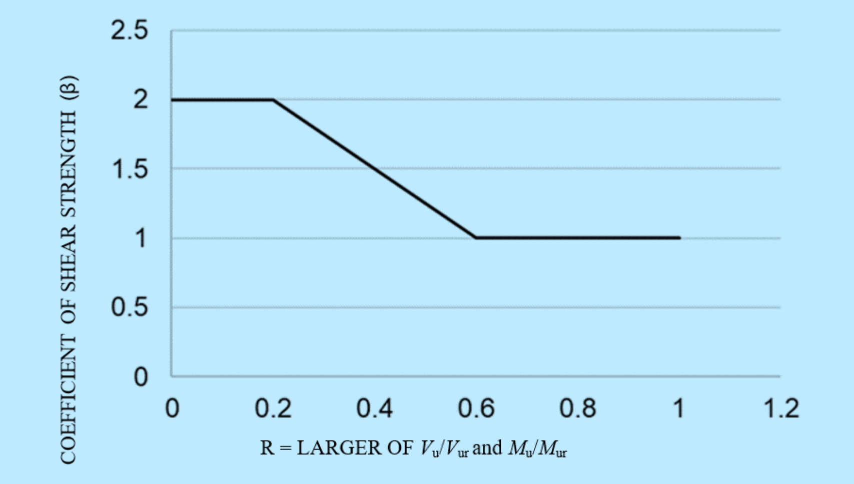


FIG. 26 COEFFICIENT OF SHEAR STRENGTH

7.11.16.4 For ledges supporting a continuous load or a series of closely spaced concentrated loads, punching shear strength per metre run shall be determined as per the following:

$$V_{uR} = 0.675\sqrt{f_{ck}}h_l$$

7.11.16.5 If the applied factored load exceeds the strength as determined above, the ledge shall be designed for shear transfer and diagonal tension in accordance with **7.11.15.8** through **7.11.15.10**.

7.11.16.6 Transverse (cantilever) bending of the ledge requires flexural reinforcement ($A_s = A_f + A_n$), shall be computed using **7.11.17.5**. Such reinforcement shall be uniformly spaced over a width of 6h_l on either side of the bearing, but not to exceed half the distance to the next load. Bar spacing shall not exceed the ledge depth h_l or 450 mm whichever is less.

7.11.16.7 Longitudinal reinforcements shall be placed in both the top and bottom of the ledge portion of the beam and calculated as per the following:

$$A_l = \frac{200 l_p d_l}{0.75 f_y}$$

where

d_l = design depth of A_l reinforcement in Fig. 25.

7.11.16.8 Hanger steel A_{sh} shall be computed using following equation and distributed in the web of the beam. The reinforcement shall be uniformly spaced over a width of 6 h_l on either side of the bearing, but shall not exceed half the distance to the next load. The area of reinforcement shall not be additive to shear and torsional reinforcement.

$$A_{sh} = \frac{Vu}{0.75 f_y}(m)$$

where

m for L beam

$$m = \frac{(d_s + a) - \left(3 - 2\frac{h_l}{h}\right)\left(\frac{h_l}{h}\right)^2 \left(\frac{b_l}{2}\right) - e\gamma_t \frac{x_l^2 y_l}{(x_l^2 y_l + x_w^2 y_w)}}{d_s} \geq 0.6, and$$

m for inverted tee-beam

$$m = \frac{\left(\frac{b}{2} + e\right) - \left(3 - 2\frac{h_l}{h}\right)\left(\frac{h_l}{h}\right)^2 \left(\frac{b}{2}\right) - e\gamma_t \frac{x_l^2 y_l}{(x_l^2 y_l + x_w^2 y_w)}}{d_s} \geq 0.4$$

where

d_S = distance from outside face of web to A_{SH} reinforcement;

b_l = width of web plus ledge being designed;

x_l, y_l, x_W, y_W, = defined in Fig. 27.

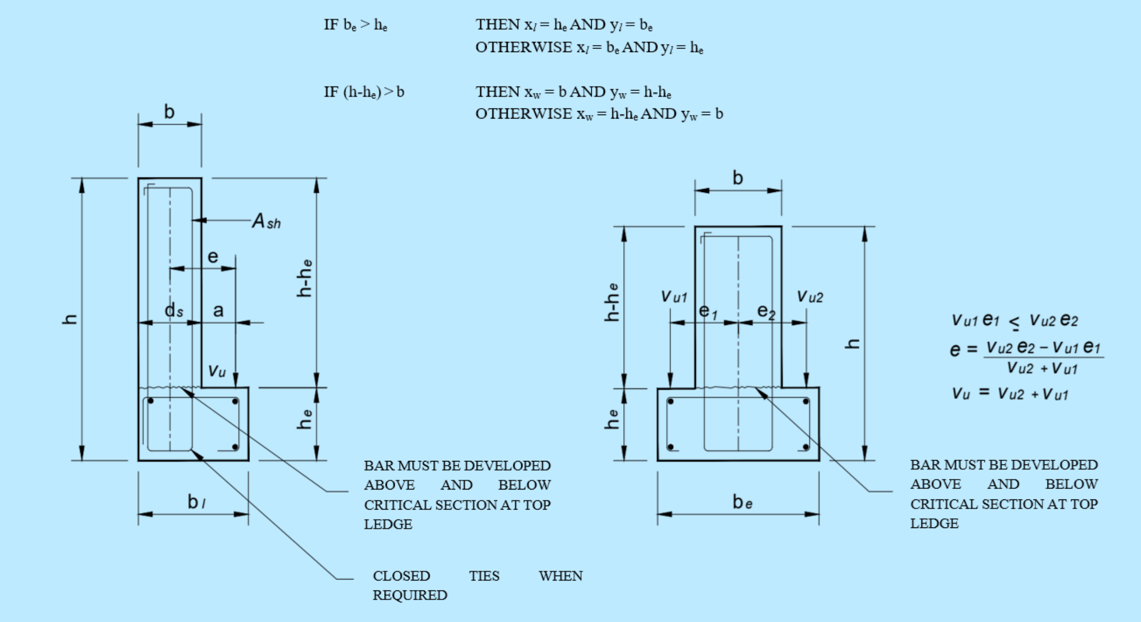

IF b_e > h_e
THEN x_l = h_e AND y_l = b_e
OTHERWISE x_l = b_e AND y_l = h_e
IF (h-h_e) > b
THEN x_w = b AND y_w = h-h_e
OTHERWISE x_w = h-h_e AND y_w = b
b
A_sh
e
h
d_s
a
h-he
V_u
he
b_l
BAR MUST BE DEVELOPED ABOVE AND BELOW CRITICAL SECTION AT TOP LEDGE
CLOSED TIES WHEN REQUIRED
b
h-he
V_u1
e_1
e_2
V_u2
h
he
b_e
V_u1 e_1 ≤ V_u2 e_2
e = (V_u2 e_2 − V_u1 e_1) / (V_u2 + V_u1)
V_u = V_u2 + V_u1
BAR MUST BE DEVELOPED ABOVE AND BELOW CRITICAL SECTION AT TOP LEDGE

FIG. 27 LEDGE HANGER STEEL GEOMETRY

7.11.17 *Concrete Corbels*

7.11.17.1 *General*

Concrete corbels are short cantilevers that support other components and transmit the load to the supporting component and tend to act as simple trusses or deep beams (*see* Fig. 28).

7.11.17.2 The design based on strut and-tie method shall be as per Part C/Section 5 of this NBCS. For steel brackets, Part C/Section 6A of this NBCS shall be referred.

7.11.17.3 The cantilever beam method of designing a corbel presented in this section shall be used according to following limitations:

a) $a_V/d \leq 1$; and

b) $N_U \leq V_U$.

7.11.17.4 The dimensions of a corbel shall be selected such that the nominal shear strength shall not exceed the strength calculated as per Table 6.

7.11.17.5 The area of primary tension reinforcement A_{sc} shall be greater of ($A_f + A_n$) and (2/3) $A_{vf} + A_n$

7.11.17.6 The area of reinforcement A_f shall be calculated as per the following equation:

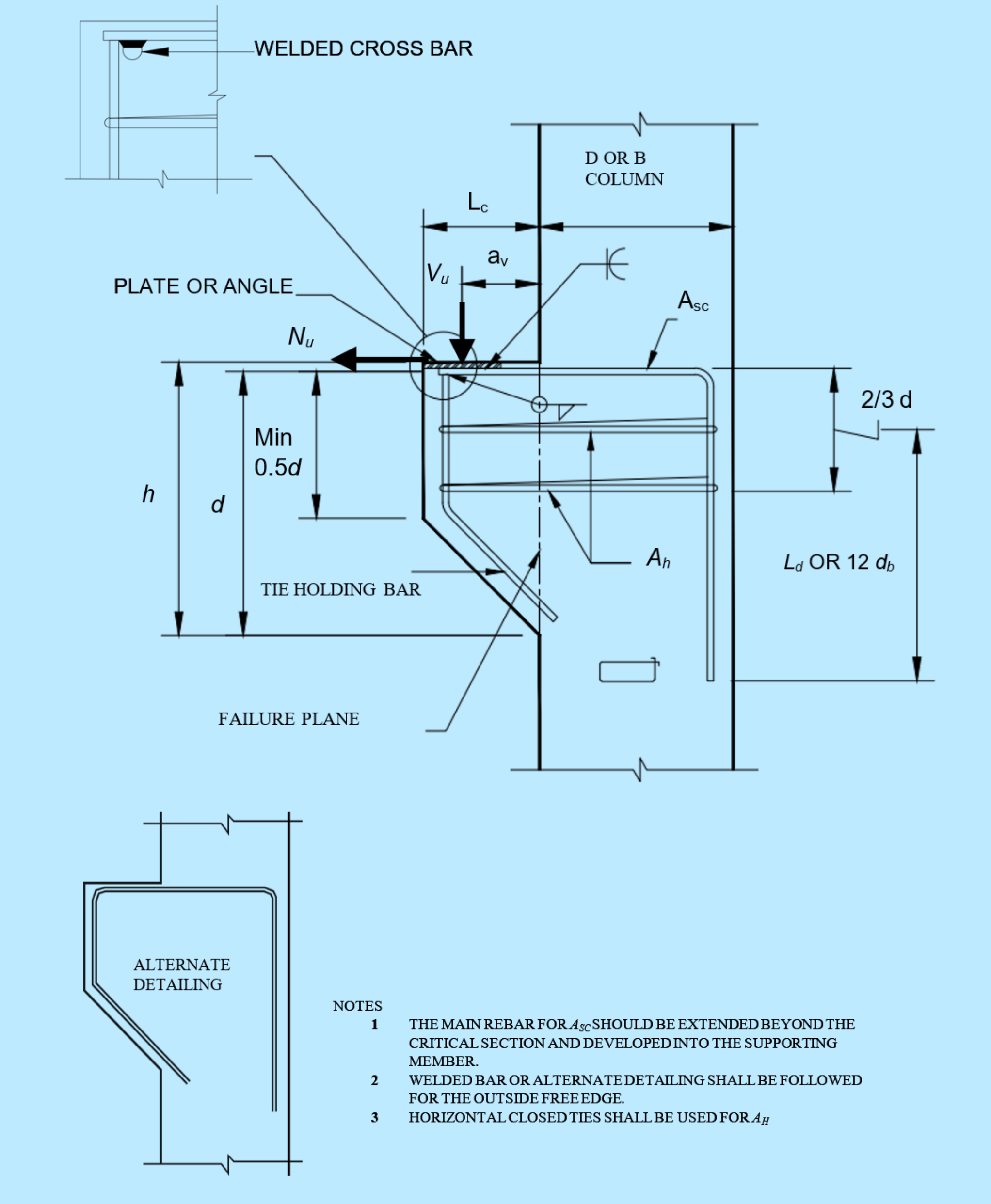
$$A_f = \frac{V_u a_v + N_u(h-d)}{0.7 f_y d}$$

7.11.17.7 The area of reinforcement A_n shall be calculated as per the following equation:

$$A_n = \frac{N_u}{0.75 f_y}$$

7.11.17.8 The area of reinforcement A_{vf} shall be calculated as per shear friction (*see* 7.12).

7.11.17.9 Unless tensile forces are prevented from being applied to the bracket or corbel, N_u shall be considered as $0.2V_u$ or as specified in the project.


WELDED CROSS BAR
D OR B COLUMN
L_c
a_v
V_u
PLATE OR ANGLE
N_u
A_{sc}
2/3 d
Min 0.5d
h
d
A_h
L_d OR 12 d_b
TIE HOLDING BAR
FAILURE PLANE
ALTERNATE DETAILING

NOTES

1 THE MAIN REBAR FOR A_{SC} SHOULD BE EXTENDED BEYOND THE CRITICAL SECTION AND DEVELOPED INTO THE SUPPORTING MEMBER.

2 WELDED BAR OR ALTERNATE DETAILING SHALL BE FOLLOWED FOR THE OUTSIDE FREE EDGE.

3 HORIZONTAL CLOSED TIES SHALL BE USED FOR A_H

FIG. 28 DESIGN OF CONCRETE CORBELS

7.11.17.10 If bearing pads are used to avoid tensile forces, the value of N_u that corresponds to the force causing the pad to slip shall be considered.

7.11.17.11 Minimum reinforcement (A_{sc}) shall be calculated as per the following equation. Where the corbel depth is larger than required by design a reduced depth *d* may be used consistently in all the design equations:

$$A_{sc,min} = 0.032\frac{f_{ck}}{f_y}bd$$

7.11.17.12 The area of stirrups (A_h) shall be calculated as per the following equation:

$$A_h \geq 0.5(A_{sc} - A_n)$$

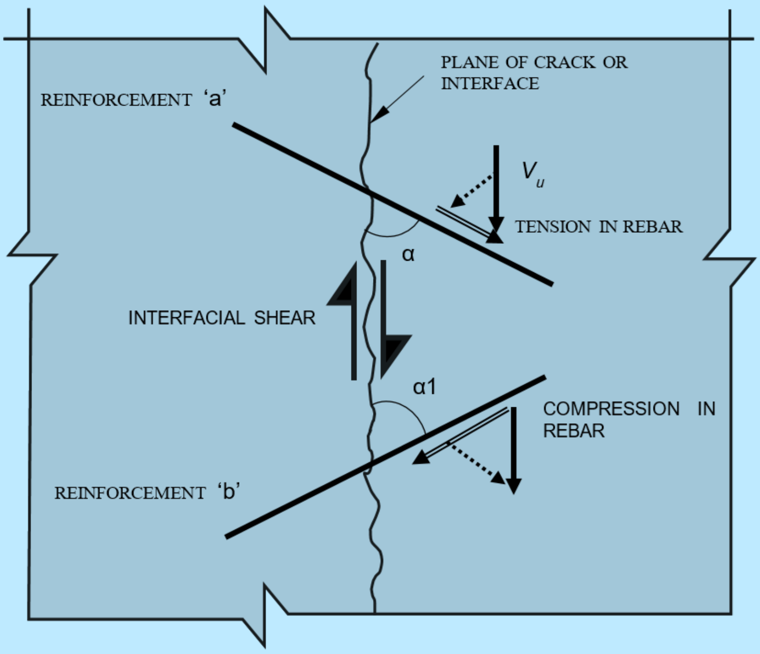
7.11.17.13 The shear reinforcement shall be provided as closed stirrups and uniformly distributed within 2/3 d measured from the primary tension reinforcement.

7.11.17.14 The development length for primary tension reinforcing bar shall be as per good practice [C-7(2)]. Development length for tension reinforcement shall be measured from the assumed failure plane (face of the supporting member). For member not having enough embedment length, hooked bars shall be used.

7.11.17.15 The main tension steel within the concrete corbel shall be developed at the outer edge of the corbel by welding to a cross bar, bearing plate with cross bar, angle section or bending along the depth of corbel.

7.12 Shear Friction

Shear friction shall be applied to consider shear transfer across interface between dissimilar materials or interface between concrete cast at different time or across a shear plane as shown in Fig. 29, reinforcement ‘a’. The following clauses shall be used.



NOTE – Reinforcement ‘a’ shall be considered in shear transfer and reinforcement ‘b’ shall be neglected.

FIG. 29 SHEAR FRICTION REINFORCEMENT

7.12.1 *Nominal Shear Strength*

7.12.1.1 Value of V_{uR} across the assumed shear plane shall be calculated using equation in 7.12.1.2 or 7.12.1.3 depending on the angle of shear reinforcement.

7.12.1.2 If shear-friction reinforcement is perpendicular to the shear plane, nominal shear strength across the assumed shear plane shall be calculated by:

$$V_{uR} = 0.75\mu A_{vf} f_y$$

7.12.1.3 If shear-friction reinforcement is inclined to the shear plane and the shear force induces tension in the shear friction reinforcement, nominal shear strength across the assumed shear plane shall be calculated by:

$$V_{uR} = 0.75\ A_{vf} f_y\ (\mu\ sin\ sin\ \alpha + cos\ cos\ \alpha)$$

where

A_{vf} = area of reinforcement crossing the assumed shear plane to resist shear;

μ = coefficient of friction in accordance with Table 6; and

α = angle between shear-friction reinforcement and assumed shear plane.

7.12.2 The value of V_{uR} across the assumed shear plane shall not exceed the limits in Table 5. Where concretes of different strengths are cast against each other, the lesser value of f_{ck} shall be used in Table 5.

Table 5 Maximum V_{uR} Across the Assumed Shear Plane

(*Clause* 7.12.2)

Sl No.	**Surface Condition**	**Maximum** V_{uR}	
(1)	(2)	(3)	
i)	Concrete placed monolithically or placed against intentionally roughened surface (amplitude of 6 mm or more)	$0.12 f_{ck} A_{cr}$, *or* $(2.475 + 0.049 f_{ck})\ A_{cr}$, *or* $8.25 A_{cr}$	Equation given in **7.12.1.2** least of the three
ii)	Other cases	$0.12 f_{ck} A_{cr}$ or $4.125 A_{cr}$	Equation given in **7.12.1.3** least of the two

Table 6 Coefficient of Friction

(*Clauses* 7.11.14.3, 7.11.17.4 *and* 7.12.1.3)

Sl No.	**Contact Surface Condition**	**Coefficient of Friction**
(1)	(2)	(3)
i)	Concrete placed monolithically	1.4
ii)	Concrete placed against hardened concrete that is clean, free of laitance and intentionally roughened to a full amplitude of approximately 6 mm	1.0
iii)	Concrete placed against hardened concrete that is clean, free of laitance and not intentionally roughened	0.6
iv)	Concrete placed against as-rolled structural steel that is clean, free of paint and with shear transferred across the contact surface by headed studs or by welded deformed bars or wire	0.7

7.12.3 The frictional component of compression load (if any) present at the interface shall be considered along with the shear friction capacity.

7.12.4 Shear friction capacity shall not be considered for a joint producing compression in the joint reinforcement as shown in Fig. 29 reinforcement 'b'.

7.13 Serviceability Design Checks

7.13.1 *Deflection*

Deflection calculations and permissible limits shall comply with the provisions of Part C/Section 5 of this NBCS. Partial fixity provided by the structural topping and nominal connections may be considered for serviceability checks.

7.13.2 *Crack*

The relevant provisions of good practice [C-7(2)] shall be followed for crack width calculations and limits. If structural cracks are observed on the tension face of the element, testing of the element shall be carried out in accordance with **10** or as directed by engineer-in-charge and the client.

7.13.3 *In-Service Considerations*

The relevant provisions of good practice [C-7(2)] shall be followed for service consideration calculations and limits.

7.14 Design of Demoulding, Handling Systems and Temporary Forces

7.14.1 *Demoulding Forces*

Forces on the elements during lifting from the casting bed due to suction or adhesion between the precast elements and the mould should be accounted while deciding the strength of concrete. These are accounted for by applying an equivalent load factor to the self-weight of the member and treating it as an equivalent static force to evaluate the stresses in the precast element. Table 7 gives recommended minimum values of equivalent load factor for demoulding forces for different product types and finishes.

Table 7 Recommended Load Factors to Account for Forces in Demoulding of Elements

(*Clauses* 7.14.1, 10.8 *and* 10.8.3)

Sl No.	Product Type	Finish	
		Exposed Aggregate with Retarder	Smooth Mould (form oil only)
(1)	(2)	(3)	(4)
i)	Flat with removable side forms. No formed rebates or reveals	1.2	1.3
ii)	Flat with removable side forms with formed rebates or reveals	1.3	1.4
iii)	Fluted with proper draft	1.4	1.6
iv)	Sculptured	1.5	1.7

NOTES

1 These factors are to be applied to the flexural design of precast elements only. For lifting inserts, *see* Table 10.

2 The above values are recommended values only. Guidance should also be sought from the precast manufacturer based on their pre-casting experience if the load factors need to be increased.

3 The associated imposed loads or wind loads, if any, are to be assessed and considered under the appropriate load combination.

7.14.2 *Handling Stresses*

Precast elements shall be designed and handled to prevent permanent damage during demoulding, storage, transportation, and erection. Design shall account for all loads acting during these stages. Minor cracks within acceptable design crack widths shall be repaired using methods approved by the contract or chemical supplier guidelines.

7.14.3 *Handling and Transportation*

An allowance should be made for dynamic loads and impact forces arising in handling, transportation and erection. Similar to demoulding force consideration, Table 8 gives recommended values for equivalent load factor to be applied to the self-weight of members to allow for these forces.

Table 8 Recommended Load Factors to Account for Dynamic Forces Arising During Handling, Transportation and Erection of Elements

(*Clause* 7.14.3)

Sl No. (1)	Stage (2)	Load Factor (3)
i)	Yard handling	1.2
ii)	Transportation	1.5
iii)	Erection	1.2

NOTES

1 These factors are to be applied to the flexural design of precast elements only. For lifting inserts, refer **7.14.6**.

2 The above values are recommended values only. Under certain conditions higher factors may apply that is certain unfavourable load conditions.

3 The associated imposed loads or wind loads, if any, are to be assessed and considered with the appropriate load combination.

7.14.4 *Early Demoulding/Handling of Precast Element*

For precast elements lifted and handled prior to gaining full strength the elements together with any lifting inserts should be designed accordingly. Recommended minimum concrete strengths for lifting and handling of precast elements are given in Table 9. Precast elements should be designed, using these lower strengths, to span between lifting points without excessive cracking or deflection. For prestressed concrete, consideration should also be given to stresses resulting from transfer of prestressing forces.

Table 9 Recommended Minimum Concrete Strength for Lifting and Handling

(*Clauses* 7.14.4 *and* 10.8.4.1)

Sl No. (1)	Application (2)	Minimum Concrete Strength N/mm^2 (3)
i)	None specified, fine controlled crane, non-prestressed	10*
ii)	Lifting which involves significant impact or high acceleration	15*
iii)	All units where concrete strength for lifting is specified in the specification	As specified
iv)	Concentrically prestressed elements (piles, wall panels, or thin floor slabs)	20
v)	Eccentrically prestressed (T beam, deep flowing units)	25
vi)	Highly stressed prestressed elements	30 or as specified

---

*Depending on anchor length or as recommended by insert manufacturer.

7.14.5 *Temporary Stages/Erection Sequence*

The design of precast elements at temporary stages can be critical compared to the permanent stages. Consideration should be given to the loading imposed on the precast elements during each phase of construction. The following shall be verified:

a) Precast sections of composite elements which are required to support self-weight plus construction load prior to casting of an in-situ topping;

b) Lower precast floor slabs or precast stair flights which support propping to upper levels during installation; and

c) Bearing or halving joints which support higher temporary construction loads because of back propping to upper levels.

The design should also take into consideration that the structural action and framing might be different during the temporary stages resulting in higher stresses in individual members.

7.14.6 *Lifting Inserts*

The number of lifting inserts and location of inserts shall be decided by the following:

a) Lifting insert capacity (safe working load);

b) Total weight of the element;

c) Strength of concrete at age of lifting;

d) Shape of the unit;

e) Location of the inserts so that the failure of any one insert does not cause failure of the entire lifting system thereby ensuring the element can still be safely supported;

f) Position of any cut-outs and/or openings;

g) Rigging arrangement; and

h) Anchorage of inserts.

All lifting inserts shall be designed by accounting the factors of safety given in Table 10. Typically lifting inserts shall be designed with a factor of safety of 4.

Table 10 Recommended Factors of Safety for Lifting Inserts

(*Table 7 and Clause 7.14.6*)

Sl No. (1)	Item (2)	Recommended Factor of Safety (3)
i)	Bracing members	2
ii)	Bracing connections	3
iii)	Bracing inserts cast into precast members	3
iv)	Lifting inserts, normal circumstances	4
v)	Lifting inserts, multiple usage	5
vi)	Rebar inserts, single usage	2
vii)	Rebar inserts, multiple usage	4

7.14.7 *Bracing Design*

Bracing should be designed for both construction and wind loading. The construction load should be a minimum value of 1.5 kN/m² but should be increased if considered appropriate.

Wind loads shall be calculated in accordance Part C 'Structural Design, Section 1 Loads and Load Effects' of this NBCS and the bracing shall be designed for it.

8 JOINTS AND CONNECTIONS

8.1 Basic Design Considerations

A joint shall be considered based on the action of force transfer (tension, compression, shear, moment, etc) at an interface (one or many) between the precast components. A connection, which is a zone that includes various joints, shall be designed in combination of any of the following forces:

a) Compressive force;

b) Tensile force;

c) Shear force; and

d) Flexural and torsional moments, as applicable.

8.1.1 *Transfer of Compressive Force*

8.1.1.1 The precast or cast in-situ member supporting the other elements shall be designed to safely resist all the compressive forces generated by various load combination.

8.1.1.2 The joint shall be designed for all other forces arising from the external forces along with the predominant compression. Shear forces more than 0.1 P_u (axial load) shall not be neglected in the design of the joint.

8.1.1.3 The members may rotate because of temperature change, creep and shrinkage, hence bearing pads or strips shall be provided to account for the rotation. Minimum thickness of the joint shall be decided based on tolerance requirements, and shall not be less than 10 mm.

8.1.1.4 Appropriate edge distance for the bearing pad shall be provided to avoid crushing or cracking of edges.

8.1.1.5 Connection having bearing materials harder than concrete shall be checked for ultimate limit state as per the provisions of good practice [C-7(2)]. Busting reinforcement shall be provided in the supporting member, if required.

8.1.1.6 Connection having bearing materials softer than concrete shall be checked for serviceability limit states as per the provisions of good practice [C-7(2)]. Splitting reinforcement shall be provided in the supporting member, if required.

8.1.1.7 Joint using steel inserts for connection shall be properly designed and executed as per the design requirements. The steel components shall be anchored to the concrete members for proper transfer of compressive forces to the main reinforcement.

8.1.1.8 Connections shall be provided with reinforcement as follows or with equivalent connection:

a) For walls elements, dowels shall be placed at a maximum spacing of 1/4th of the length of the wall panels or 450 mm or as required by design. Also, at least two extreme edge dowels shall be continuous from foundation till roof using Class H coupler as per [C-7(9)] or any other connection;

b) For column minimum four corner bars of 12 mm diameter or as per design requirements shall be continuous from foundation till roof using Class H coupler as per [C-7(9)] or any other connection;

c) For beam at least one 12 mm dowel at centre of the bearing region of the beam shall be provided to avoid accidental failure; and

d) For any other member appropriate reinforcement shall be provided to avoid accidental lateral loads.

8.1.2 *Transfer of Tensile Forces*

8.1.2.1 Tensile forces generated at the joint shall be resisted by tie bars sufficiently anchored at both the sides of the joint.

8.1.2.2 Adhesive bond between the members shall not be accounted in force transfer.

8.1.2.3 The tensile stresses generated in the connecting members shall also be linked to the reinforcement of the member by proper provision of ties or any other connection.

8.1.2.4 Premature brittle failure shall be avoided for tie members and material selected for making tie shall be ductile.

8.1.2.5 Joints with grout filled tubes or sleeves shall be utilised with adequate development length. International practice indicates that the confinement of dowel tube enhances the rebar anchorage performance, reducing the required development length. Hence, for determining development length reduced development length shall be adopted based on test results as per 12. In absence of test results, the bond strength of concrete shall be considered. Alternatively, other joint configurations may be adopted, provided their performance is evaluated through assemblage and system level testing along with nonlinear analysis and approved from competent authorities or institutes of repute.

8.1.2.6 A joint using bolting, welding or lap splicing shall be properly anchored to the precast components and transfer of forces in the member shall be verified.

8.1.2.7 Reinforcement loops (U-bars) protruding from precast elements may be used to provide tie between the elements as shown in Fig. 30. Reinforcement of 8 mm or higher diameter shall be provided as longitudinal reinforcement (preferably four numbers with U-bars) as shown in the Fig. 30. Lap length, spacing of loop bars and overlapping length shall be as per the Fig. 30.

8.1.2.8 Anchoring of reinforcement shall be such that high stress concentration in the members are avoided.

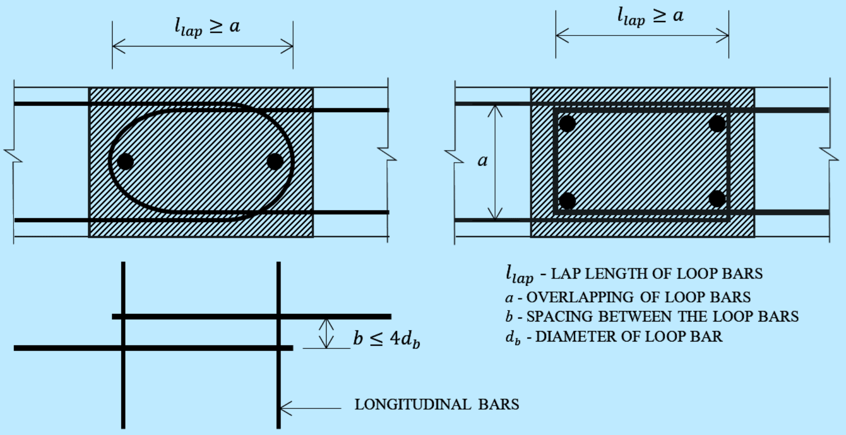

$l_{lap} \geq a$
$l_{lap} \geq a$
a
$b \leq 4d_b$
l_{lap} - LAP LENGTH OF LOOP BARS
a - OVERLAPPING OF LOOP BARS
b - SPACING BETWEEN THE LOOP BARS
d_b - DIAMETER OF LOOP BAR
LONGITUDINAL BARS

FIG. 30 REINFORCEMENT LOOP JOINT FOR TRANSFERRING TENSION

8.1.3 *Transfer of Shear Force*

8.1.3.1 Shear forces may be transferred between concrete elements by adhesion or friction at joint interfaces, shear-key effect at indented joint faces, dowel action of transverse steel bars, pins and bolts, or by other mechanical connection devices. The frictional resistance can be enhanced by the pull-out resistance of tie bars properly placed across the joint.

8.1.3.2 Adhesive bond or adhesion between the interfaces of elements shall not be considered in the calculation of shear strength of the joint.

8.1.3.3 Shear resistance of joint between two elements with reinforcement may be calculated using shear friction (*see* 7.12) equation or as per good practice [C-7(2)]. Shear friction shall not be used if the reinforcement crossing the joint is subjected to compressive forces by the displacement of the members.

8.1.3.4 Permanent compressive stresses acting on the joint shall also be considered along with shear friction.

8.1.3.5 Unreinforced shear keys or castellation or indented joint face shall be used for members subjected to very high shear forces. This connection shall be designed to remain elastic under ultimate limit states to avoid sudden brittle failure of the joint. Transverse reinforcement across the interfaces shall be provided to prevent sudden separation of the members.

8.1.3.6 The dimension of shear keys shall be as per Fig. 31.

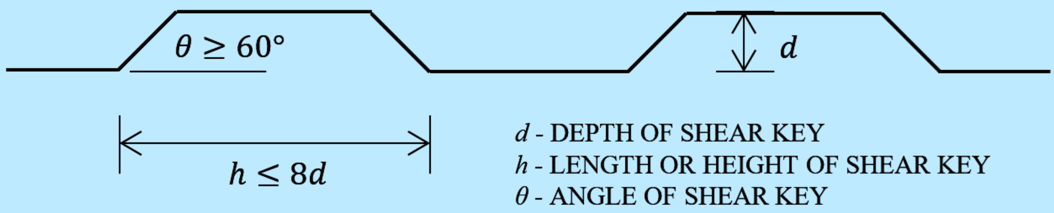

$\theta \geq 60°$
d
$h \leq 8d$
d - DEPTH OF SHEAR KEY
h - LENGTH OR HEIGHT OF SHEAR KEY
θ - ANGLE OF SHEAR KEY

FIG. 31 DETAILING OF SHEAR KEY WITHOUT REINFORCEMENT

8.1.4 *Transfer of Bending and Torsional Moment*

8.1.4.1 Strong connections shall be used possessing stiffness, strength and ductility confirming to that of cast in-situ construction.

8.1.4.2 Moment resisting connections shall be designed such that ductile failures occur without any local modes of brittle failure (shear, pull-out, etc).

8.1.4.3 Continuity within the joint may be obtained by any of the following or combination:

a) Lapping of bars;

b) Reinforcement grouted into apertures;

c) Overlapping loop or U-bars;

d) Reinforcement connected using threaded couplers; and

e) Any other type of connection with appropriate testing of the connection.

8.2 Connection Based on Precast Concrete Seismic Systems

The connection of seismic moment resisting frames and structural walls incorporating precast concrete elements generally fall into two broad categories, either ‘equivalent monolithic (emulative)’ systems or, ‘jointed’ systems. The distinction between these types of construction is based on the design of the connections between the precast concrete elements as provided in the following sections.

8.2.1 *Equivalent Monolithic Systems* (*Emulative*)

A precast concrete structural system satisfying the requirements of this clause shall have strength and toughness equivalent to that provided by a comparable monolithic reinforced concrete structure.

8.2.1.1 *Connections in monolithic systems*

The connections between precast concrete elements of equivalent monolithic systems can be subdivided into two categories:

a) *Strong connections of nominal ductility*

In moment resisting frames and structural walls these connections are protected by a capacity design approach which ensures that flexural yielding occurs away from the connection region.

b) *Ductile connections*

Ductile connections of equivalent monolithic systems typically comprise longitudinal reinforcing bars in the connection which are expected to enter the post-elastic range in a severe earthquake.

In moment resisting frames yield penetration may occur into the connection end-region. The potential plastic hinge region may extend a distance along the end of the member as in cast-in-place construction.

8.2.2 *Jointed Systems*

This system is not in the purview of this NBCS.

8.3 Design of Connections

The design of connections shall follow those design methods and considerations for reinforced concrete, prestressed concrete and structural steel. Proprietary connections shall be based on tests and approved from competent authority or institutes of repute. The following types are the broad category of the connections based on connecting members:

a) Column to foundation;

b) Column to column;

c) Beam to column;

d) Beam to beam;

e) Beam to slab;

f) Beam to wall;

g) Wall to wall;

h) Wall to slab; and

j) Slab to slab.

Examples of typical connections are shown in Annex E. These connections are for illustrative purposes only. In all instances, the design should demonstrate that the connections are able to resist the applied structural actions. Where appropriate, the suitability of the connection to act as a pinned or moment connection is highlighted. The location of the connections for a framed structure shall be as per **6** (Fig. 2, Fig. 3, Fig. 4 and Fig. 5).

8.3.1 *Detailing of Reinforcement*

The following shall be considered:

a) *Lapping of bars* — Where bars passing through the connection are lapped to provide continuity of reinforcement, the recommendations good practice [C-7(2)] and integrity tie requirements shall be followed;

b) Reinforcement grouted into aperture — An adequate capacity should be provided for grouted reinforcing bars to prevent pull-out. Embedment length shall be as per manufacturer guidelines, however testing shall be carried out as per **12**. If grouted tube is used, the embedment length of dowel shall be at least 300 mm or as required by design, whichever is higher;

c) *Reinforcement loops* — Loop reinforcement shall be provided as per **8.1.2** and Part C 'Structural Design, Section 5 Structural Concrete' of this NBCS;

d) *Couplers* — Reinforcement may be connected by couplers. The concrete cover to the couplers (other than grouted tube or duct) shall be at least 25 mm or as per specifications of the project. A locking device should be used for threaded coupler connections where there is a risk of the threaded connection working loose, for example during vibration of in-situ concrete. Reference should be made to [C-7(9)] and the manufacturers' technical specifications for guidance and acceptance criteria for the usage. Testing of couplers shall be as per **12** and relevant guidelines of [C-7(9)]. When the system is part of lateral force resisting system, the grout strength shall not be less than 90 MPa and testing shall be carried out as per **12** by the supplier of the coupler or as agreed upon by the project team. Modify to mention 12 for LFRS and 7(9) for regular coupler without lateral force; and

e) *Welding of bars* — When bars are connected by welding, the connection shall ensure full capacity of the bar is achieved and failure of weld is avoided. Testing of the welded samples shall be as per relevant standards. Welding of rebar shall be avoided for normal circumstances, to be used for repair or strengthening of a connection, if required.

8.3.2 *Connections in Compression*

8.3.2.1 The design of connections in tension shall follow the guidelines of 8.1.1.

8.3.2.2 In normal circumstances, the area of concrete to be utilized for calculating the strength of the connection in a wall or column should be the greater of:

a) 75 percent of the area of contact between the wall or column and connection; or

b) The area of the in-situ concrete excluding the part of any intruding slab or beam units. However, those parts of the floor slab or beam units that are solid over the bearing may be included in calculating the strength and such units should be properly bedded on concrete or mortar of adequate quality. This area should not be taken as greater than 90 percent of the wall or column area.

8.3.3 *Connections in Tension*

8.3.3.1 The design of connection in tension shall follow the guidelines of 8.1.2.

8.3.3.2 Stirrups shall be placed along the lap length, for the connection utilizing lapping of bars, grouted duct, or grouted coupler for transfer of tensile forces.

8.3.3.3 Welding or bolting shall be used with appropriate design. The embedded inserts shall be appropriately anchored to the primary member.

8.3.4 *Connection in Shear*

8.3.4.1 The design of connection in shear shall follow the guidelines of 8.1.3.

8.3.4.2 A shear connection may be considered effective, if the connection is grouted with a suitable concrete or mortar mix of strength of at least 5 MPa higher than the connecting members and the criteria of 8.1.3 is satisfied.

8.3.4.3 For joints subjected to minimal shear between wall panels or thin members, looped wire ropes shall be used to connect between the members with a maximum spacing of 450 mm. These connections shall not be used in lateral force resisting system and in transfer of seismic forces.

8.3.4.4 Transfer of forces solely by friction caused due to gravity load shall not be used.

8.3.5 *Bond*, *Anchorage*, *Bearing*, *Laps*, *Joints and Bends in Bars*

8.3.5.1 Provision of bond, anchorage, bearing, laps, joints and bend in bars shall be as follows:

a) *Avoidance of bond failure due to ultimate loads* — At both sides of any cross-section the force in each bar should be developed by an appropriate embedment length or other end anchorage;

b) *Anchorage bond stress* — Anchorage bond stress (τ_b) is assumed to be constant over the effective anchorage length. It may be taken as the force in the bar divided by its effective surface anchorage area, as given below:

$$\tau_b = \frac{F_s}{\pi \varphi_E L}$$

where

τ_b = bond stress;

F_s = force in the bar or group of bars;

φ_E = effective bar size which, for a single bar is equal to the bar size and, for a group of bars; and

L = anchorage length.

c) *Values for design ultimate anchorage bond stress* — Values for design ultimate anchorage bond stress τ_{bu} may be obtained from the equation. The anchorage bond stress (τ_b) shall not exceed the design ultimate anchorage bond stress:

$$\tau_{bu} = \beta\sqrt{f_{cu}}$$

where

τ_{bu} = design ultimate anchorage bond stress; and

β = a coefficient dependent on the bar type.

The values of β may be taken from Table 11. These values include a partial safety factor (γ_m) of 1.4.

Table 11 Values of Bond Coefficient β

[*Clause* 8.3.5.1(c)]

Sl No.	**Bar Type**	β	
		Bar in Tension	Bar in Compression
(1)	(2)	(3)	(4)
i)	Plain bar	0.28	0.35
ii)	Deformed bar	0.4	0.63

8.4 Connections Other than Those Involving Continuity of Reinforcement

8.4.1 *Joints with Structural Steel Inserts*

Joints with structural steel inserts generally consist of a steel plate or rolled steel section projecting from the face of a column to support the end of a beam. The reinforcement in the ends of the supported member shall be designed in accordance with the provisions mentioned in Part C/Section 5 of this NBCS. Detailed design provisions shall include the following:

a) The steel sections and any bolted or welded connections should be designed in accordance with the appropriate recommendations;

b) Design ultimate bearing stresses shall be as per **7.11**; and

c) Consideration should be given in the design to the possibility of vertical splitting under the steel section because of shrinkage effects and localized bearing stresses, for example under narrow steel plate.

8.4.2 *Resin Adhesives*

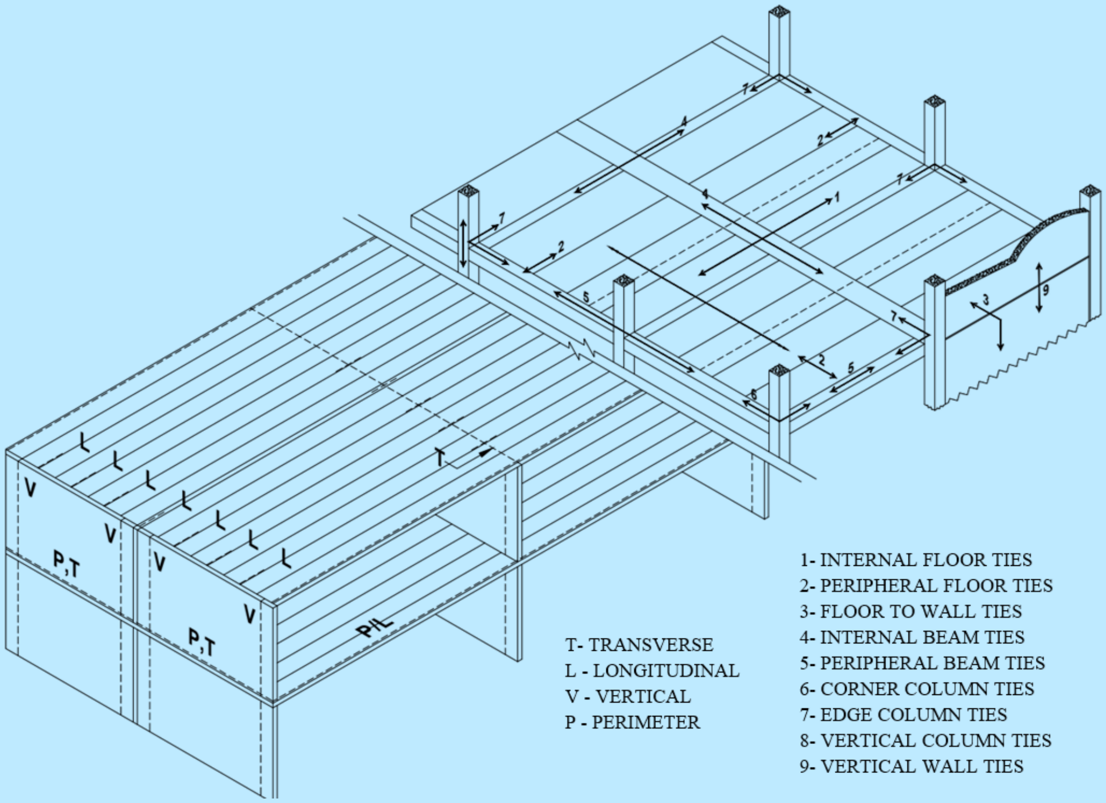
Resin adhesives may be used to form joints subjected to compression but not to resist tension or shear. These adhesives should only be used where they are adequately protected against the effects of fire.

8.4.3 *Other Types of Connections*

Any other type of connection that can be shown to be capable of carrying the ultimate loads acting on it may be used. Amongst those suitable for resisting shear and flexure are those made by prestressing across the joint.

8.5 Structural Integrity and Progressive Collapse

Reinforcement and connections shall be detailed to tie the structure together effectively maintaining adequate structural integrity and to prevent progressive collapse. Integrity ties shall be followed in accordance with the following clauses. Figure 32 shows the typical arrangements of integrity ties in a large panel structure and frame structure. Progressive collapse requirements shall be as per **8.5.10**.

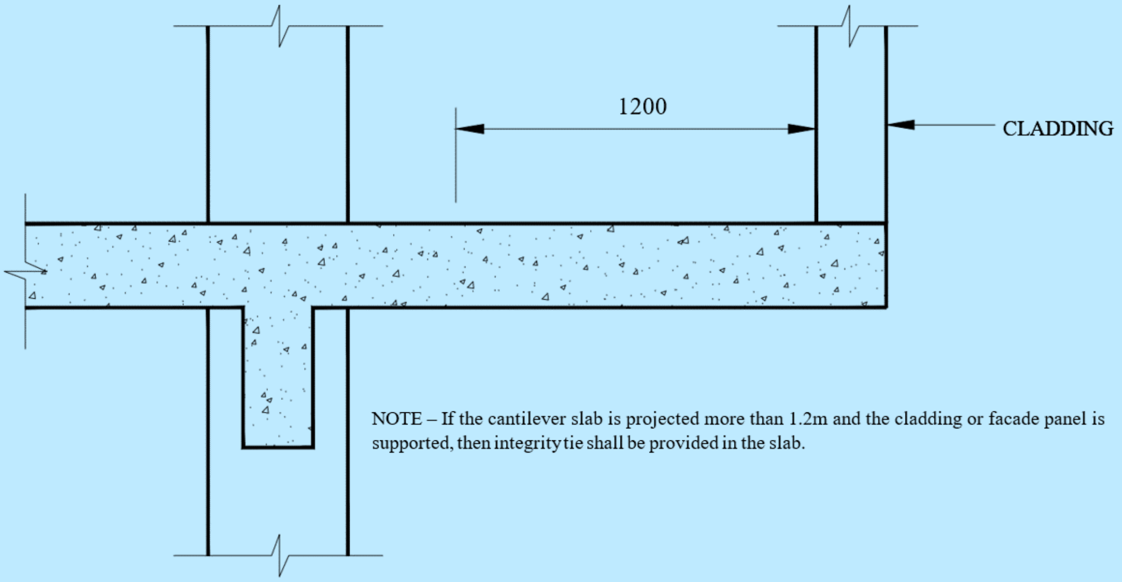


T- TRANSVERSE
L - LONGITUDINAL
V - VERTICAL
P - PERIMETER
1- INTERNAL FLOOR TIES
2- PERIPHERAL FLOOR TIES
3- FLOOR TO WALL TIES
4- INTERNAL BEAM TIES
5- PERIPHERAL BEAM TIES
6- CORNER COLUMN TIES
7- EDGE COLUMN TIES
8- VERTICAL COLUMN TIES
9- VERTICAL WALL TIES
V
L
P,T
P/L
T

FIG. 32 TYPICAL ARRANGEMENT OF INTEGRITY TIES

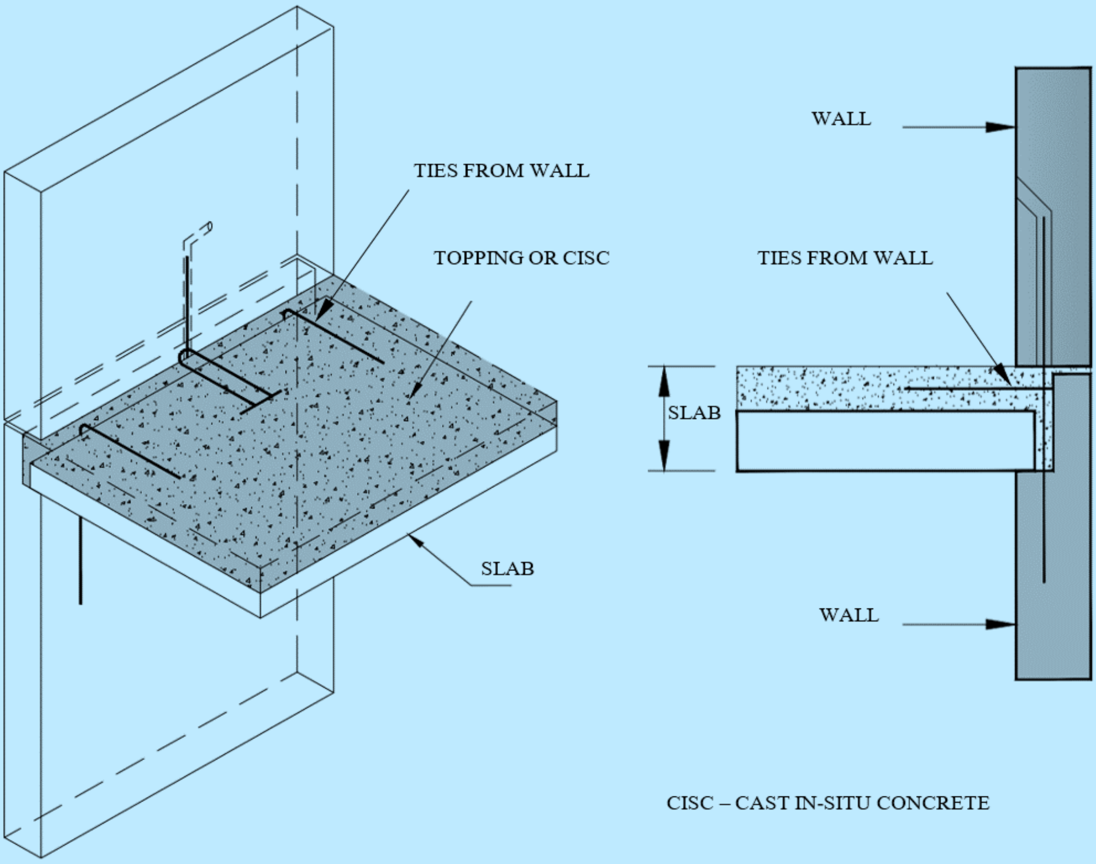
8.5.1 *Peripheral Ties*

At each floor and roof level an effectively continuous tie shall be provided within 1.2 m of the edge of the building or within the perimeter wall (*see* Fig. 33). The tie shall be capable to resist a tensile force of F_t equal to 60 kN or (20 + 4N) kN, whichever is less, where N is the number of storeys (including basement).


1200
CLADDING

NOTE – If the cantilever slab is projected more than 1.2m and the cladding or facade panel is supported, then integrity tie shall be provided in the slab.

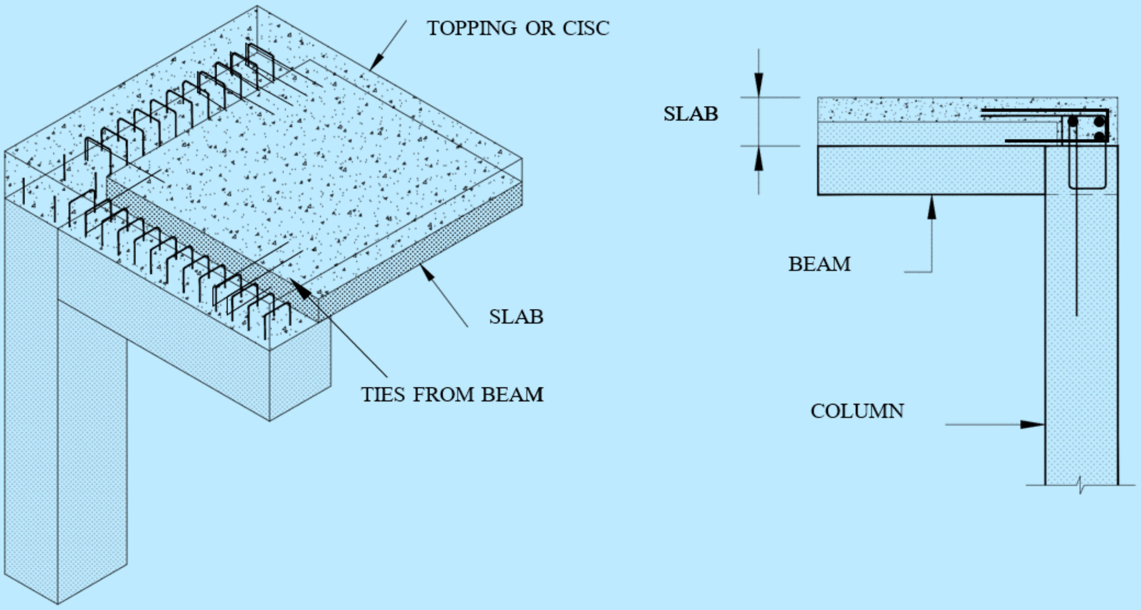
33A) POSITION OF PERIPHERAL TIE


TIES FROM WALL
TOPPING OR CISC
SLAB
WALL
TIES FROM WALL
SLAB
WALL

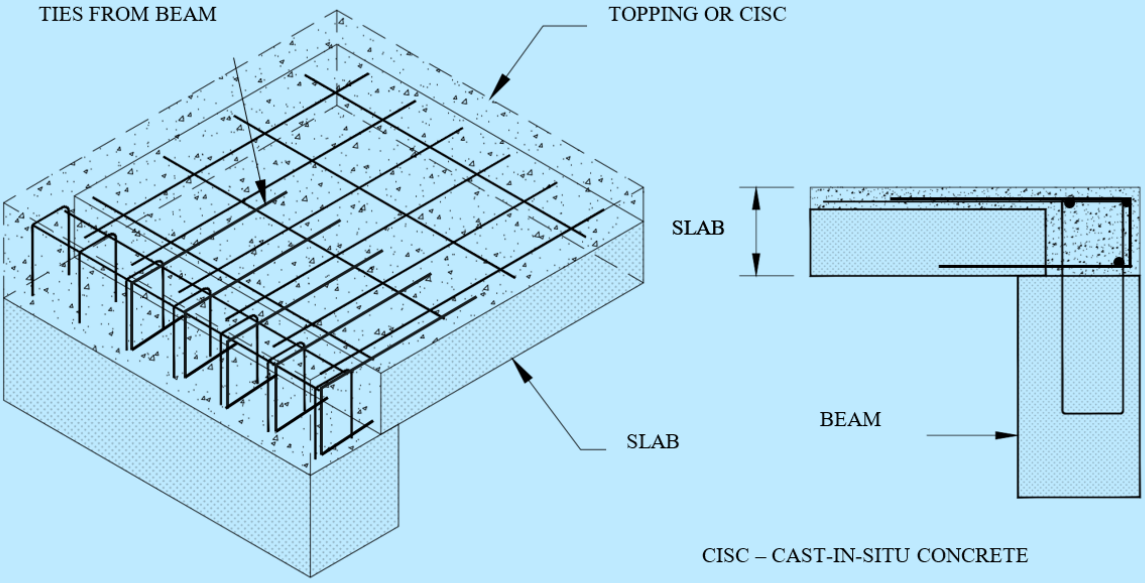
CISC – CAST IN-SITU CONCRETE

33B) PRECAST WALL TO WALL CONNECTION WITH SHEATHING PIPE

FIG. 33 POSITION FOR PERIPHERAL TIE (CONTINUED)


TOPPING OR CISC
SLAB
SLAB
TIES FROM BEAM
BEAM
COLUMN

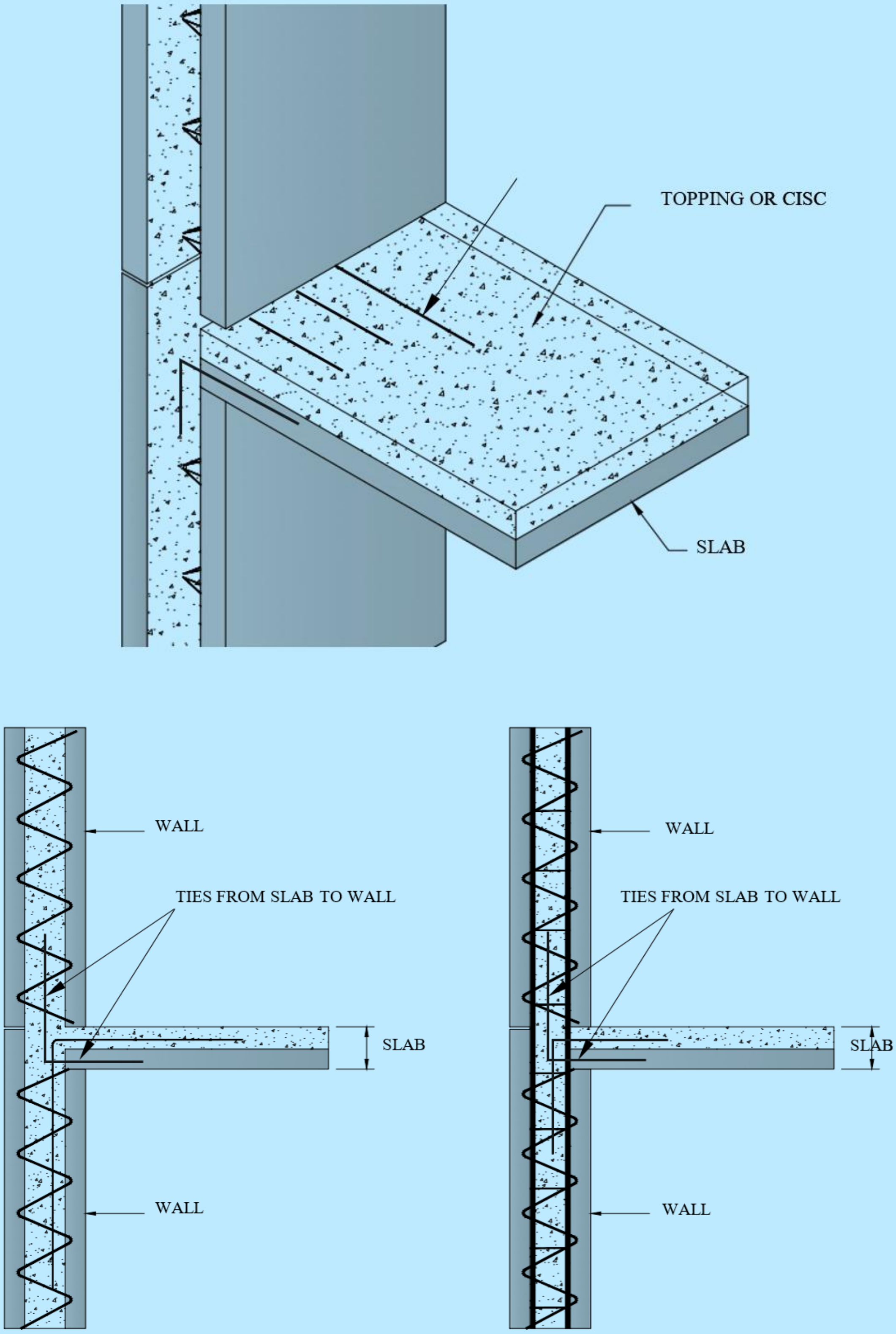
33C) PRECAST COLUMN, BEAM AND SLAB CONNECTION


TIES FROM BEAM
TOPPING OR CISC
SLAB
SLAB
BEAM

CISC – CAST-IN-SITU CONCRETE

33D) PRECAST BEAM SLAB CONNECTION

FIG. 33 POSITION FOR PERIPHERAL TIE (CONTINUED)


TOPPING OR CISC
SLAB
WALL
TIES FROM SLAB TO WALL
SLAB
WALL
WALL
TIES FROM SLAB TO WALL
SLAB
WALL

CISC – CAST-IN-SITU CONCRETE

33E) PRECAST BEAM SLAB CONNECTION

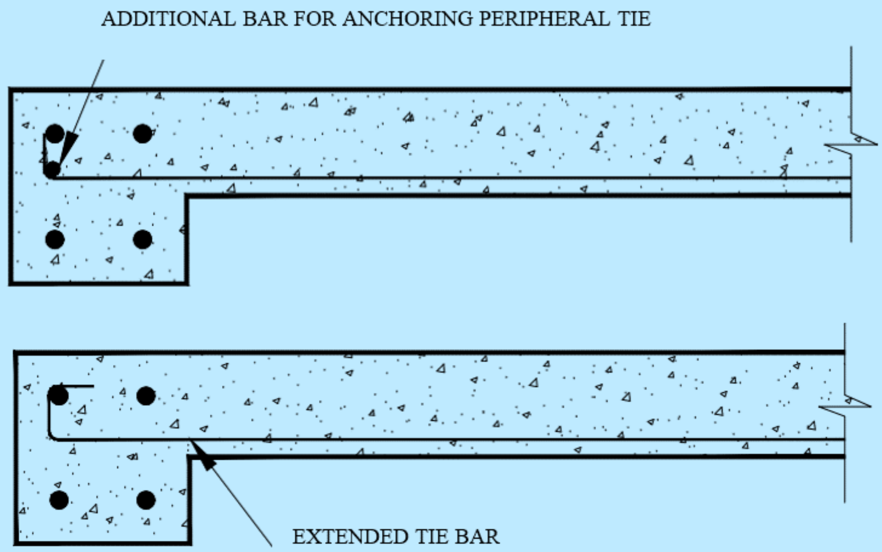
FIG. 33 POSITION FOR PERIPHERAL TIE

8.5.2 *Internal Ties*

These shall be provided at each floor and roof level in two directions approximately at right angles. Ties shall be effectively continuous throughout their length and be anchored to the peripheral tie at both ends, unless continuing as horizontal ties to columns or walls (*see* Fig. 34). The tensile strength, in kN/m width shall be the greater of:

$$\left(\frac{g_k+q_k}{7.5}\right)\frac{L_rF_t}{5}\ and\ F_t$$

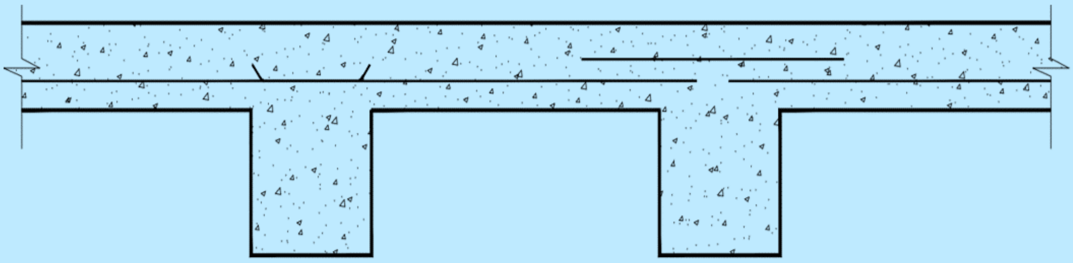
where, $(g_k + q_k)$ is the sum of average characteristic dead and imposed floor loads, in kN/m^2 and L_r is the greater of the distance between the centre of columns, frames or walls supporting any two adjacent floor spans in the direction of the tie under consideration.



NOTE – If the peripheral tie consists of bars in an edge beam, then the bottom bars in the slabs will not be at the same level as the peripheral tie bars. It is suggested that either an additional bar be used for anchoring in the peripheral tie or the internal tie bars be extended and anchored around the top bar in the beam.

FIG. 34 ANCHORING OF TIES IN SLABS

The bars providing these ties shall be distributed evenly in the slabs (*see* Fig. 35) or shall be grouped at or in the beams, walls or other appropriate positions but at spacing generally not greater than 1.5 L_r.



NOTE – For continuity in continuous slabs, bars are distributed evenly in a floor slab by means of lapping some bottom slab reinforcement at supports, either by extending existing bars or by an addition of splice bar.

FIG. 35 CONTINUITY REQUIREMENT FOR SLAB

8.5.3 *Horizontal Ties to Column and Wall*

All external load-bearing members such as columns and walls shall be anchored or tied horizontally into the structure at each floor and roof level. The design force for the tie shall be greater of:

a) $2F_t$ kN or $Ls \times (F_t/2.5)$ kN, whichever is less for a column or for each metre length, if there is a wall (Ls is the floor to ceiling height in metre); and

b) 3 percent of the total ultimate vertical load in the column or wall at that level.

For corner columns, this tie force should be provided in each of two directions approximately at right angles.

8.5.4 *Vertical Ties*

Each column and each wall carrying vertical load should be tied continuously from the foundation to the roof level.

8.5.4.1 The reinforcement provided is required to resist a nominal tensile force of at least 50 kN per horizontal metre of wall.

8.5.4.2 At least two integrity ties shall be provided in each wall panel.

8.5.4.3 Connection between precast column shall have vertical integrity ties, with a nominal tensile strength of $1.4A_g$, where A_g is the gross area of the column. For column with larger cross section reduced effective area equal to the actual cross section required shall be used. However, the reduced area shall be at least one-half of the gross area of column.

8.5.4.4 In situation where provision of vertical ties cannot be done, the element should be removed, and the surrounding members shall be designed to bridge the gap.

8.5.4.5 All members in the lateral force resisting system shall have one tie continuous from foundation to terrace at each end of the member with Class H coupler as per [C-7(9)] (ties as per design) or direct lapping (ties as per lapping requirements).

8.5.5 *Tie Anchorage*

A tie crossing another tie at right angles may be considered anchored if the bars extend 12 times the bar diameter or an equivalent anchorage beyond the other tie; or an effective anchorage length, calculated from the tension force, beyond the centreline of the other tie. At abrupt changes in construction or at re-entrant corners, it shall be ensured that the ties are sufficiently anchored or to be made effective by other means.

8.5.6 *Continuity of Ties*

A continuous tie shall satisfy **8.3.1**. The minimum thickness of in-situ concrete section where tie bars are provided shall be at least the total dimension of the bar diameter (or two diameters at laps) and twice the maximum aggregate size plus 10 mm.

To provide continuity, the tie shall also satisfy one of the following:

a) A bar in a precast concrete unit lapped with a bar encased in in-situ concrete bounded on two opposite sides by rough faces of the same precast unit (*see* Fig. 36);

b) A bar in a precast concrete unit lapped with a bar encased in the topping of in-situ concrete tied to the precast unit by links or stirrups. The tensile resistance of such links and stirrups should not be less than the designed tension in the tie (*see* Fig. 37); and

c) Bars lapped within in-situ topping concrete with projecting links or stirrups from the supporting precast units, such as beams or slabs (*see* Fig. 38).

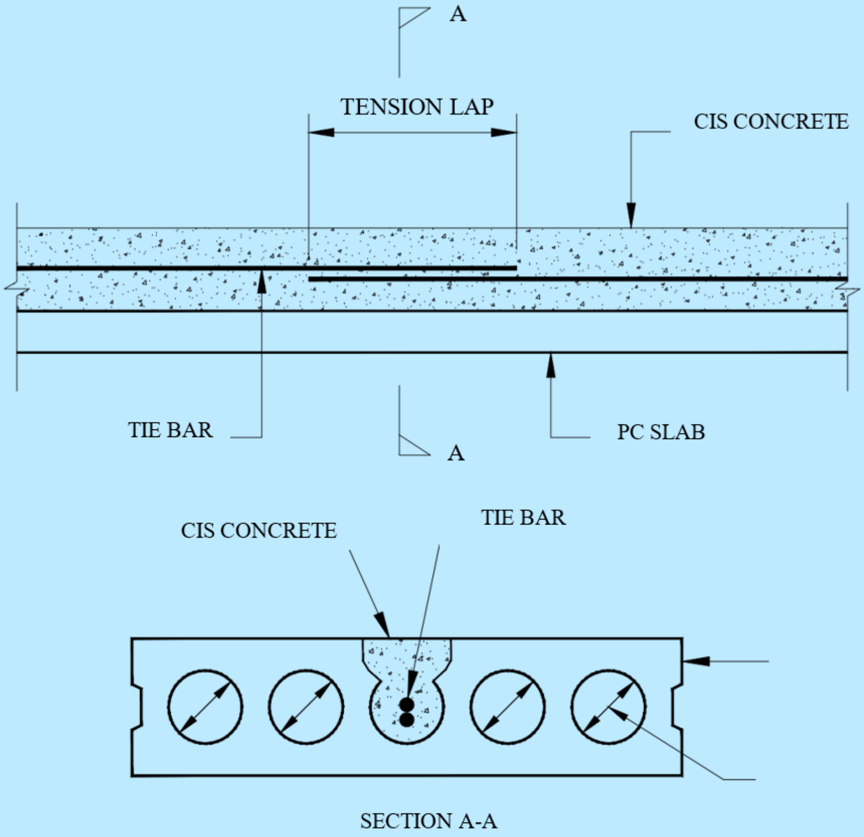

A
TENSION LAP
CIS CONCRETE
TIE BAR
A
PC SLAB
CIS CONCRETE
TIE BAR
SECTION A-A

FIG. 36 CONTINUITY OF TIES: BARS IN PRECAST MEMBER LAPPED WITH BAR IN CIS

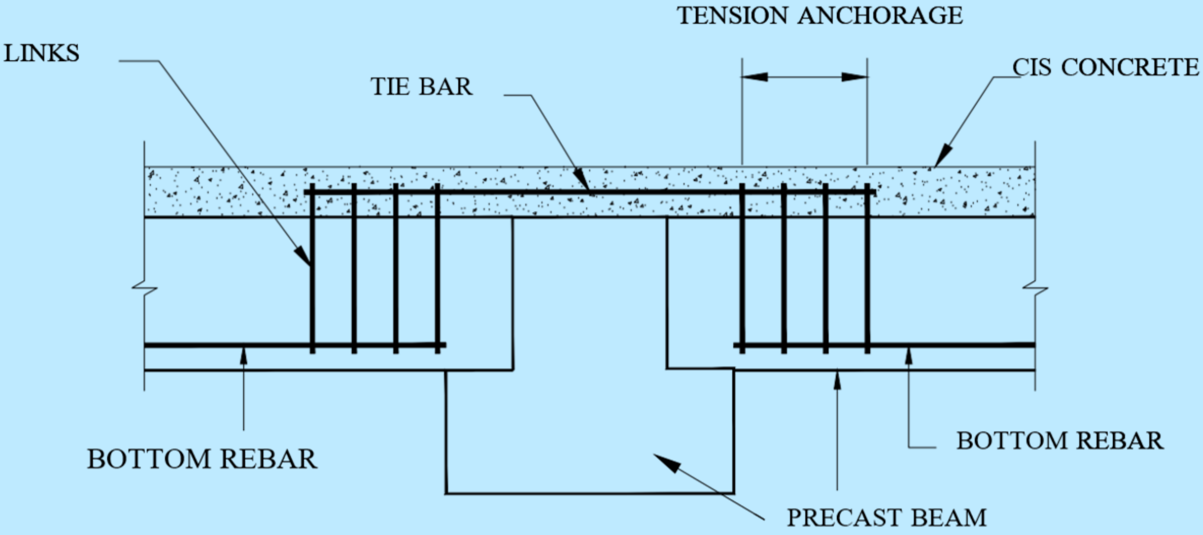

TENSION ANCHORAGE
LINKS
TIE BAR
CIS CONCRETE
BOTTOM REBAR
BOTTOM REBAR
PRECAST BEAM

FIG. 37 CONTINUITY OF TIES: ANCHORAGE BY ENCLOSING LINKS

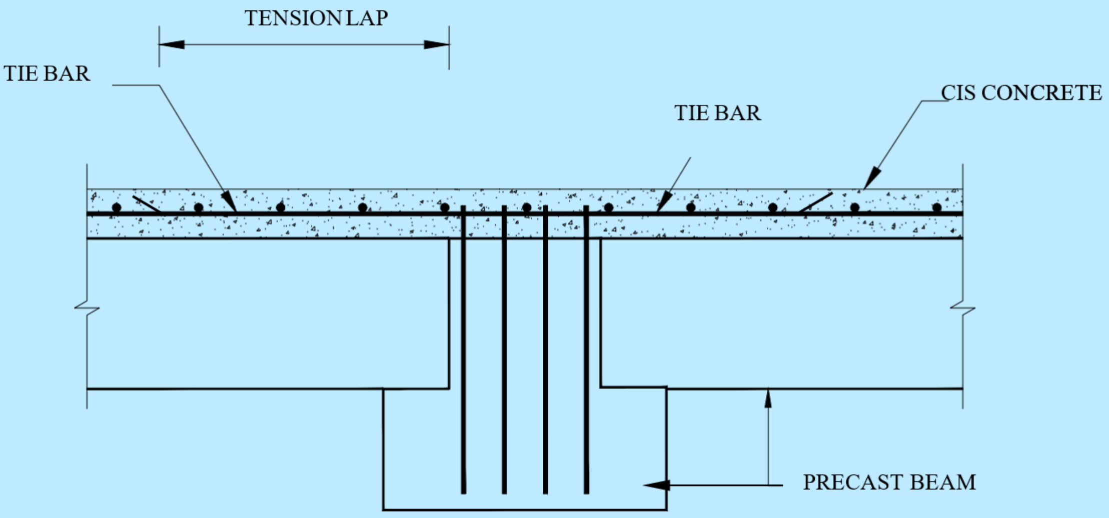


FIG. 38 CONTINUITY OF TIES: BARS LAPPED WITHIN IN-SITU CONCRETE

8.5.7 *Ties between Precast Element and Topping*

In potential plastic hinge regions, the consequences of delamination of the topping from the precast members shall be assessed. If the maximum shear stress at any section exceeds 0.4 MPa, connectors shall be provided between the topping and precast to achieve composite action as per the following guidelines:

a) Ties with an effective area of 40 mm^2 per m^2 of floor area, or equivalent connectors, shall connect the topping to the precast element;

b) Spacing of connectors shall not exceed 1 500 mm and the tributary area of topping reliant on each connector shall not exceed 2.25 m^2;

c) Connectors shall engage horizontal reinforcement, or shall be otherwise effectively anchored into both the topping and the precast element, or into the joints between precast elements; and

d) In HCS appropriate connection shall be placed in slab joints.

8.5.8 *Anchorage in Structures*

All precast floor and precast roof units should be effectively anchored if these units are not utilised to provide the ties. The anchorage shall be capable of supporting the dead weight of the precast unit to that part of the structure which contains the ties.

8.5.9 *Eccentricity*

Ties connecting precast floor or roof units shall be so designed and placed as to minimise eccentricity.

8.5.10 *Anchorage at supports*

In case reinforcing bars are used to provide the structural integrity of slab ends supported on corbels or nibs, great care shall be taken to ensure it is adequately lapped and anchored. Allowance should also be made for constructional inaccuracies.

8.5.11 *Progressive Collapse*

The following recommendations shall be followed for ensuring stability of prefabricated structures:

a) Adequate strengthening of external joints of external wall panels is important since these elements are not fully restrained on both sides by floor panels. Adequate design precautions shall be taken.

Connections for the external wall panels are likely to be the weakest points of a precast panel building, if not designed properly;

b) Restraint shall be provided to all load bearing elements at the corners of the building. These elements and the external ends of cross-wall units shall be stiffened either by introducing columns as connecting units or by jointing them to non-structural wall units, which in emergency shall act in force transfer;

c) In prefabricated construction, the possibility of gas or other explosions which can damage primary structural elements leading to progressive collapse of the structure shall be considered. It is, therefore, necessary to consider the possibility of progressive collapse in which the failure or displacement of one element of a structure causes the failure or displacement of another element and results in the partial or total collapse of the building;

d) Provision in the design to reduce the probability of progressive collapse is essential in buildings of height more than 15 m and is of relatively higher priority than for buildings of lower height. However, buildings of special importance shall be checked for progressive collapse irrespective of height guidelines. One way of preventing progressive collapse of external wall panels is to design the combined precast wall panels of entire width as a beam of depth equal to the floor height for the impact loading of upper floors and provide reinforcement accordingly at the top and bottom of all precast wall panels at each floor. To make reinforcement continuous across joints, top and bottom bars projected into joints between wall panels shall be joined with lapping bars;

e) It is necessary to ensure that any local damage to a structure does not spread to other parts of the structure remote from the point of mishap and that the overall stability is not impaired, but it may not be necessary to stiffen all parts of the structure against local damage or collapse in the immediate vicinity of a mishap, unless the design briefs specially require this to be done. The requirements as specified at **8.5** shall be followed to prevent progressive collapse of the structure;

f) Additional protection may be required in respect of damage from vehicles. Further, it is necessary to consider the effect of damage to or displacement of a load-bearing member by an uncontrolled vehicle. It is strongly recommended that important structural members are adequately protected by concrete kerbs or similar method. In areas with possibility of passenger vehicular impact, the precast components shall be designed for an un-factored load of 27 kN, in any direction, acting at heights between 450 mm and 700 mm on an area not larger than 300 mm × 300 mm to produce maximum load effect. This load is not required to act concurrently with any handrail or guard rail system loads; and

g) In all aspects of erection that affect structural design, it is essential that the designer shall maintain a close liaison with the builder/contractor regarding the erection procedures to be followed.

8.5.12 *Key Element*

For buildings of five or more storeys, the layout should be checked to identify key elements. A key element is such that its failure would cause the collapse of more than a limited area close to it. The limited area defined above may be taken equal to 70 m^2 or 15 percent of the area of the storey, whichever is less. If key element exists, it is preferable to modify the layout so that the key element is avoided or design the element for a force of 36 kN/m^2.

8.6 Miscellaneous Items for Joints

8.6.1 *Sealants for Joints*

In choosing the appropriate type of sealant for the joints, consideration should be made in respect of the movements between the components to be joined, the bond that is achievable between the components and the sealant and the nature of the sealing material itself. Hybrid, PU (polyurethane, polysulphide), silicone based, or any other sealant shall be used depending on requirements.

8.6.2 *Joint Width*

Joint widths should be sized to accommodate construction tolerances and movements without overstressing the jointing material. Irrespective of movement, a joint width of 10 mm is the minimum practicable for sealant application.

8.6.2.1 Minimum width of joint between the erected elements or supporting elements shall be as follows:

a) 10 mm, if not specified;

b) 20 mm for wall elements;

c) 30 mm for column elements; and

d) For larger elements as per grouting requirements but shall preferably not exceed 50 mm.

8.6.3 *Joint Preparation*

Satisfactory performance is critically dependent on the satisfactory adhesion of the sealant to the joint surfaces. Primers may be recommended by the manufacturer for some materials. Formwork oils, curing compounds, silicone waterproofing admixtures and surface coating materials may reduce bond and require special precautions.

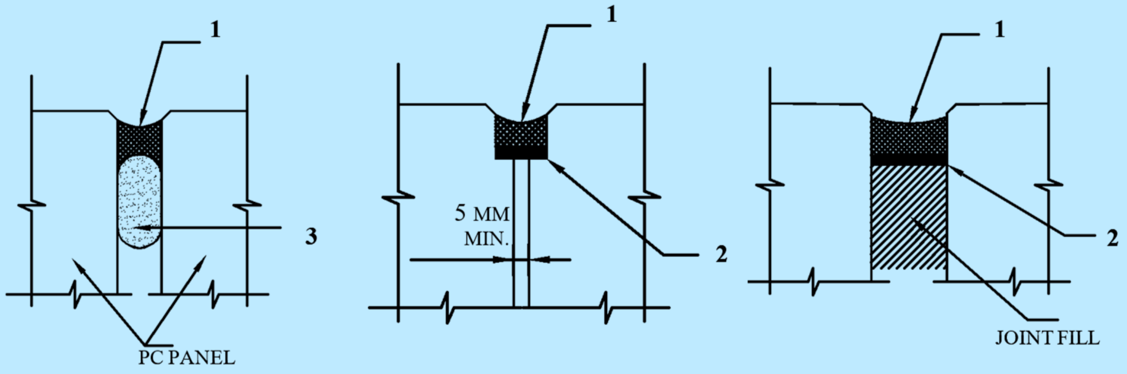
Water jetting, sand blasting, wire brushing or the use of retarder may be required to prepare the concrete joint surfaces in certain instances. Consideration should be given to the use of chamfers to reduce edge damage.

8.6.4 *Back up Material and Bond Breaker*

To ensure good adhesion, a firm backing should be provided for the application of sealants. The required shape and proportions of the sealant are achieved by the correct installation of the back up material.

Sealants in movement joints should not adhere to the backing material to avoid any unnecessary restraint. To ensure that the sealant and back up materials, bond breakers and joints fillers are compatible and appropriate for the proposed end use, advice from the manufacturer should be obtained as necessary.

The sealant backing may be provided by a closed cell foam back up material alone (*see* Fig. 39A), a thin self-adhesive bond breaker tape (*see* Fig. 39B) or a joint filler separated from the sealant by a thin self-adhesive bond breaking tape (*see* Fig. 39C).



39A CLOSED CELL FOAM BACKING

39B) BOND BREAKER TAPE BACKING

39C) JOINT FILLER WITH BOND BREAKER TAPE

1 - SEALANT,
2 - BREAKER TAPE OR BOND BREAKER
3 - BACKER ROD

FIG. 39 BACK-UP MATERIALS AND BOND BREAKERS IN MOVEMENT JOINTS

8.6.4.1 *Minimum joint gap widths*

For elastic sealants, the minimum thickness shall be 5 mm, the ratio of width to thickness should never exceed 1 : 1 and for optimum performance 2 : 1.

8.6.4.2 *Sealant application*

High moisture content may be detrimental to the adhesion of the sealant. Sealing should not be undertaken if there is free water present on the surface of the concrete.

8.6.4.3 *Performance, choice and failure of sealant*

The magnitude of the movement, and also the mode, frequency and rate of movement affect the performance of a sealed joint.

There are many factors affecting the choice of sealant suitable for different types of movement. However, as a general rule, joints which have to accommodate frequent and rapid movement need an elastic sealant, while joints in massive components, with high thermal inertia resulting in much slower movement, may be satisfactorily sealed with an elastoplastic, plasto-elastic or a plastic sealant.

The different ways in which sealants can fail as a consequence of different factors including climatic conditions, environmental factors, substrate incompatibility, abrasion and traffic loading need to be considered when selecting a sealant.

8.6.5 *Sealing Strips*

Preformed sealing strips of appropriate sizes and sections shall be used as required. There are two basic types:

a) Mastic strips; and

b) Impregnated or coated cellular strips.

8.6.5.1 *Mastic strips*

These should be normally installed during the assembly of components. They require an initial compression to ensure proper adhesion to the components forming the joint. As a degree of compression is also required during in service, mastic strips should not be used for joints which open beyond their assembled size.

8.6.5.2 *Impregnated or coated cellular strips*

Impregnated or coated cellular strips may be supplied in a pre-compressed form, and one face may be adhesive coated. When pre-compressed, they can readily be installed within the joint gaps, but should be of a suitable size to be maintained under the degree of compression specified by the manufacturer throughout the range of joint movements. The degree of compression may be varied according to the level of sealing performance required.

To ensure uniformity of compression and stability of the seal, it is important that the joint faces are parallel. Sufficient joint depth shall be provided to accommodate the seal with these depths to width ratios. For external applications, sealing strips should have adequate exposure resistance for the proposed service conditions.

8.6.6 *Joint Fillers*

Fillers for movement joints should be carefully selected to suit their intended use. To ensure that the sealant and filler are compatible, advice from the manufacturer should be sought. Fillers should be non-absorbent with appropriate elastic properties and fire resistant.

8.6.7 *Overlapping of Precast Facade*

The resistance to water penetration between the upper and lower panel of precast facade is commonly provided by an upstand profile. A minimum overlap of 75 mm between the upper and lower panel is recommended.

9 CONSTRUCTION PLANNING

9.1 Pre-Engineering and Design Coordination

9.1.1 *Importance of Pre-Engineering*

Pre-engineering plays a critical role in the planning and execution of any precast concrete project. To ensure a successful outcome, the planning engineer should begin working from the design stage to ensure proper production, installation, connections, and logistics. Key resources must be identified and prepared for each phase of the project, including:

a) Availability land/approvals/water and electricity for a site-based factory;

b) Suitable plant and machinery;

c) Steel moulds;

d) Lifting machinery at factory;

e) Trailers;

f) Lifting machinery on site (tower cranes/mobile cranes); and

g) Site access for transportation of large elements as well as route studies and local regulations and hours for operating large trailers.

9.1.2 *Resource Planning and Feasibility Factors*

The resources should be carefully planned based on the types of project elements and their quantities. The engineer is also responsible for reserving these resources throughout the project duration. Key feasibility considerations include:

a) *Building geometry* — Ensure shapes and geometry are as symmetrical and regular as possible;

b) *Grid-lines* — Column and wall locations should, preferably, follow a standardized pattern;

c) *Height clearances* — Consideration of clear height expectations between beams and slabs;

d) *Grid spacing* — Optimize grid spacing to take full advantage of precast elements; and

e) *Standardization* — Standardize elements within one floor and across multiple floors when feasible.

9.1.3 *Pre-Engineering Design Stage Process*

The pre-engineering design stage should include the following steps:

a) Study of building functionality;

b) Load assumptions and calculations;

c) Preparation of the design basis report (DBR);

d) Structural analysis;

e) Preliminary framing plan selection for precast elements;

f) Approval of preliminary framing plans by the architect/client;

g) Review meetings with architects and consultants;

h) Finalization of the structural framing plan after incorporating feedback and value engineering;

j) Release of the good for construction (GFC) and structural framing plan (R0), including:

    1) Geometry of precast elements;

    2) General arrangement (GA) drawings with reinforcement details; and

    3) Connections and inserts.

k) Coordination with mechanical, electrical, plumbing and other service consultants should occur during the early stages.

9.2 Project Planning, Scheduling and Monitoring

9.2.1 *Production Planning*

Careful planning is essential for ensuring that precast concrete systems are produced efficiently. Key factors to address include:

a) Synchronization of manufacturing schedules and resources to meet construction and storage needs;

b) Anticipation of any special transportation or access challenges;

c) Use of detailed production shop drawings to facilitate smooth execution; and

d) Factory curing periods for high strength concrete elements.

9.2.1.1 *Shop drawings*

Shop drawings should contain:

a) Member shapes (elevations and sections) and dimensions;

b) Details of reinforcement, anchors, inserts, etc;

c) Connection details;

d) Production tolerances;

e) Handling and lifting devices;

f) Finishing and bearing seat details;

g) Transportation and storage methods; and

h) Unique identification of elements (ID, location and orientation).

9.2.1.2 *Factory vs on-site production*

A decision whether precast elements should be produced in an off-site factory or on-site, based on factors such as:

a) Project scale and volume;

b) Availability of factory space near the site;

c) Contractual agreements regarding space provision;

d) Element type, weight, and size; and

e) Cost-benefit analysis.

9.2.2 *Production Schedule*

9.2.2.1 *Cycle time and throughout rate and the key aspects*

a) *Cycle time* — refers to the total time to complete one production cycle of an element, from mould preparation to quality checks and delivery; and

b) *Throughput rate* — refers to the rate of production (units per day, week, or month).

9.2.2.2 *Developing the production schedule*

A production schedule developed based on the following:

a) Splitting the floor plan into various ‘installation parts’, typically aligned with crane locations and capacities;

b) Estimation the number of elements per part and the installation duration for each part based on element type and connection complexity;

c) Using historical data and experience to estimate installation cycle times for each element;

d) Assigning unique element IDs to each installation part and sequence them accordingly;

e) Publishing a sequence chart that includes:

    1) Planned drawing release date;

    2) Planned casting date;

    3) Planned transportation date; and

    4) Planned installation date.

9.3 Project and Factory Logistics Planning

9.3.1 *Haulage Planning*

Transportation constraints influence the size and shape of precast elements. The following factors should be considered in haulage planning:

a) Trailer lengths (standard lengths of 6 m, 12 m, with special cases up to 30 m);

b) Trailer width (typically between 2.4 m to 2.7 m);

c) Height clearance (3.6 m to 4 m, adjustable with low-bed trailers);

d) Weight capacity (25 MT to 35 MT);

e) Special permits for oversized loads that may be needed;

f) Route surveys and permissions to be obtained if crossing bridges or navigating urban areas; and

g) Large element transportation time slots through day/night as per local regulations.

9.3.2 *Factory Stockyard and Logistics Coordination*

Precast elements in the factory stockyard should be stored using first in, first out (FIFO) or last in, first out (LIFO) methods, depending on site requirements. Proper stock registers and inventory management software should be used for efficient tracking and organization. Storage size of the yards should be defined by the minimum concrete strength and curing periods.

9.3.3 *Crane Planning*

A comprehensive crane layout should be developed in collaboration with the installation planning engineers considering the following:

a) Types of cranes (tower cranes, mobile cranes);

b) Site constraints (space, access);

c) Ground strata for crane footing;

d) Lifting capacities and feeding locations;

e) Crane removal and repositioning areas; and

f) Double handling constraints due to storage at site or crane reach.

9.4 Installation Sequence

Once the casting sequence is set, installation dates to each element should be assigned based on factors such as:

a) Crane type and operational speed;

b) Reduced crane efficiency where multiple cranes are deployed with overlapping zones;

c) Element type and installation cycle time;

d) Connection complexity;

e) Grouting and curing durations;

f) The number of shifts and crane operation hours; and

g) Adjustment of installation dates and resources as needed based on available machinery and logistics.

9.5 On Site Work Planning

9.5.1 *Surveying*

The first activity on-site is surveying and line-out. It should be ensured that key points are marked, including:

a) Building corners and faces;

b) Compound wall boundaries;

c) Grid lines and column centres;

d) Footing corners;

e) Shear wall grid lines; and

f) Site constraints such as high-tension lines or existing canals or water bodies or filled up areas or marsh lands.

9.5.1.1 Drone surveys are recommended for more accurate and automated site measurements, which also help in tracking progress.

9.5.2 *Cast-In Situ Works*

Cast in-situ (CIS) work is crucial in precast projects. The interface between precast and CIS activities typically occurs during installation and connection phases. The interfaces of the joints shall be roughened to ensure proper bonding with the CIS concrete or grout. Minimizing inter-trade dependencies improves project success in terms of both time and cost. This interface also needs careful attention, as the dowels projecting from precast elements may have higher variation that affects precast installation. Detailed as-built surveys must be completed well in advance to avoid last minute repairs and long delays.

9.6 Digital Tracking and Monitoring Tools

To enhance precision and efficiency, building information modelling (BIM) may be implemented for both production and assembly of precast elements. This technology supports:

a) Access to real-time drawing by all engineers, reducing errors;

b) Seamless use across production, installation, and progress monitoring stages; and

c) Required infrastructure such as Wi-Fi network and system access between various agencies are be in place.

10 CONSTRUCTION, MANUFACTURE, STORAGE, TRANSPORT AND ERECTION OF PRECAST ELEMENTS

10.1 Manufacture of Precast Concrete Elements

10.1.1 A precast facility shall be located based on proximity to raw materials, logistics infrastructure, storage capacity, and crane access to ensure economic production and streamlined erection.

10.1.2 *Manufacture*

Precast elements may be manufactured at a permanent factory or temporary site facility, selected based on project scale, logistics, and environmental goals. For reduction in site pollution and wastage to achieve sustainability in precast construction a reference may be made to G-4.

10.1.2.1 *Factory prefabrication*

Factory prefabrication involves the commercial production of standardized components in a factory setting, typically for long-term manufacturing. It is a capital-intensive process where work is carried out year-round, ideally under a covered shed to minimize the impact of seasonal variations. This type of facility allows for high levels of mechanization, with production organized in a factory-like manner, supported by a consistent team of workers.

10.1.2.2 *Site prefabrication*

Site prefabrication refers to the production of precast components at or near the construction site and shall be adopted for large-scale or long-duration projects where it offers measurable advantages in transportation cost and productivity. Although temporary, the site factory should be comparable to a permanent facility with strict quality control. There are the following two types of site prefabrication:

a) *Semi-mechanized* — Carried out in open areas using primarily local labour, with minimal equipment; moulds may be stationary or mobile, and the level of skill shall be appropriate to the component complexity; and

b) *Fully-mechanized* — Conducted within covered sheds using skilled labour and factory-grade machinery, designed for high-volume and high-quality precast production.

10.1.2.3 *Precast factory quality audits*

All precast production facilities shall undergo quality audits at least annually. Audits shall be conducted by a competent team jointly approved by the contractor and client. Audit scope shall include production quality, safety and documentation.

10.1.3 The manufacturing of precast elements shall involve three categories of processes: core, auxiliary and subsidiary. Each category shall be planned and coordinated to ensure continuous, high-quality production.

10.1.3.1 *Core process*

The main processes that include the following steps:

a) Providing and assembling moulds, positioning the reinforcement cage for reinforced concrete work and stressing the wires for prestressed elements;

b) Installing concealed service conduits/pipes;

c) Fixing inserts and tubes as necessary (for handling purposes);

d) Pouring concrete into the moulds;

e) Vibrating and finishing the concrete;

f) Curing the concrete; and

g) Demoulding the forms and stacking the precast products.

10.1.3.2 *Auxiliary process*

These processes are necessary for the successful completion of the core processes and include the following:

a) Mixing and producing fresh concrete (carried out in a mixing station or batching plant);

b) Prefabricating the reinforcement cage (performed in a steel yard or workshop);

c) Manufacturing inserts and other finishing components to be incorporated into the main precast products; and

d) Finishing the precast products.

10.1.3.3 *Subsidiary process*

Subsidiary processes shall include material handling, maintenance and utility services essential for uninterrupted production. These shall include:

a) Proper storage of raw materials;

b) Internal transport systems for fresh concrete and cages;

c) Safe movement and stacking of precast elements;

d) Periodic servicing of equipment and moulds; and

e) Maintenance of curing and utility facilities (for example, steam).

10.1.4 The manufacturing of precast elements requires systematic planning of all the processes to achieve the following objectives:

a) A cyclic working method to enhance speed and cost-efficiency in production;

b) Mechanization of processes to boost productivity and improve quality;

c) Optimal production levels that meet quality control standards while maintaining the desired construction speed;

d) Improved working conditions for the workforce; and

e) Minimization of weather-related disruptions to the manufacturing schedule.

10.1.5 The various stages of precasting, as outlined in Table 12, are classified based on the equipment required for each stage. This classification facilitates the mechanization and rationalization of work throughout the process. Stages 6 and 7, as shown in Table 12, represent the core processes in the manufacturing of precast concrete elements. For these stages, various technological processes are employed, tailored to the specific concrete product being produced. These methods have been proven to be rational, economical and time-saving. Figure 40 provides a diagrammatic representation of the different stages involved in the plant process.

10.1.6 The accepted methods of manufacturing precast units can be broadly classified into two categories:

a) The stationary method, where the moulds remain in a fixed position and the various processes are carried out in a cyclic order at the same location; and

b) The circulation method, where the precast unit moves through different stages of production, with the processes being carried out in an assembly-line fashion.

The various accepted pre-casting methods are listed in Table 13 along with the details regarding the elements that can be manufactured by these methods.

Table 12 Stages of Precasting of Concrete Products

(*Clause* 10.1.5)

Sl No. (1)	**Precasting Stage No.** (2)	**Name of Process** (3)	**Operations Involved** (4)
i)	1	Procurement and storage of construction materials	Unloading and transport of cement, coarse and fine aggregates and steel, and storing them in bins, silos or storage sheds
ii)	2	Testing of materials	Testing of all materials including steel
iii)	3	Design of concrete mix	Testing of raw materials, plotting of grading curves and trial of mixes in laboratory
iv)	4	Making of reinforcement cages	Unloading reinforcement bars from wagons or lorries and stacking them in the steel yard, cutting, bending, tying or welding the reinforcements and making in the form of a cage, which can be directly introduced into the mould
v)	5	Applying form release agent and laying of moulds in position	Moulds are cleaned, applied with form release agent, and assembled and placed at the right place
vi)	6	Placing of reinforcement cages, inserts and fixtures	The reinforcement cages are placed in the moulds with spacers, etc, as per data sheet prepared for the specific prefabricate units. Pre-tensioning of wires in the case of pre-stressing of concrete element

Table 12 (*Concluded*)

Sl No. (1)	Precasting Stage No. (2)	Name of Process (3)	Operations Involved (4)
vii)	7	Preparation of green concrete	Taking out aggregates and cement from bins, silos, etc, batching and mixing
viii)	8	Transport of green concrete	Transport of green concrete from the mixer to the moulds. In the case of precast method involving direct transfer of concrete from mixer to the mould or a concrete hopper attached to the mould this prefabrication stage is not necessary
ix)	9	Pouring and consolidation of concrete	Concrete is poured and vibrated to a good finish
x)	10	Curing of concrete and demoulding	Either natural curing with water or an accelerated curing using steam and other techniques. In the case of steam curing using trenches or autoclaves, this stage involves transport of moulds with the green concrete into the trench or autoclave and taking them out after the curing and demoulding elements. Cutting of protruding wires also falls in this stage. In certain cases, the moulds have to be partly removed and inserts have to be removed after the initial set. Final demoulding is done after concrete has gained designed strength, enough to resist handling stress, and the components are then allowed to be cured further. The minimum curing duration is as per Part C/Section 5 of this NBCS except in cases where the design strength of the precast element is achieved earlier. In that case, curing only up to achieving the design strength is sufficient, subject to appropriate approvals
xi)	11	Stacking of precast elements	Lifting of precast elements from the mould and transporting to the stacking yard for further transport by trailer or rail is part of this stage
xii)	12	Testing of finished components	Tests are carried out on the components individually and in combination to ensure the adequacy of their strength
xiii)	13	Miscellaneous	a) Generation of steam involving storing of coal or oil necessary for generation of steam and providing insulated steam pipe connection up to the various lines b) Repair of machines used in the production

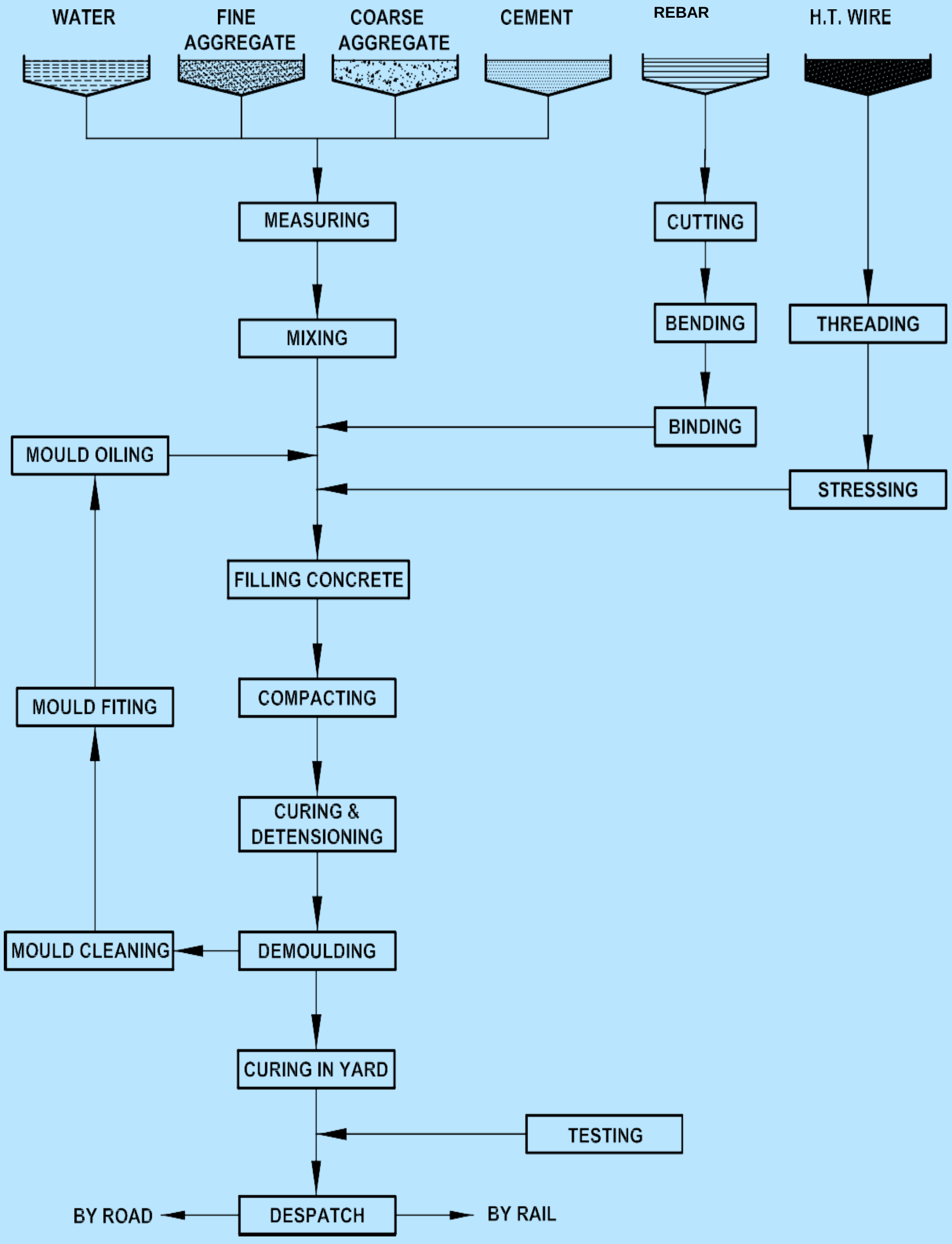

WATER
FINE AGGREGATE
COARSE AGGREGATE
CEMENT
REBAR
H.T. WIRE
MEASURING
CUTTING
MIXING
BENDING
THREADING
BINDING
MOULD OILING
STRESSING
FILLING CONCRETE
MOULD FITING
COMPACTING
CURING & DETENSIONING
MOULD CLEANING
DEMOULDING
CURING IN YARD
TESTING
BY ROAD
DESPATCH
BY RAIL

FIG. 40 PLANT PROCESS

Table 13 Precasting Methods

(*Clauses* 10.1.6 *and* 10.6.1)

Sl No.	Precasting Method	Where Used	Recommended Dimensions and Weights	Advantages and Remarks
(1)	(2)	(3)	(4)	(5)
i)	*Individual mould method* — Precasting method using mould which may be easily assembled out of bottom and sides, transportable, if necessary. This may be either in timber or in steel using needle or mould vibrators and capable of taking pre-stressing forces	Ribbed slabs, beams, girders, window panels, box type units and special elements, prestressed railway sleepers, parts of pre-stressed girders, etc	No limit in size and weight. It depends on the equipment used for demoulding, transporting and placing	Strengthening of the cross-section possible Openings are possible in two planes
ii)	*Battery mould method* — The shuttering panels may be adjusted into the form of a battery at the required distances equal to the thickness of the concrete member	Interior wall panels, shell elements, reinforced concrete battens, rafters, purlins, roof and floor slabs	Length ≤ 9 m Height ≤ 3 m Mass ≤ 5 t	Especially suitable for mass production of wall panels where shuttering cost largely reduced. Vapour or steam curing may be adopted by taking the steam pipes through the shuttering panels
iii)	*Stack method*	Floor and roof slab panels	Length: Any desired length Breadth: 1 to 4 m Mass ≤ 5 t	For casting identical reinforced or pre-stressed panels one over the other with separating media interposed in between
iv)	*Tilting mould method* — This method is capable of being skipped vertically using hydraulic jacks	Exterior wall panels where special finishes are required on one face or for sandwich panel	Length ≤ 6 m Breadth ≤ 4 m Mass ≤ 5 t	Suitable for manufacturing the external wall panels
v)	*Long line prestressing bed method*	Double tees, ribbed slabs, purlins, piles and beams	Length ≤ Any desired length Breadth ≤ 2 m Height ≤ 2 m Mass : Up to 10 t	Ideally suited for pretension members
vi)	*Extrusion method* — Long concrete mould with constant cross-section where concreting and vibration are done automatically just as in hollow cored slab casting	Roof slabs, foam concrete wall panels and beams cross-section	Length : Any desired length Breadth : < 2 m Height : < 3 m	May be used with advantage in the case of un-reinforced blocks, foam concrete panels

10.1.7 *Preparation and Storage of Materials*

Proper storage of materials is crucial in the precast industry, as errors in planning this aspect can significantly impact production economics. In a precast factory, where quality is paramount, the proper storage and preservation of building materials especially cement, coarse aggregates and fine aggregates are essential. Materials should be stored in accordance with accepted standard [C-7(21)]. Additionally, precast elements should follow a 'first-in, first-out' (FIFO) system to minimize or avoid issues related to shrinkage, creep and other material-related concerns.

10.2 Moulds

10.2.1 Moulds used for the manufacture of precast elements may be made from steel, timber, concrete, plastic, or a combination of these materials. When designing moulds for various elements, special attention should be given to facilitating easy demoulding and the assembly of parts. Additionally, the rigidity, strength, and watertightness of the mould are critical, especially considering the forces involved during the pouring of green concrete and the vibrating process. The deflection of any supporting member of the mould shall not exceed $L/350$ or 3 mm, whichever is less, where L represents the span of the member in millimetres).

10.2.2 Tolerances

The moulds shall be designed to accommodate the tolerances as per the casting tolerances given in Table 14.

Table 14 Casting Tolerances for Precast Components

(*Clause* 10.2.2)

Sl No.	Product (*See* Key No.)	Product Tolerances
(1)	(2)	(3)
i)	*Length*:	
	1, 10, 12, 15, 16, 17	± 5 mm
	9, 11	± 10 mm
	2, 3, 4, 6, 7, 8	± 10 mm
	5	± 2 mm for length below and up to 500 mm ± 5 mm for length over 500 mm
	13, 14, 18, 19	± 15 mm
ii)	*Thickness/cross sectional dimensions*:	
	1	± 3 mm
	2, 8	± 3 mm or 0.1 percent, whichever is greater
	4, 5, 7, 10, 12, 15	± 3 mm, for thickness up to 300 mm ± 5 mm, for thickness greater than 300 mm
	3, 6, 9, 11, 16, 17, 18, 19	± 5 mm
	13, 14	+ 5 mm, - 3 mm
iii)	*Straightness/bow*:	
	2, 4, 5, 7, 8, 10, 15, 16, 18	1/360 of length, maximum of ± 10 mm
	1, 5	± 3 mm
iv)	*Squareness* — When considering the squareness of the corner, the longer of two adjacent sides being checked shall be taken as the base line:	
	a) *Skew across width of an end:*	
	15	± 3 mm per 300 mm length, with maximum of ± 5 mm
	7, 9	± 3 mm per 300 mm length, with maximum of ± 10 mm
	1, 2, 4, 5, 8, 10, 11	± 3 mm per 300 mm length, with maximum of ± 15 mm

Table 14 (*Concluded*)

Sl No.	Product (*See* Key No.)	Product Tolerances
(1)	(2)	(3)
	b) *Skew across thickness or depth or height of an end*:	
	12, 16	± 3 mm
	4, 7, 8, 16	± 3 mm per 300 mm length
	13, 14	Depth ≤ 600 mm, ± 5 mm Depth ≥ 600 mm ± 1.5 mm for 300 mm length with maximum of ± 15 mm
v)	*Twist* — Any corner shall not be more than the tolerance given below from the plane containing the other three corners:	
	2, 8	5 mm, Up to 600 mm in width and up to 6 m in length 10 mm, Over 600 mm in width and for any length
	4	± 1/1 500 of dimension or ± 5 mm, whichever is less
	1	± 3 mm
	7	± 1 mm
vi)	*Flatness* — The maximum deviation from 1.5 m straight edge placed in any position on a nominal plane surface shall not exceed:	
	2, 8	± 5 mm
	4	± 3 mm
	1	± 2 mm
	5	± 5 mm or maximum of 0.1 percent length
vii)	*Warping* — Deviation from plane in which the corners of the panel do not fall within the same plane:	
	2, 4, 5, 7, 8, 16, 18	± 1.5 mm per 300 mm length
	10, 15	± 5 mm

Key No.

1	Channel unit	7	Precast planks	14	Double tee
2	Ribbed slab unit/hollow slab	8	Ribbed/plain wall panel	15	Stadium riser
3	Waffle unit	9	Column	16	Cladding panel/facade
4	Large panel prefabricatio	10	Step unit	17	H-Frame
5	Cellular floor/roof slabs	11	Beam and spandrel	18	Foundation units
6	Prefabricated brick panel	12	Modular unit	19	Drain
		13	Single tee		

10.2.3 *Mould Wall Slopes*

To facilitate the easy removal of precast elements from the mould, particularly when the mould has fixed sides and the elements need to be lifted out, the side slopes should ideally be 1 in 6 but shall not be less than 1 in 12. For slopes less than 1 in 6, the mould should have provisions of appropriate hydraulic jacks at the base of the mould to assist demoulding. A gentle slope helps prevent the elements from becoming stuck in the mould during demoulding.

10.3 Accelerated Curing

In precasting factories, using accelerated or artificial curing methods is economical, as it allows elements to be demoulded much earlier, enabling the early re-use of moulds. Any of the following methods shall be adopted:

10.3.1 *Steam Curing*

10.3.1.1 The steam curing of concrete products shall take place under tarpaulin in tents, under hoods, under chambers, in tunnels or in special autoclaves. The steam shall have a uniform flow throughout the length of the member. The precast elements shall be so stacked with sufficient clearance between each other and the bounding enclosure, to allow proper circulation of steam.

10.3.1.2 Before the concrete products are subjected to any accelerated method of curing, the cement to be used shall be tested for soundness, setting time and suitability for steam curing.

10.3.1.3 In the case of elements manufactured by accelerated curing methods, concrete admixtures to reduce the water content may be allowed to be used. The normal aeration agents used to increase the workability of concrete should not be allowed to be used. Use of calcium chloride-based admixtures should not be used for reinforced concrete elements so as to meet the chloride limits prescribed in Part C 'Structural design, Section 5 Structural Concrete' of this NBCS.

10.3.1.4 The inside face of the steam curing chamber, tunnel or hood shall have a damp-proof layer to maintain the humidity of steam. Moreover, a proper slope shall be given to the floor and the roof to allow the condensed water to be easily drained away. When steam is first let into the curing chambers, the air inside shall be allowed to go out through openings provided in the hoods or side walls which shall be closed soon after moist steam is seen jetting out.

10.3.1.5 It is preferable to let in steam from the top of the chamber through perforated pipelines to allow uniform entry of steam throughout the chamber.

10.3.1.6 The fresh concrete in the moulds should be allowed to get the initial set before allowing the concrete to come into contact with steam. The regular heating up of fresh concrete products from about 20 °C to 35 °C should start only after a waiting period ranging from 2 h to 5 h depending on the setting time of cement used. It may be further noted that steam can be let in earlier than this waiting period, provided the temperature of the concrete product does not rise beyond 35 °C within this waiting period.

10.3.1.7 The second stage in steam curing process is to heat up the concrete elements, moulds and the surroundings in the chamber in the following manners:

a) In the low-pressure steam curing, the airspace around the member is heated up to a temperature of 75 °C to 80 °C at a gradual rate, usually not faster than 30 °C/h (this process takes around 1 h to 1 h 30 min depending upon outside temperature); and

b) In the case of curing under high pressure steam in autoclaves, the temperature and pressure are gradually built up during a period of about 4 h.

10.3.1.8 The third stage of steam curing is to maintain the uniform temperature and pressure for a duration depending upon thickness of the section. This may vary from 3 h to 5½ h in the case of low-pressure steam curing and 4 h to 7 h in the case of high-pressure steam curing.

10.3.1.9 The fourth stage of steam curing is the gradual cooling down of concrete products and surroundings in the chamber and normalization of the pressure to bring it at par with outside air. The maximum cooling rate, which is dependent on the thickness of the member, should normally not exceed 30 °C/h.

10.3.1.10 In all these cases, the difference between the temperature of the concrete product and the outside temperature should not be more than 60 °C for concrete up to M30 and 75 °C for concretes of M45 or greater. In the case of light weight concrete, the difference in temperature should not be more than 60 °C for concretes less than M25. For concretes greater than M50, the temperature differences can go up to 75 °C.

10.3.2 *Vapour Curing*

Vapour curing shall consist of maintaining a high relative humidity around the concrete by means of application of moisture in the form of vapour or steam. The system and requirements shall be similar to those specified under 10.3.1. The temperature range to be maintained shall be as recommended by the manufacturer of the equipment, depending upon the product requirements.

10.3.3 *Steam Injection during Mixing of Concrete*

Low pressure saturated steam shall be injected into the mixer during the mixing of aggregates. This process shall raise the temperature of the concrete to about 60 °C. Concrete so produced, when placed in the moulds, shall develop high early strength.

10.3.4 *Heated Air Method*

The concrete elements are kept in contact with hot air with a relative humidity not less than 80 percent. This method is particularly suitable for light weight concrete products using porous coarse aggregates.

10.3.5 *Hot Water Method*

The concrete elements shall be immersed in a bath of hot water maintained at a temperature between 50 °C and 80 °C. The principles of this method shall generally be similar to those of steam curing.

10.3.6 CO_2 *Curing*

Carbon dioxide shall be injected into the concrete during mixing. This promotes faster hydration and is particularly effective in accelerating the hardening of precast concrete elements, thereby improving both efficiency and quality.

10.3.7 Concrete elements subjected to any of the accelerated curing methods specified in **10.3.2** to **10.3.6** shall be subjected thereafter to normal curing methods, so as to enable the development of the final strength.

10.3.8 *Other Methods of Accelerated Hardening*

Accelerated hardening of concrete may also be achieved by one or more of the following techniques:

a) *Use of Construction Chemicals* — Suitable construction chemicals may be used for promoting early hardening;

b) *Consolidation by Spinning* — This method shall generally be employed in centrifugal moulding of pipes and similar units. The spinning action removes excess water, effects consolidation, and permits earlier demoulding;

c) *Pressed Concrete* — This method shall be suitable for the fabrication of small or large products at high rates of production. Presses in the range of 100 t to 200 t capacity shall be used to compress the wet concrete in rigid moulds, thereby expelling excess water. This results in early handling and produces dense, wear-resistant concrete;

d) *Vacuum Treatment* — In this method, surplus air and water shall be removed from the freshly placed concrete (for example, slabs and similar elements). A suction of up to 70 percent of an atmosphere shall be applied for a period of 20 min to 30 min per cm thickness of the units; and

e) *Consolidation by Shock* — This method shall be suitable for small concrete units placed in strong moulds and subjected to repeated dropping from a height. The number of shocks required to expel excess water and air may vary from 6 to 20 and the height of drop may be up to half the depth of the mould.

10.3.9 *Stacking During Transport and Storage*

Every precaution shall be taken against overstress or damage, by the provision of suitable packing at agreed points of support. In general, the final condition of the elements in the structure should be studied to finalize on the staking support. Even number of supports is preferred over the odd number of supports. Particular attention is directed to the inherent dangers of breakage and damage caused by supporting other than at two positions, and by the careless placing of packing (for example, not vertically one above the other). Ribs, corners and intricate projections from solid section should be adequately protected. Packing pieces shall not stain, disfigure or otherwise cause permanent mark on units or members. Stacking shall be arranged, or the precast units protected, to prevent the accumulation of trapped water or rubbish and, if necessary, to reduce the risk of efflorescence.

The following points shall be kept in view during stacking:

a) Care should be taken to ensure that the flat elements are stacked as per their final position at the structure. For identification, top surfaces should be clearly marked;

b) Stacking should be done on hard and suitable ground to avoid any sinking of support when elements are stacked;

c) In case of horizontal stacking, packing materials shall be at specified locations and shall be exactly one over the other to avoid cantilever stress in panels;

d) Components should be packed in a uniform way to avoid any undue projection of elements in the stack which normally is a source of accident;

e) In general, vertical stacking should be limited to 6 components to 10 components. Minimum ground capacity shall be 5 t/m^2 for stacking of panels. Where the ground is only compacted, the maximum ground load at support should be restricted to 15 t/m^2. Where the ground is of PCC layer, the maximum ground load at support should be restricted to 30 t/m^2 subjected to capacity of the ground. In both cases, the ground should be levelled, and the support should be continuous along the width of the panels; and

f) All wall panels shall be stacked, preferably symmetrically on both sides, against steel A-frames. The slope of the sides of the A-frame shall be between 75° and 80° to the horizontal and the bottom of the frame shall be provided with concrete footings to resist component of self- weight and horizontal wind pressure on the wall panel. A similar type of A-frame should be used for transporting wall panels.

10.4 Handling Arrangements

10.4.1 Lifting and handling positions shall be clearly defined particularly where these sections are critical. Where necessary special facilities, such as bolt holes or projecting loops, shall be provided in the units and full instructions supplied for handling. For bolts/hooks, bond strength shall be the criteria for embedded bolts and bearing strength for through bolts. For bond strength, pull out test of concrete shall be carried out. *See* **10.8** for additional design considerations.

10.4.2 For precast pre-stressed concrete members, the residual pre-stress at the age of operation of handling and erection shall be considered in conjunction with any stresses caused by the handling or erection of member. The compressive stress thus computed shall not exceed 50 percent of the cube strength of the concrete at the time of handling and erection. Tensile stresses up to a limit of 50 percent above those specified in Part C/Section 5 of this NBCS shall be permissible.

10.5 Identification and Marking

All precast units shall bear an indelible identification, location and orientation marks as and where necessary. The date of manufacture shall also be marked on the units.

The identification markings on the drawings shall be the same as that indicated in the manufacturer's literature and shall be shown in a tabular format on the setting schedule together with the length, type, size of the unit, and the sizes and arrangement of all reinforcement. Implementation of QR Code or similar stickers pasted on precast elements with above mentioned details are highly recommended.

10.6 Transport

Transport of precast elements inside the factory and to the site of erection is of considerable importance not only from the point of view of economics but also from the point of view of design and efficient management. Transport of precast elements shall be carried out with extreme care to avoid any impact and distress in elements and handled as far as possible in the same orientation as it is to be placed in the final position. *See* **10.8** for additional design considerations.

10.6.1 *Transport Inside the Factory*

Transport of precast elements moulded inside the factory depends on the method of production selected for the manufacture as given in Table 13.

10.6.2 *Transport from Stacking Yard Inside the Factory to the Site of Erection*

10.6.2.1 Transport of precast concrete elements from the factory to the site of erection should be planned in such a way to be in conformity with the traffic rules and regulations as stipulated by the Authorities. The size of the elements is often restricted by the availability of suitable transport equipment, such as tractor-cum-trailers, to suit the load and dimensions of the member in addition to the opening dimensions under the bridge and load carrying capacity while transporting the elements over the bridge.

10.6.2.2 While transporting elements in various systems, that is, wagons, trailers, trucks, etc, care should be taken to avoid excessive cantilever actions and desired support are maintained. Transportation of prefabricated elements should be carried out with care. Sufficient care should be taken to also protect the steel inserts and reinforced bars of the precast elements during transportation. Precast elements should be secured with safety ties to ensure that vibrations to the elements in transit are minimum. Special care should be taken at location of sharp bends and on uneven or slushy roads to avoid undesirable stresses in elements.

10.6.2.3 Before loading the elements, care should be taken to ensure that the base packing for supporting the elements is located at specified positions only. Subsequent packing shall be kept strictly one over the other.

10.7 Erection

10.7.1 Tower cranes or other mobile cranes have varying lifting capacities at different radii, with the maximum weight at a radius closer to the centre and the minimum weight at a radius farther from the centre. To minimize the number of precast elements, the selected crane should be capable of handling the heaviest precast elements at its maximum radius. The floor plan should indicate the weight of panels at different crane radii, ensuring they align with the crane's lifting capacity at each radius.

In the erection of precast elements, all the following items of work are meant to be included:

a) Slinging of the precast element;

b) Tying up of erection ropes connecting to the erection hooks;

c) Cleaning of the elements and the site of erection;

d) Cleaning of the steel inserts before incorporation in the joints, lifting of the elements, setting them down into the correct envisaged position;

e) Adjustment to get the stipulated level, line and plumb by means of levelling bolts and adjustable props;

f) Welding of cleats;

g) Changing of the erection tackles;

h) Putting up and removing the necessary scaffolding or supports;

j) Welding of the inserts, laying of reinforcements in joints and grouting the joints; and

k) Finishing the joints to bring the whole work to be like finished product.

See **10.8** for additional design considerations.

10.7.2 Since the erection work in various construction jobs using prefabricated concrete elements differs from place to place depending on the site conditions, safety precautions in the work are of utmost importance. Hence, only those skilled foremen, trained workers and fitters who have been properly instructed about the safety precautions to be taken should be employed on the job.

10.7.3 Transport of people, workers or visitors, by using cranes shall be strictly prohibited on an erection site.

10.7.4 *For Travelling Cranes*

a) The travel tracks shall be perfectly levelled both longitudinally and transversally;

b) The gauge shall be constant and the rail tracks perfectly straight and with the same shape along the entire path;

c) The rail tracks shall be placed on a solid base;

d) Travelling stop buffers shall be placed at the ends of the rail tracks;

e) For rail shape tolerances, the OEM’s installation manual shall be referred; and

f) The track of the crane should be checked daily to see that all fish plates and bolts connecting them to the sleepers are in place and in good condition.

10.7.5 The operation of all equipment used for handling and erection shall follow the operations manual provided by the manufacturer. All safety precautions shall be taken in the operations of handling and erection.

10.7.6 *Erection Tolerances*

As per Table 15.

Table 15 Erection Tolerance for Precast Components

(*Clause* 10.7.6)

Sl No. (1)	Product (2)	Tolerances mm (3)
i)	Level differences between support lines of floor or wall panels	± 5
ii)	Plumb lines of wall panels	± 5
iii)	Bearing for precast floor panels	± 5
iv)	Joint dimensions	± 5
v)	Maximum accumulated deviation	
	a) Till 10 storey building	1/1 250 of height or length or ± 20
	b) Greater than 20 storey building	1/1 250 of height or length or ± 50 (whichever is lesser)
vi)	Variation in plan location (any column or beam, any location)	± 10 for column ± 15 for beams
vii)	Variation in plan parallel to specified building lines	+ 2 mm per meter for any beam less than 6 m long or adjacent to columns paced 6 m apart or less 15 mm maximum for adjacent columns spaced more than 6 m

10.8 Design Considerations

Based on the design intent, production environment and aesthetic requirements of the prefabricated panels, the resultant stresses should be controlled to minimize cracking in precast and/or prestressed panels. Precast (non-prestressed) components are generally designed as ‘cracked’ unless cracking is an aesthetic concern. However, demoulding of precast elements shall not be allowed until the concrete achieves a strength of at least 1.25 times the (extreme fibre) stress which the concrete may be subjected at the time of demoulding. The same shall be applicable while transporting and erection. Reference may be made to Table 7 for load multiplier to ascertain handling stress. The strength referred to shall be that of concrete using the same cement and aggregates and admixture, if any, with the same proportions and cured under conditions of temperature and moisture similar to those existing on the work.

10.8.1 Structural design requirements of minimum spacing, skin reinforcement and crack width criteria as specified in Part C 'Structural Design, Section 5 Structural Concrete' of this NBCS should be applicable.

10.8.2 Lifting hooks should be located such that while lifting the panel, minimum bending moments are produced.

10.8.3 Static load multipliers should be used to account for impact, and demoulding forces as per Table 7.

10.8.4 The load multipliers are only needed for the flexural design and are not applicable for the lifting devices. Lifting hooks shall be designed as per **7.14.6**.

10.8.4.1 For wall panels cast vertically on tilting moulds, battery moulds, and other vertically cast elements, the required concrete strength is not always dictated by flexural stresses. Instead, the minimum concrete strength during the initial lift may be governed by the capacity requirements of the lifting inserts. The capacity of the lifting inserts may be lower than their rated value due to factors such as inadequate embedment depth, insufficient edge distances, or low concrete strength at the time of lifting. Therefore, higher concrete strengths than those recommended in Table 9 may be necessary to fully develop the capacity of certain lifting inserts and ensure the safe handling of the panels.

10.8.4.2 For prestressed elements, special care must be taken to ensure that lifting devices are anchored in compression zones, unless otherwise specified by the design.

10.8.4.3 Initial lifting should be done cautiously and gradually to overcome suction and friction, avoiding the application of sudden impact forces.

10.9 Equipment

10.9.1 The strategic equipment used in the precast concrete industry/construction may be classified into the following categories:

a) *Production equipment* — Batching plant, concrete shuttle conveyors concrete vibrators, circulation tables, EOT, gantry, shear lines, stirrup making machines, weld mesh machines, robots;

b) *Erection equipment* — Tower cranes, Mobile cranes, derricks, hoists, chain pulley blocks, etc;

c) *Transport machinery* — Tractor-*cum*-trailers, dumpers, lorries, locomotives and rarely even helicopters;

d) *Workshop machinery* — For making and repairing steel and timber moulds;

e) Minor tools and tackles, such as lifting equipment, electric vehicle-dumpers, concrete buckets, etc; and

f) Steam generation plant for accelerated curing.

Each of the above groups may further be classified into various categories of machines and further to various other types depending on the source of power and capacity. For use of renewable energy sources to achieve sustainability in precast construction **G-3** shall be referred.

10.9.2 *Mechanization of the Construction and Erection Processes*

The processes can be mechanized/automated, similar to other industries, to achieve the benefits of mass production of standardized components. This approach will enhance productivity, lower production costs over time and ensure consistent product quality.

10.10 Systems for Mixed and Composite Construction

The system of mixed and composite construction depends on the extent of the use of prefabricated components, their materials, sizes and the technique adopted for their manufacture and use in building.

10.10.1 *Combinations of System Components for Mixed and Composite Construction*

The following combinations may be used in mixed and composite construction:

a) Structural steel work and timber roofs on precast frames;

b) Precast half slab, solid slabs, hollow core slabs (floors) onto steel and concrete beams and masonry walls;

c) Profiled metal decking on precast beams;

d) Cast in situ slab on precast wall;

e) Precast slab on cast in situ wall/3D printed wall;

f) Precast frames onto cast in-situ foundations, retaining walls, etc;

g) Precast frames stabilized by masonry walls, steel bracing, etc;

h) Precast cladding in steel or cast in-situ frames and vice-versa;

j) Glass curtain walling, stone cladding or metal sheeting onto precast concrete frames, etc; and

k) Reinforced concrete and structural steel as composite columns and beams.

10.10.2 Precast concrete may be combined with cast in-situ concrete, often termed hybrid construction. Cast in-situ is mostly used to form homogenous connections between precast elements and provide a structural topping for horizontal diaphragm action. In other cases, it is used to form the foundations and sub-structure to the building.

10.10.3 Structural steel work is largely used in long span prestressed concrete floors (hollow core) supported on rolled and prefabricated steel beams and also as steel roof trusses supported on concrete columns.

10.10.4 Timber may be used as long span glue-laminated beams and rafters, with precast concrete. Precast floors may be used in timber frame construction. Similarly, timber frames with precast elements shall be used as a building system.

10.10.5 Brick and block masonry may be combined with precast concrete structures and floors. The most common combination is to use prestressed floors on load bearing walls.

NOTE — Any prefabricated floor system covered under other Indian Standards, for example, reinforced concrete plank system and speed floor system may be combined with load bearing masonry walls/insulating concrete form (ICF) walls/precast large reinforced concrete wall panels/precast or cast in-situ reinforced concrete column-beam frames provided overall structural design safety, stability and integrity for composite structure is ensured in accordance with this section and other safety standards, such as good practice [C-7(1)], **5** of Part C/Section 1 of this NBCS including fire safety and safety against progressive collapse as per provisions of respective good practices, such as [C-7(19)], Part C/Section 5 and Part C/Section 6A of this NBCS.

10.10.6 *Design Considerations*

The mixed and composite structures shall be analysed appropriately and the joints in them designed to take the forces of an equivalent discrete system. Resistance to horizontal loading shall be provided by placing beams, walls and/or bracings in two directions at right angles or otherwise. The individual components shall be designed, taking into consideration appropriate end conditions and loads at various stages of construction. The components of the structure shall be designed for loads in accordance with good practices [C-7(1)] and[C-7(20)] and **5** of Part C 'Structural Design, Section 1 Loads and Load Effects' of this NBCS. In addition, members shall be designed for handling, erection and impact loads that may be expected during handling and erection.

For mixed and composite construction, the following shall be considered:

a) *Positions of stability cores, walls, bracing, etc* — In high rise buildings, the most popular method is a central core constructed several storeys ahead of the framework. The core could be built using either precast concrete panels, or cast in-situ walls, or steel cross bracing or precast concrete diagonal bracing;

b) *Maturity of connections* — Cast-in-situ grouted joints need temporary propping until desired design strength is achieved unless combined mechanical connections are also used. The overall construction sequence should be planned ahead of time carefully as per the design requirements. The design of temporary bracing system using key components should be looked at critically;

c) *Availability and/or positioning of equipment to transport and erect components* — The size and weight of the various components shall be organized to make optimum use of crane capacity, for example, the lightest units farthest from the operating zone;

d) *Erection safety and speed of construction, with attention to cast in-situ concreting sequences* — This is particularly important where fixing gangs are unaccustomed to working with different materials; and

e) *Tolerances for construction* — This is particularly important where different manufacturers are producing components in different materials.

Other design considerations and safety requirements against progressive collapse shall be in accordance with this NBCS.

10.11 Prefabricated Structural Units

For the design and construction of composite structures made up of prefabricated structural units and cast in-situ concrete, reference may be made to good practice [C-7(22)].

For design and construction of precast reinforced and prestressed concrete triangulated trusses, reference may be made to good practice [C-7(23)].

For design and construction of floors and roofs using various precast units, reference may be made to good practice [C-7(24)].

For construction of floors and roofs with joists and filler blocks, reference may be made to good practice [C-7(25)].

11 QUALITY ASSURANCE AND QUALITY CONTROL

The provisions for quality assurance as per good practice Part C/Section 5 of this NBCS shall apply. A documented quality assurance program covering various stages from precast unit/element production to erection shall be implemented and maintained. Common defects and remedies in precast concrete elements are presented in Annex F. For achieving sustainability in precast concrete construction a reference may be made to Annex G. Additionally, the flow chart given in Fig. 41 shall be considered.

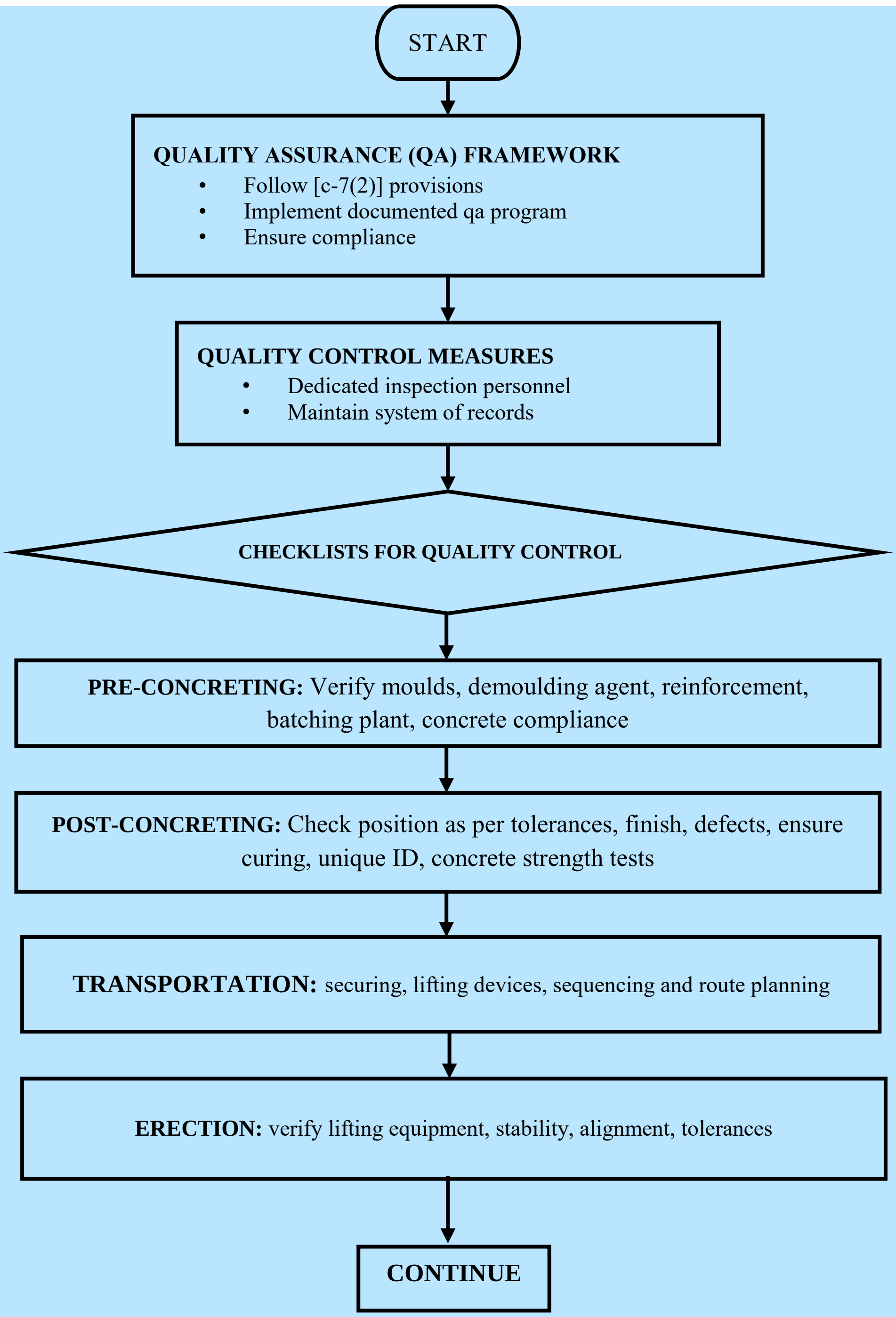

START
QUALITY ASSURANCE (QA) FRAMEWORK
Follow [c-7(2)] provisions
Implement documented qa program
Ensure compliance
QUALITY CONTROL MEASURES
Dedicated inspection personnel
Maintain system of records
CHECKLISTS FOR QUALITY CONTROL
PRE-CONCRETING: Verify moulds, demoulding agent, reinforcement, batching plant, concrete compliance
POST-CONCRETING: Check position as per tolerances, finish, defects, ensure curing, unique ID, concrete strength tests
TRANSPORTATION: securing, lifting devices, sequencing and route planning
ERECTION: verify lifting equipment, stability, alignment, tolerances
CONTINUE

FIG. 41 FLOWCHART FOR QUALITY ASSURANCE AND CONTROL (CONTINUED)

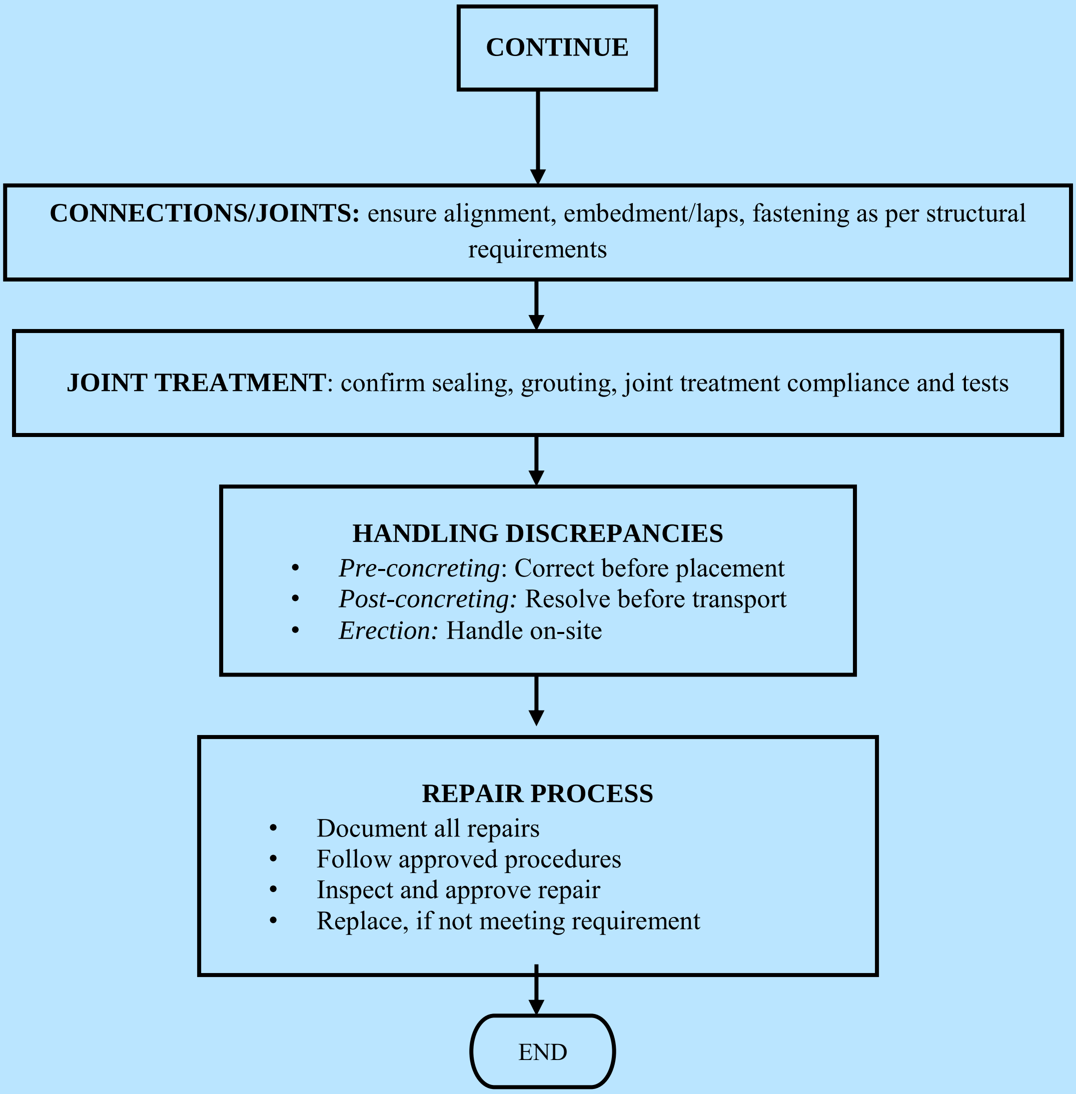

CONTINUE
CONNECTIONS/JOINTS: ensure alignment, embedment/laps, fastening as per structural requirements
JOINT TREATMENT: confirm sealing, grouting, joint treatment compliance and tests
HANDLING DISCREPANCIES
• Pre-concreting: Correct before placement
• Post-concreting: Resolve before transport
• Erection: Handle on-site
REPAIR PROCESS
• Document all repairs
• Follow approved procedures
• Inspect and approve repair
• Replace, if not meeting requirement
END

FIG. 41 FLOWCHART FOR QUALITY ASSURANCE AND CONTROL

12 TESTING

12.1 Sampling procedures

12.1.1 *Lot*

12.1.1.1 All the precast units of same size, manufactured from same material under similar conditions of production shall be grouped together to constitute a lot.

12.1.1.2 The number of units to be selected from each lot for dimensional requirements shall depend upon the size of the lot and shall be in accordance with col (3) and col (4) of Table 16.

12.1.1.3 The units shall be selected from the lot at random. In order to ensure the randomness of the selection, reference may be made to accepted standard [C-7(26)].

Table 16 Sample Size and Rejection Number

(*Clauses* 12.1.1.2 *and* 12.1.2.1)

Sl No. (1)	Lot Size (2)	First Sample Size (3)	Second Sample Size (4)	First Rejection Number (5)	Second Rejection Number (6)
i)	Up to 100	5	5	2	2
ii)	101 to 300	8	8	2	2
iii)	301 to 500	13	13	2	2
iv)	501 and above	20	20	3	4

12.1.2 *Number of Tests and Criteria for Conformity*

12.1.2.1 All the units selected at random in accordance with Table 16 shall be subjected to testing of dimensional tolerance requirements. A unit failing to satisfy any of the dimensional requirements shall be termed defective. The following shall be considered:

a) If no defect is found in the sample, the lot shall be considered as conforming else shall be rejected, if the number of defectives is greater than or equal to the first rejection number;

b) If the number of defectives is less than the first rejection number, the second lot shall be subjected to testing for dimensional tolerance requirements; and

c) If the combined number of defectives is less than the second rejection number, the lot shall be considered as conforming to dimensional tolerance requirements; otherwise not.

12.1.2.2 The lot which has been found satisfactory with respect to dimensional tolerance requirements shall then be considered for load testing as per **12.4**. One unit out of every 300 units or part thereof shall be selected for testing. The lot shall be considered as conforming to the strength requirement, if all units meet the requirement; otherwise not.

12.2 Testing on Individual Precast Units

12.2.1 The flexural components shall be load tested individually or along with the structural topping, depending on the requirements of the project or if any structural cracks (as per Part C 'Structural Design, Section 5 Structural Concrete' of this NBCS) or damages are observed. The testing shall be carried out on the selected sample along with one undamaged unit or part for reference. If individual element is tested, then the loads to be placed should be prorated such that element experiences similar demand over capacity levels when loaded. In either case, the element should be loaded for 24 h at its full span with a total load of 1.25 times the sum of dead (including SIDL, etc) and imposed loads used in the design. At the end of this time, it should not show obvious signs of deterioration or excessive deflection. For large span elements, larger than 10 m span, with design stresses near cracking under the ultimate loads, it is not uncommon to see hairline cracks during the load test at maximum loads in sustained conditions. Except for the design criteria of un-cracked elements, if applicable, if the test elements in such cases perform at a satisfactory level with recovery as noted in **12.2.2** and **12.2.3** as applicable, the test should be considered passed. If such cracks are substantial, the test should be further evaluated by the engineer-in-charge.

12.2.2 The recovery of maximum deflection observed during testing after 24 h should not be less than 75 percent.

12.2.3 If prestressed, it should not show any visible cracks up to the working load, and the recovery of maximum deflection observed during testing after 3 h should not be less than 85 percent.

12.2.4 For inspection and testing of the compression members, provision of Part C 'Structural Design, Section 5 Structural Concrete' of this NBCS shall apply.

12.3 Testing of Connecting Devices and Inserts

12.3.1 Grouted coupler or mechanical coupler shall be tested according to accepted standard [C-7(9)]. Where the grouted couplers are used for connections of lateral force resisting system (LFRS) transferring seismic and wind lateral loads, the grouted couplers should also be tested for the reverse cyclic load as per Table 17, in an NABL accredited laboratory or institute of repute under the supervision of appropriate authority.

Table 17 Cyclic Tension and Compression Test for Grouted Coupler

(*Clause* 12.3.1)

Sl No. (1)	Stage (2)	Tension (3)	Compression (4)	Cycles (5)
i)	I	0.95 f_y	0.5 f_y	20
ii)	II	$2\varepsilon_y$	0.5 f_y	4
iii)	III	$5\varepsilon_y$	0.5 f_y	4
iv)	IV	Load in tension till failure		

where

f_y = specified yield strength of the reinforcing bar; and

ε_y = strain of reinforcing bar at actual yield stress.

12.3.2 Any new connection assemblies such as, but not limited to, column shoe or shear connectors, that are used in connection of LFRS as noted in **12.3.1**, shall be tested for monotonic as well as reverse cyclic load as per **12.3.1** in an NABL accredited laboratory or institutes of repute under the supervision of appropriate authority. The failure should only occur in the reinforcement with evidence of ductility without any damage or deterioration in the brittle components of the connection assembly.

12.3.3 Lifting inserts and devices shall be tested for pull-out and should not show any damage till design load (factor of safety times the working load). Factor of safety shall be according to **7.14**.

12.4 Floor Load Testing of Structure or Part of Structure

12.4.1 Floor load testing on a part or entire floor shall be carried out before occupancy, depending on the requirements of the project or if any structural cracks or damages are observed or to ensure adequacy of strength or serviceability.

12.4.2 The structure should be loaded for 24 h with the full dead load and an imposed load equal to 1.25 times the specified imposed load used in design. The imposed load shall be removed, and the deflection shall be monitored. During the test, vertical struts should be placed appropriately to ensure safety.

NOTE — Dead load includes the self-weight of structural members plus weight of finishes and walls or partitions, if any, as considered in the design.

12.4.3 The recovery of maximum deflection shall be at least 75 percent otherwise the test shall be repeated after 72 h. If the recovery after second test is less than 80 percent the structure shall be deemed to be unacceptable. If unacceptable, the strengthening of this structure shall be carried out and 80 percent recovery of the structure shall be verified. The strengthening of the structure shall be verified by relevant authority.

12.4.4 If prestressed, the recovery of maximum deflection should be at least 85 percent, otherwise test shall be repeated after 72 h. If the recovery after second test is less than 85 percent the structure shall be deemed to be unacceptable.

12.4.5 If the maximum deflection in mm, shown during 24 h under load is less than 40 L^2/D, where L is the effective span in m; and D is the overall depth of the section in mm, it is not necessary for the recovery to be measured and the recovery provisions of 12.4.3 and 12.4.4 shall not apply.

12.4.6 *Testing of Connection/Joint and System*

12.4.6.1 Testing of connection or system shall be performed for proprietary or unique connection or system.

12.4.6.2 Monotonic test shall be carried out for beam-column, walls-slab, wall-wall joints for quantifying the static behaviour.

12.4.6.3 Reverse cyclical load simulation test under intended loads of beam-column, wall-slab, wall-wall joints, shall be carried out for quantifying the energy dissipation and hysteresis behaviour.

12.4.6.4 System level testing shall be carried, if required by the contract or specification of the project.

12.4.6.5 Testing shall be carried out in reputed institutes with appropriate requirements.

12.4.6.6 Acceptance criteria for such test should be mutually established by the authority and the concerned institute where testing is being conducted.

12.5 Testing for Water Tightness

12.5.1 *External Precast Wall/Facade Panels*

Any of the testing procedures given in 12.5.1.1 and 12.5.1.2 may be followed for testing of external wall and facade panel joints for water tightness as per the engineer-in-charge.

12.5.1.1 *Testing procedure* 1

12.5.1.1.1 *General*

If it is deemed necessary to demonstrate that the precast facade joints are adequate to resist water penetration, a water penetration test on a full-scale panel including joint mock-ups may be undertaken.

12.5.1.1.2 *Test procedures*

Mock-up panels to be tested for water tightness should be subjected to both static and cyclic pressure in accordance with standard accepted procedures. Available international testing procedures are to be modified for local conditions as follows:

a) Differential test pressure shall be 20 percent of the maximum inward design wind load but not less than 0.77 kPa; and

b) The test shall be performed with a water flow rate of 3.4 litre/min/m^2 for 15 min.

12.5.1.1.3 *Sampling for a water penetration test*

Water tightness testing of vertical and horizontal joints in precast facade panels shall be carried out at the rate of 0.5 percent for each type of joint and combination of panels or at least one for each joint type and precast unit, whichever is greater.

12.5.1.1.4 *Failure criterion*

The facade units or joints are deemed to have failed, if signs of water seepage through the joints or through the facade unit, including signs of damp patches, are observed during the test or within the subsequent 2 h after the test.

12.5.1.1.5 *Remedial action on failure*

Upon failure of a water penetration test on a precast facade system the cause of failure should be identified and the system revised and re-tested until a satisfactory test result is achieved. Modifications shall be realistic in terms of job conditions and shall maintain standards of quality and durability.

12.5.1.2 *Testing procedure* 2

12.5.1.2.1 For external walls, a continuous jet of water shall be sprayed on the joint corresponding to 600 litre/h from a water hose having a nozzle velocity of 2 m/s and a cone scatter of approximately 60° held at a distance of 1.2 m from the wall surface under test. The duration of the test shall not be less than 2 h. The hose shall be placed centred on the horizontal or vertical joint width. For external walls, the following tests shall be conducted for each building block as per Table 18.

Table 18 Frequency of Tests for Vertical and Horizontal Joints

(*Clause* 12.5.1.2.1)

Sl No. (1)	**Building Height** (2)	**Frequency of Tests** (3)
i)	Up to 10 storeys	5
ii)	Up to 20 storeys	10
iii)	Up to 30 storeys	15
iv)	Up to 40 storeys	20
v)	Up to 50 storeys	25

12.5.1.2.2 Twenty percent of these tests shall be carried out at the intersection of the vertical and horizontal joint.

12.5.1.2.3 These tests shall be carried out at any location as instructed by the engineer-in-charge.

12.5.1.2.4 *Acceptance criterion*

Water shall not seep into any part of the building during the test.

12.5.1.2.5 *Remedial action on failure*

For each test that fails, the tested joint shall be repaired as per the approved repair procedure as directed by the engineer-in-charge and the joint shall be retested for performance as per acceptance criterion. Two additional joints should be tested for each failed joint unless directed otherwise by the engineer-in-charge.

12.5.2 *Floor or Roof Slabs, Toilet Units and Kitchen Units*

12.5.2.1 A total of 5 percent of all horizontal floor slabs and the entire roof slab area, including bathroom/toilet floors, and kitchen floors shall be tested for water tightness by ponding of water for period of 4 h. This test shall be carried out before the application of floor finish or tiling. The depth of ponded water shall be taken as the maximum of the following:

a) At least 25 mm; and

b) 10 mm more than thickness of joint.

12.5.2.2 *Acceptance criteria*

Water shall not seep into any part of the building during the test and after 24 h. The rooms below the tested room shall not show any water leakage. Minor dampness or seepage without dripping water in limited area of less than approximately 50 cm^2 is considered acceptable at a few areas and should be repaired suitably to avoid seepage. In any other cases, the test should be repeated per **12.5.2.3**.

12.5.2.3 *Remedial action on failure*

For each test which fails, the tested joint shall be repaired as per the approved repair procedure as directed by engineer-in-charge and the joint shall be retested for water tightness. Two additional joints/areas should be tested for each failed joint unless directed otherwise by the engineer-in-charge.

ANNEX A

(*Clause* 4)

SYMBOLS AND NOTATIONS

A_n	Area of tension reinforcement
A_vf	Area of shear friction reinforcement
A_1	Loaded area (bearing constant area)
A_2	Area of the lower base of pyramid, cone or tapered wedge
b_t	Bearing width
b_w	Average width of the stem for the full depth of the section
d_e	Distance from centre of load to the end of the ledge
f_ck	Characteristic strength of concrete
f_y	Yield strength of tension reinforcement
f_ys	Yield strength of shear reinforcement
h_l	Height of beam ledge
L	Anchorage length
l_p	Length of ledge projection
N_u	Factored axial force
s	Minimum spacing of concentrated loads
V_u	Factored shear force
V_uR	Design shear resistance
β	coefficient dependent on the bar type
τ_b	Bond stress
τ_{bu}	Design ultimate anchorage bond stress
φ_E	Effective bar size which, for a single bar is equal to the bar size and, for a group of bars

ANNEX B

(*Foreword*, *Clauses* 6.5.1 *and* G-6.2.2)

GUIDELINE FOR 3D PRINTED CONCRETE STRUCTURES

B-1 GENERAL

This annex provides an overview of the materials, methods and tests associated with concrete construction using 3D printing for various applications. The provisions contained herein are based on the current state of knowledge and practice in 3D printed concrete construction. In addition to these guidelines, reference shall be made to the applicable existing Indian standards and relevant research publications. Ongoing research at the national and international levels is expected to generate design-related data, which may subsequently be utilized for the purpose of standardization.

B-2 METHODOLOGY AND SCOPE

The following points are considered while defining the application and performance guidelines:

a) *Printing technique* — This document considers only extrusion-based 3D printing technology, where layers are deposited one over the other to construct a structure;

b) *Design freedom* — 3D printing allows for flexibility in the geometry and form. The shape, size and topology of any 3D printed concrete element for any application shall not be restricted. However, the performance requirements for 3D printing need to be satisfied;

c) *Material* — The material shall be printable and buildable. As per the current state of knowledge of concrete for 3D printing, the limits on the usage of cementitious materials as given in good practice [C-7(6)] and Part C 'Structural Design, Section 5 Structural Concrete' of this NBCS would not be applicable for 3D printed concrete. The assessment of 3D printability of any concrete mixture needs to be carried out as per the available specialist literature on the subject. The mechanical, durability and long-term properties of the printable material shall be determined, as applicable. In the absence of a well-established procedure for preparation of test specimens for such evaluations, reference shall be made to recognized specialized literature. The testing shall be conducted at accredited laboratories and approved by competent authority;

d) *Performance criteria* — The performance criteria of any 3D printed components shall conform to the relevant Indian Standards for equivalent components. In the absence of any standards, an experiment-based approach shall be followed to satisfy the requirements for the specific element or component; and

e) *Special applications* — In the absence of any relevant standard, the engineer-in-charge, authorised to define the qualification requirements in accordance with the applicable Indian Standards, shall take decisions based on sound engineering judgement and established practice. The testing shall be conducted at accredited laboratories and approved by competent authority.

B-3 APPLICATION — NON-LOAD BEARING

B-3.1 Falsework/Formwork

3D-printed concrete may be used as stay-in-place (permanent) or temporary formwork for new concrete construction. The structural integrity of the formwork shall be either certified by a practicing structural engineer before the application or the formwork shall satisfy deformation limits and structural requirement mentioned in good practice [C-7(26)]. The formwork shall be designed by testing. The stay in place formwork shall not be considered as a part of the structural member.

B-3.2 3D Printed Concrete Building Blocks

The blocks can be solid as well as hollow, following the definition in accepted standard [C-7(27)]. The blocks shall have any external dimension greater than the corresponding dimension of a brick as specified in accepted standard [C-7(28)]. The size and the mass shall be such that it can be handled by as single person. In case of mechanized placement of the blocks, larger units can be used. The height of the block shall not exceed either its length or six times its width whichever is less. The faces of the block shall be manufactured based on the mutual agreement of the manufacturer and supplier/purchaser. Accepted standard [C-7(27)] shall be followed for considering the tests required to satisfy the performance criteria of the blocks.

B-3.3 Autoclaved 3D Printed Blocks

The autoclaved 3D printed solid blocks shall be tested based on the requirements mentioned in accepted standard [C-7(29)]. The blocks shall be of such dimensions and shape that they can be conveniently handled by a single person. The face of the block need not be plain, and the design shall be decided mutually by the manufacturer and supplier/purchaser.

B-3.4 Non-Load-Bearing 3D Printed Walls

3D printed concrete structures can be used as non-load bearing walls. The non-load-bearing walls can be divided into three types as mentioned as per Part C 'Structural Design, Section 4 Masonry' of this NBCS.

a) *Panel walls* — An exterior non-load-bearing wall in framed construction, wholly supported at each story but subjected to lateral loads;

b) *Curtain walls* — A non-load-bearing wall subject to lateral loads. It may be laterally supported by vertical or horizontal structural members, where necessary; and

c) *Partition walls* — An interior non-load bearing wall, one storey or part storey in height.

Such walls can be assessed for the performance requirements in the given application, and if necessary, testing of individual elements with necessary connection details can be done to ascertain lateral load resistance and intended performance.

B-3.5 Precast 3D Printed Panels

Precast 3D printed panels can be used for external or internal non-load-bearing walls. The panels shall be connected considering the guidelines provided in **8**. The printing and erection tolerance shall follow the permissible limits mentioned in **10.7**. The designing of the wall panels (including reinforcement) shall be provided by a certified structural engineer using this NBCS or following the concept of design by testing (in the absence of standardized design methods).

B-3.6 External Facing and Veneers

3D printed components can be used for external facing following the guidelines mentioned in good practice [C-7(30)]. Precast-facing concrete blocks shall generally conform to the requirements of accepted standard [C-7(27)] and, in addition, shall have special treatment regarding durability, colour and surface textures for the exposed facing. The face finish of slabs shall also be adequately waterproofed. The joint details, fixing technique and method of attachment shall be provided by a certified structural engineer following the concept of design by testing, in the absence of standardized design methods.

B-3.7 Acoustic

The acoustic treatment of non-industrial buildings, industrial establishments, and assembly spaces such as cinema halls or conference rooms is achieved through the design flexibility offered by 3D printing. The incorporation of air cavities between the inner and outer shells of walls contributes to the reduction of sound transmission between rooms. Panel and partition walls nay be printed with a suitable spacing between face shells as suggested in good practice [C-7(31)]. The semi-discontinuous and discontinuous construction mentioned in the good practice [C-7(31)] can be followed for non-industrial buildings. For industrial establishments and cinema halls or conference rooms, the reverberation time governs the acoustic experience. Good practices [C-7(32)] shall be followed to determine the reverberation time required for each application. The face of the walls and ceilings can be designed to govern the reverberation time while satisfying the requirements in the standards mentioned.

B-4 APPLICATION — LOAD BEARING

B-4.1 Design Philosophy

3D printed concrete structure shall satisfy the strength as well as serviceability requirements. The scope of this NBCS is limited to the load-bearing members in a building. Other structural applications are not considered for the purpose of this NBCS. Additionally, the durability and long-term behaviour of the printed structure shall be considered during design.

The load-bearing walls consist of a 3D printed shell and cast in-situ reinforced concrete core. In these cases, the 3D printed shell is considered to act integrally with the core. Depending on the application and the loading, the requirement of the reinforced concrete core may be done away with, in which case, the shell itself is capable of resisting both in-plane and lateral loads.

The design of load bearing walls shall be dependent on the load resistance mechanism. For the following two applications, the design using available information, and based on established principles of analysis and deriving load resistance, as commonly used in established codes of practice may be followed:

a) If the load resistance is derived from cast in-situ reinforced concrete core, (*see* Fig. 42); and

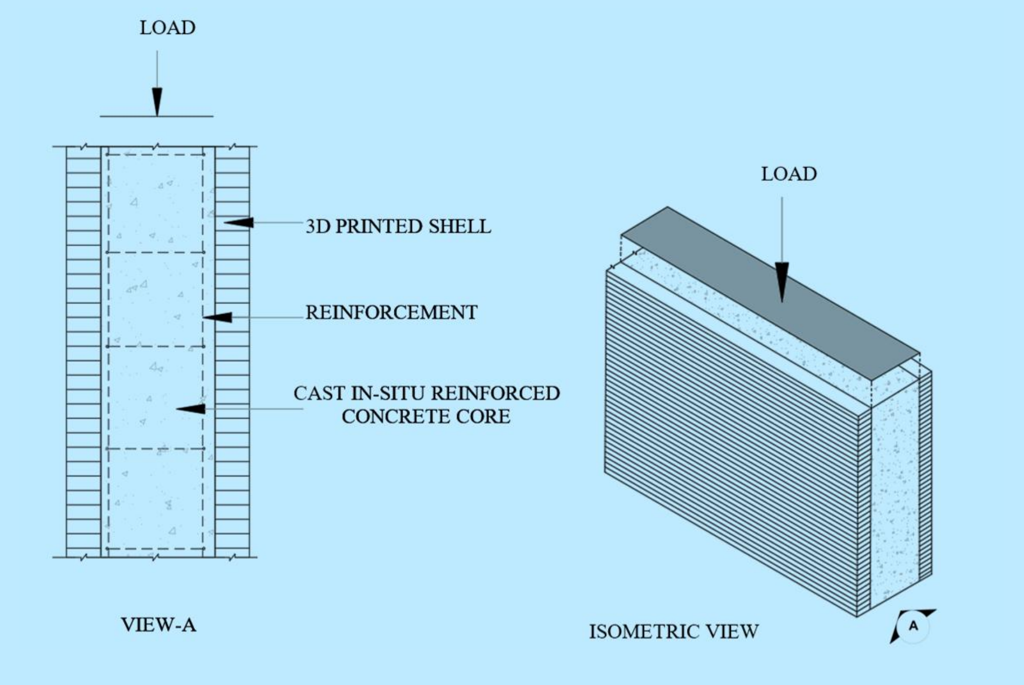


FIG. 42 LOAD RESISTANCE IS DERIVED FROM CAST IN-SITU REINFORCED CONCRETE CORE

b) If both 3D printed shell and cast in situ reinforced core are made using the same concrete mix, resulting in monolithic behaviour (*see* Fig. 43).

Where load resistance is derived using composite action between printed shell and cast in-situ core, design by testing the individual components may be followed.

All attempts to make the printed object behave in a ductile manner should be made to the extent possible, irrespective of the nature of usage.

NOTE — Specialized literature may be referred to while designing the test methods for the evaluation of structural walls. Alternatively, load-bearing 3D printed structures can be constructed with the approval of a certified external authority.

The use of load bearing walls is limited to gravity load. The use for load resistance subjected to earthquake loading as per good practice [C-7(20)] and **5** of Part C 'Structural Design, Section 1 Loads and Load Effects' of this NBCS and the requirements of ductile detailing as per good practice [C-7(1)] are outside the scope of this annex. Design by testing approach may be followed for any specific application. Additionally, the foundation shall comply all the requirements of good practice [C-7(33)] and to any other relevant Indian standards.

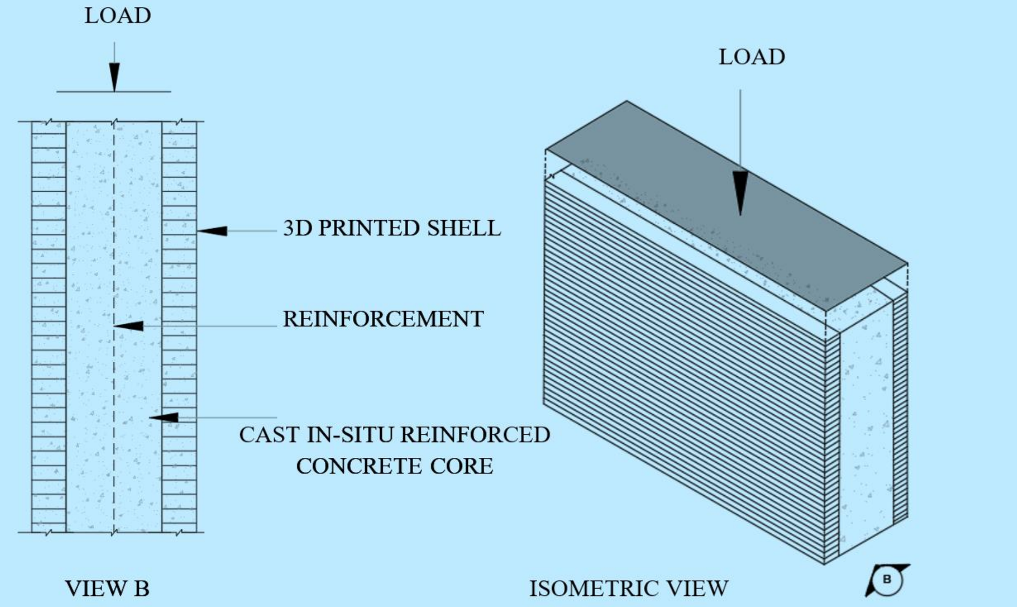


FIG. 43 LOAD RESISTANCE IS DERIVED FROM 3D PRINTED SHELL AND CAST IN-SITU REINFORCED CONCRETE CORE

B-4.2 Loads

The load criteria shall be as per Part C 'Structural Design, Section 1 Loads and Load Effects' of this NBCS. The lateral and earthquake load shall be taken special care of while designing the load bearing structures. The components of the structures shall be tested at full scale individual element level with necessary boundary conditions.

B-4.3 On-Site and Off-Site Construction

In case of an on-site construction, the printer is expected to be stationed at the location and construction to be carried out in-situ. For off-site construction, panels/sub-parts of the structure are printed in a factory and assembled at the site. In such a case, particular attention is to be paid to the design of the connections, as per the prevailing standards and codes.

B-4.4 Load Bearing Wall

3D printed load bearing walls can be used for buildings up to a height where the effect of lateral load is not severe, which may be restricted to building of height of 12 m. For buildings beyond 12 m height, the structural design and construction methodology shall be approved by the competent authority. Special care shall be taken while designing the connection between wall to slab, wall to beam and wall to footing. The minimum effective thickness of the load bearing wall shall be 100 mm in accordance with the guidelines of Part C 'Structural Design, Section 5 Structural Concrete' of this NBCS. The 3D printed load bearing wall can be considered as:

a) 3D printed perimeter (with or without printed internal rib filaments) and cast in situ concrete core. Depending on the application and extent of loading, these walls can be fully solid (that is with the core completely filled with cast in situ reinforced concrete), hollow (that is without any internal filling) or partially filled (with reinforced concrete in some of the cavities); or

b) Completely printed wall with no hollow space.

The cover depth of 3D printed wall shall consider exposure condition and fire resistance as per Part C 'Structural Design, Section 5 Structural Concrete' of this NBCS. The cover depth should include the thickness of the 3D printed perimeter filament and the cover (if any) provided by the core concrete. The minimum reinforcement criteria laid down in Part C 'Structural Design, Section 5 Structural Concrete' 5 of this NBCS shall be followed. Horizontal reinforcement in the form of high yield strength deformed (HYSD) rebar or welded wire mesh or textile mesh shall be provided to connect the outer leaves to the inner core, when the design assumes a composite action of the 3D printed perimeter and the inner core. In other cases, the printed leaves shall be considered as stay-in-place formwork and shall not be taken as a part of the load-bearing wall. However, even in such cases, efforts should be made to ensure that spalling or collapse of the outer periphery does not occur in extreme events such as earthquakes.

The walls shall satisfy the strength and serviceability criteria of the load bearing walls as per Part C 'Structural Design, Section 5 Structural Concrete' of this NBCS. If required, the design shall be on basis of testing of individual elements with necessary boundary conditions or connection details. For testing guidelines, specialist literature and publication may be referred if necessary.

NOTE — Specialist literature/publication may include those published by International Code Council, etc.

B-4.5 Load Bearing Column

Column shall be designed using as per Part C 'Structural Design, Section 5 Structural Concrete' of this NBCS. If required, test results obtained by full scale testing of individual elements with necessary boundary conditions or connection details shall be used. Buckling load criteria shall be satisfied considering the end-restraint conditions by testing. A certified structural engineer shall design the column as per logical reasoning based on experimental evidence.

B-4.6 Shear Walls

The shear walls shall be solid walls designed as per the requirements of good practice [C-7(2)]. The design guidelines similar to that of load-bearing 3D printed walls shall apply. The performance of 3D printed shear walls under lateral and earthquake load shall be tested. The design shall be on basis of experimental outcomes by a certified structural engineer.

B-4.7 Load-Bearing Beams and Slabs

The 3D printed beam and slab shall satisfy the load and serviceability requirements mentioned in Part C 'Structural Design, Section 5 Structural Concrete' of this NBCS. The flexural capacity of the printed beam shall be tested using 3-point and 4-point bending test at full-length-scale element level. The characteristic strength of the printable mix shall not be used to design the flexure member. The results from full-length-scale element level tests shall be used. A certified structural engineer shall design the flexural members as per the reports from the testing.

B-4.8 Foundation

A 3D printed foundation shall be designed following the design by testing method. The foundation can be printed in-situ or assembled at site like precast foundation after printing at the factory. The foundation shall be designed by a certified structural engineer while considering inputs from geotechnical engineers about the soil bearing characteristics. Durability requirements, as mentioned in good practice [C-7(2)], for the foundation shall be strictly satisfied.

If the outer perimeter of the foundation is only printed and the core is cast as conventional foundation, then the printed part shall not be taken into the load calculation and shall be treated as a formwork.

B-4.9 Retaining Wall and Basement

Retaining wall and basement shall be solid for load-bearing applications. Reinforcement strategy shall follow the guidelines mentioned for 3D printed load bearing walls.

B-4.10 Concrete-Reinforcement Bond Strength and Development Length

These are to be determined for each case and the structural engineer shall take into account the same while designing the reinforcement. The effect of layer time gap and moisture loss shall also be considered while designing the reinforcement. The bond between the rebar and the printed concrete shall be measured before designing the reinforcement.

B-4.11 Connections

Connections between the elements, including, but not limited to between two printed elements; printed non-structural element and cast in-situ structural reinforced concrete element; printed non-structural element and precast structural element; printed structural element and precast structural element; follow the requirements given in Part C ‘Structural Design, Section 5 Structural Concrete’ of this NBCS. If required, the connections shall be designed by testing. However, the connection between cast in-situ reinforced core and other structural elements shall follow standard design practice.

B-5 OTHER APPLICATIONS

B-5.1 Boundary Walls

The 3D-printed boundary wall shall not be a retaining wall or any load-bearing structure.

B-5.2 Design Elements for Outdoor Spaces

These elements shall comprise, but are not limited to, the following:

a) Pavement and other pedestrian movement spaces such as footpaths, plaza assembly spaces, kerb to footpath, steps and ramps;

b) Parking and vehicular movement corridors such as road dividers, road marking, etc;

c) Traffic management units such as gate/access control, barriers, traffic separators, etc;

d) Outdoor public conveniences such as seating, drinking fountains, toilet/washrooms, etc;

e) Shelter and kiosks such as bus shelters, police and telephone booth, food stall, information desk, etc;

f) Outdoor illumination such as street light pedestals, etc;

g) Tree guards, tree grates and planters;

h) Litter bins, and spittoons; and

j) Service utilities relating to water supply network, storm water network, sewerage system, irrigation network, etc.

These structures shall be designed by a certified structural engineer following the reports from experimental evaluation.

B-6 CURING

The printed structures shall be cured following the provisions mentioned in Part C ‘Structural Design, Section 5 Structural Concrete’ of this NBCS. However, curing shall be initiated at the early age to avoid plastic shrinkage cracks. Water spraying in the form of a fine mist must be started even before the initial set. At any given instance, the surface shall not be dry. The curing shall be done until the designed strength is reached for the 3D printed walls and slabs. Curing compounds can be used to reduce the number of days of water curing. The engineer-in-charge shall take the decision regarding the curing requirements based on experimental evidence.

B-7 QUALITY ASSURANCE AND QUALITY CONTROL

The following properties shall be assessed for determining the quality of the 3D printable concrete mix. The sampling shall be done as per Part C ‘Structural Design, Section 5 Structural Concrete’ of this NBCS:

a) The mechanical properties including cube compressive strength, elastic modulus, split tensile strength, and flexural strength of the concrete shall be tested following the method in accepted standard [C-7(34)]. The properties of water permeability, drying shrinkage, and rapid chloride permeability shall also be tested following the relevant Indian standards. The tests shall be performed on the specimens sawn/cored from printed samples. The anisotropy of the structure shall be tested along X, Y and Z coordinates. The test shall be conducted on the cast specimen also with the concrete used for printing the structure; and

b) Additionally, the bond strength of the layer shall be tested by extracting beam specimens of 40 mm × 40 mm × 160 mm from the printed structure, or a special test element. 3-point and 4-point bending test shall be performed on the extracted specimens with a minimum number of 5 specimens for each sample.

ANNEX C

(*Foreword and Clause* 6.5.2)

PREFABRICATED PREFINISHED VOLUMETRIC CONSTRUCTION (PPVC)

C-1 GENERAL

This annex provides a comprehensive guideline on prefabricated prefinished volumetric construction (PPVC) methods, materials, design standards and performance criteria for use by building professionals and other stakeholders involved in modular construction. This annex aims to facilitate the understanding and practical application of PPVC across various types of construction projects, including residential, commercial and industrial buildings. By outlining the key requirements and standards, this annex supports efficient and effective PPVC project planning, production, and assembly of PPVC to ensure high-quality, durable and sustainable modular structures.

This annex provides insights into essential aspects of prefabricated prefinished volumetric construction (PPVC), including design principles, manufacturing and installation practices, quality assurance, transportation and site assembly. It also highlights critical considerations for structural integrity, fire safety, environmental sustainability and inspection protocols, thereby promoting the adoption of best practices and supporting ongoing efforts to advance safe and innovative construction methods.

C-2 METHODOLOGY

The following points are considered while defining the application and performance guidelines.

C-2.1 Design

Design of PPVC modules considers both architectural and structural planning, taking into account modularization, alignment, and standardization of dimensions. It ensures that the modules comply with specifications for efficient on-site assembly, structural integrity and adherence to applicable building standards and design requirements.

C-2.2 Off-Site Manufacturing

The modules should be constructed in a controlled factory environment. This allows precise manufacturing with minimal errors and faster production times. Components, including concrete and steel modules, are cast, cured and finished with necessary fixtures, plumbing, and electrical setups before transportation to the construction site.

C-2.3 Transportation

Once manufactured, modules are carefully transported to the construction site. The transportation plan ensures that modules remain damaged and conform to transportation regulations, accounting for dimensions, weight and route restrictions.

C-2.4 On-Site Assembly

This stage involves the installation and connection of PPVC modules at the construction site. Modules are hoisted and secured in position, followed by finishing operations, including joint sealing and final inspections, to ensure that the assembled structure complies with all applicable quality and safety standards.

C-2.5 Modular Dimensions

PPVC modules should designed to fit within standard transportation limits to ensure easy delivery to construction sites. Common dimensions range from 3 m to 12 m in length, 2.5 m to 3.5 m in width, and 2.5 m to 4.5 m in height. Specific adaptations shall account for the maximum width (2.5 m), height (4.5 m including truck height), and length (up to 18 m) based on transportation guideline.

C-2.6 Transportability and Site Constraints

The size and weight of PPVC modules are influenced by on-site access, route clearance and crane requirements. The structure shall be modularized to ensure efficient on-site alignment and joining of modules, while minimizing the need for additional handling at the construction site.

C-2.7 Materials

a) *Concrete and steel modules* — PPVC modules are typically constructed from high-performance materials like reinforced concrete (RC) or steel. Reinforced concrete offers durability and structural integrity, whereas steel provides a lighter alternative, especially useful for high-rise buildings; and

b) *Enhanced material specifications* — Materials are chosen for performance under factory conditions and transportation stresses. For instance, high-strength/performance concrete (HPC) and steel conforming to relevant Indian Standard (such as Fe 500 or higher for reinforcement) are preferred. The use of sustainable materials, such as fly ash and other admixtures, is also encouraged to improve durability and reduce environmental impact.

C-2.8 Connections

Connections should be strong enough to secure modules under various stresses, including lifting, transportation, and environmental forces. Common PPVC connection methods include grouted couplers, wire loop boxes, dowel systems, and mechanical fasteners. These ensure that modules are securely integrated without compromising flexibility needed for seismic or wind forces.

Vertical joints (for stacking modules) and horizontal connections (for lateral stability) are essential for PPVC structures. These connections often involve interlocking systems or bolted end plates that provide stability while allowing for some movement to accommodate load and environmental stresses.

Connections should be designed to follow the Indian Standards for seismic and wind loads, such as good practice [C-7(35)] and **5** of Part C/Section 1 of this NBCS, to ensure safety and resilience under local conditions. Proper connection systems are necessary to transfer loads between modules and secure them as a unified structure.

C-2.9 Alignment

The alignment of prefabricated prefinished volumetric construction (PPVC) modules is critical to ensure that the final building is structurally sound and aesthetically pleasing. There are several key considerations to keep in mind when aligning PPVC modules:

a) The foundation on which the PPVC modules are placed should be level and square. If the foundation is not level, it can cause the modules to shift and potentially compromise the structural integrity of the building. Unless it is designed as a paper joint, a minimum 20 mm joint thickness shall be detailed between the top of the foundation and the PPVC module to account for site tolerances. The joint shall be later grouted with high strength grout as per design specification for structural integrity as well as continuity for functional performance;

b) Each PPVC module should be precisely aligned with the adjacent modules to ensure that the building is straight and true. This is typically achieved using alignment pins or other methods to ensure that the modules are aligned both vertically and horizontally. The erection tolerances shall be followed as per **10.7.6**;

c) Ensuring that the PPVC modules are level vertically is also critical to the structural integrity of the building. Laser levels and other tools can be used to ensure that the modules are plumb and aligned with the adjacent modules; and

d) The facade of the building, which includes windows, doors, and exterior finishes, should also be precisely aligned with the PPVC modules to ensure that the final building looks aesthetically pleasing.

C-2.10 Structural Design and Load Compliance

PPVC modules should comply with load standards as outlined in Part C ‘Structural Design, Section 1 Loads and Load Effects’ of this NBCS, for addressing dead loads, live loads, wind loads and other special loads requirements.

Modules should also meet seismic design requirements under **5** of Part C/Section 1 of this NBCS to ensure stability during earthquakes.

Structural elements for concrete and steel structures shall follow Part C 'Structural Design, Section 5 Structural Concrete' and Part C 'Structural Design, Section 6A Steel' of this NBCS, ensuring that all modules meet load-bearing and durability criteria. The Limit State Method is typically applied for PPVC modules, which includes safety factors to manage risks associated with live loads, dead loads and extreme environmental forces.

C-2.11 Material Standards

a) *Concrete and reinforcement compliance* — For concrete quality, PPVC construction shall follow Part C 'Structural Design, Section 5 Structural Concrete' of this NBCS, including high-performance concrete or self-compacting concrete for durability. Reinforcements use deformed steel bars as per accepted standard [C-7(36)] for high-strength requirements, ensuring modules can withstand handling, transportation and on-site stresses; and

b) *Admixtures and aggregates* — Chemical and mineral admixtures should comply with accepted standards [C-7(5)] and Part C 'Structural Design, Section 5 Structural Concrete' of this NBCS, which specify performance standards for durability and workability. Aggregates are selected as per accepted standard [C-7(4)], ensuring strength and proper gradation.

C-2.12 Fire Safety and Compartmentation

For fire resistance, PPVC structures shall comply with the requirements specified in Part F 'Fire and Life Safety' of this NBCS, including provisions for compartmentation. Each PPVC unit shall be provided with fire-rated walls, floors and doors, as required, to restrict the spread of fire and smoke and to ensure adequate means of egress and safety of occupants.

All materials used shall meet the relevant requirements of Part F 'Fire and Life Safety' of this NBCS for fire safety. Structural elements shall be designed to withstand high temperatures and achieve the required fire resistance in accordance with the relevant provisions of Part C/Section 5 of this NBCS.

C-2.13 MEP (Mechanical, Electrical, Plumbing) Standards

a) Electrical installations in PPVC buildings should meet the accepted standard [C-7(30)] and Part D 'Building Services/Section 2 Electrical and Allied Installations' of this NBCS, ensuring safe and reliable connections between modules. Additionally, accepted standard [C-7(38)] and Part D/Section 2 of this NBCS should be used for lightning protection systems to prevent electrical hazards; and

b) Plumbing systems follow good practice [C-7(39)] and Part E 'Plumbing Services, Section 1 Water Supply and Section 2 Drainage and Sanitation' for water supply and drainage, ensuring leak-proof, pressure-resistant pipes that meet durability and sanitation requirements in modular installations.

CI-2.14 Construction Tolerances

Construction tolerance limits in prefabricated prefinished volumetric construction (PPVC) refer to the allowable deviation from the intended design and specified dimensions. These limits are important to ensure that the final building is structurally sound and aesthetically pleasing. The construction tolerance limit in PPVC can vary depending on the specific materials and construction techniques used, as well as the local building standards and regulations. Permissible tolerances from the specified dimension of a PPVC module should conform to casting tolerances provided in **10.7.5**.

C-2.15 Performance Criteria

The performance criteria of any PPVC components should conform to the relevant Indian Standard for equivalent components. In the absence of any Indian Standard, the safety and durability of the specific element or component should be demonstrated through testing.

C-2.16 Special Applications

In the absence of any standards, the engineer-in-charge should make decisions based on logical reasoning and practical evidence. The test program should be conducted at accredited/approved laboratories and approved by statutory bodies.

C-3 APPLICATIONS

C-3.1 Residential and Commercial Buildings

PPVC modules for residential and commercial buildings shall be permitted for use in multi-storey structures and may be designed as either load-bearing or non-load-bearing units. Load-bearing modules shall be designed to resist vertical loads and shall satisfy requirements of stability and safety for multi-level configurations. Non-load-bearing modules shall be used as partitions or infill components. The provisions of Part F 'Fire and Life Safety' of this NBCS shall apply for fire safety requirements, while Part C 'Structural Design, Section 4 Masonry' of this NBCS shall govern structural requirements, sound insulation and seismic load-bearing capacity. The design shall ensure adequate connections and overall structural integrity of the system.

C-3.2 Educational and Healthcare Facilities

Modules are pre-finished to meet spatial needs, such as classrooms and patient areas, integrating critical systems like mechanical, electrical and plumbing (MEP) as per good practice [C-7(40)] and Part E 'Plumbing Services, Section 1 Water Supply and Section 2 Drainage and Sanitation' for water supply and drainage.

C-3.3 Industrial Buildings

PPVC in industrial buildings such as warehouses and factories requires modules engineered to meet the load-bearing and lateral resistance standards outlined in Part C 'Structural Design, Section 6A Steel' of this NBCS for structural steel and Part C 'Structural Design, Section 5 Structural Concrete' of this NBCS for reinforced concrete. The modular units allow for open, high-capacity spaces that can bear substantial loads, with compliance to Part C 'Structural Design, Section 1 Load and Load Effects' of this NBCS for design loads, wind, snow loads and for seismic considerations. Structural configurations shall also align with fire safety standards as per good practice [C-7(19)] to facilitate efficient integration of services. This approach enables high-speed assembly, structural integrity and durability for industrial purposes while meeting all requirements.

C-3.4 Design Philosophy

PPVC structures should be designed to meet strength and serviceability requirements, ensuring structural integrity under the anticipated loads. This focuses on load-bearing applications within PPVC, excluding non-structural or purely aesthetic uses. Additionally, the design should account for durability and long-term performance, particularly as modules are prefabricated off-site and subjected to transportation and on-site assembly stresses.

Load-bearing PPVC modules typically consist of a reinforced concrete or steel core surrounded by a prefinished volumetric structure. The core provides essential stability, especially under vertical and lateral loads. In certain applications, the volumetric shell itself may be designed to carry both in-plane and lateral loads, with the core providing additional structural redundancy.

The design approach for load-bearing PPVC modules depends on the load resistance mechanism employed, as outlined below:

a) *Core-based load resistance* — Where the primary load resistance is provided by a reinforced concrete or steel core, which may be cast in-situ or prefabricated; and

b) *Monolithic module design* — Where the PPVC module's core and shell use a compatible concrete mix or reinforcement design to behave as a single monolithic unit under load.

For cases where the load resistance is derived from the combined action of the volumetric shell and the core, individual component testing is recommended to validate the composite action. Efforts to promote ductile behaviour are essential, ensuring that load-bearing PPVC elements respond safely under stress.

NOTE — Testing and certification can be carried out as per specialised literature (reference may be made to applicable standards/Codes of the International Code Council (ICC) for structural evaluation methods), or structures may be certified through recognized government bodies in India. The scope of this section is limited to gravity loads. For resistance to earthquake-induced forces and ductile detailing as per Part C/Section 1 and Part C/Section 5 of this NBCS, additional testing and validation may be required.

C-3.5 Loads

Load criteria for PPVC modules should conform to good practices, with particular attention to lateral and seismic loads. Structural components should be validated through full-scale testing of individual elements, ensuring that boundary conditions simulate actual applications. Testing should confirm that PPVC modules meet all load-bearing and serviceability requirements, as specified accepted standards, for safe deployment in permanent structures.

C-3.6 Foundations

A PPVC foundation should be designed following a design-by-testing approach to confirm compliance with all load-bearing and durability standards. The foundation may be cast in-situ or prefabricated off-site as a precast unit for on-site assembly. Design shall be overseen by a certified structural engineer, with essential geotechnical input to evaluate soil bearing capacity, ensuring that the foundation is appropriate for the specific site conditions. Durability requirements per ‘Structural Design, Section 5 Structural Concrete’ of this NBCS should be strictly observed to maintain long-term performance and stability under applied loads.

To ensure a secure connection between the PPVC modules and the foundation, appropriate dowel bars or reinforcement should be incorporated into the foundation design. These reinforcement provisions should align with the load transfer requirements and provide structural continuity between the foundation and the modular components. Proper anchorage and placement of dowels will prevent differential movement and provide stability for the assembled structure.

C-4 CURING

As PPVC modules are manufactured in an off-site, controlled environment, advanced curing methods may be implemented to expedite the process and ensure consistent quality. In addition to following ‘Structural Design, Section 5 Structural Concrete’ of this NBCS, rapid curing techniques, such as steam curing, warm water curing, or the use of curing compounds, can be employed to accelerate strength development. These methods enable the modules to achieve the desired performance levels within a shorter time frame, which is critical for modular construction timelines.

The curing approach should ensure that modules reach their designed strength before transportation to the construction site. The decision on curing methods and duration should be based on testing and performance requirements, as determined by the supervising engineer, to guarantee durability and structural integrity.

C-5 QUALITY ASSURANCE AND QUALITY CONTROL

Compliance with good practices includes ongoing quality checks at both the manufacturing and construction stages. Regular inspections, as per relevant provisions this NBCS and relevant Indian Standards, to verify structural integrity, alignment and safety of each module, especially focusing on connections and material durability over time.

C-6 MAINTENANCE AND INSPECTION

Regular inspection and maintenance protocols should be set to identify wear or structural concerns in connections and external finishes, ensuring longevity and safety as outlined in relevant provision of this NBCS.

ANNEX D

(*Foreword and Clause* 6.6)

GUIDELINES FOR DESIGN FOR MANUFACTURING AND ASSEMBLY (DFMA)

D-1 The concept of design for manufacturing and assembly (DFMA) emphasizes the use of precast and prefabricated building components. The underlying principles of DFMA call for more efficient building design and construction detailing, especially in the area of precast concrete connection designs, so as to minimize the amount of wet works on-site.

To develop an advanced pre-cast concrete system (APCS), it is important for the various building disciplines to first understand the functional considerations, building aesthetics, and design approaches. This understanding will enable the conceptualization and development of the APCS design, ensuring it meets the project specifications. It is essential that the APCS design is coordinated with the manufacturing specification for components, construction planning and site work to ensure seamless integration and efficient construction processes.

D-2 DESIGN BASIS FOR ADVANCED PRECAST CONCRETE

The following are key principles of efficient construction using APCS systems:

a) *Modular architecture layouts* — Designing buildings in modules to allow for greater use of precast and prefabricated components, reducing on-site construction time and costs;

b) *Precast repetition* — Using standard precast elements repeatedly throughout the building, simplifying the construction process and reducing the need for customization;

c) *Efficient structural design* detailing (standardize design and detailing) — Designing precast connections that can be easily assembled on-site, reducing the need for wet works and temporary supports;

d) *Quick assembly detailing* — Designing connections and components that can be quickly and easily assembled on-site, reducing construction time and costs; and

e) *Limited use of temporary supports* — Designing precast components that can be assembled without the need for temporary supports, further reducing construction time and costs.

D-3 FACADE STANDARDIZATION

Architectural design is a process to create a built environment with functionality for human comfort and sustainability through art and engineering design. In an effective precast concrete construction, the external facade design is generally achieved through optimal standardization in the following:

a) *Shapes* — FRP/rubber-lined moulds can be used to create various shapes for precast concrete components;

b) Textures such as sandblasted or acid-etched finishes can also be added to enhance the visual appearance of the precast components;

c) Different colours can be achieved using pigments or concrete colours, allowing for a wide range of design options;

d) *Repetition* — Standard precast elements can be repeated throughout a building's facade, making construction faster and more efficient;

e) *Modular design* — It allows for the precast components to be easily assembled on-site, reducing the need for wet works and temporary supports;

f) *Small complex facade panels* — Glass reinforced concrete (GRC) can be used instead of concrete for small complex facade panels;

g) *Complex facade as a separate add-on* — Complex facade elements can be designed and manufactured separately from the building structure, allowing for easier handling and installation on-site;

h) *Layouts rotated over mirrored* — Rotating layouts over mirrored elements can make use of the same assembly for construction; and

j) *Checklists* — Checklists can be used to ensure good precast arch design, covering aspects such as structural integrity, aesthetic appeal and ease of construction.

D-4 STRUCTURAL DESIGN

Structural design has a direct impact on the ease of precast concrete manufacturing and site erection works. The key consideration for structural system design solutions are:

a) *Simple design and detailing* — Precast concrete components should be designed with simple connections that can be easily assembled on-site, reducing construction time and costs;

b) *Commercial - long spans* — Precast concrete components can be used for long-span commercial buildings, such as warehouses or shopping centres;

c) *High rise residential* — In high-rise residential buildings, precast concrete wall panels can be used in conjunction with precast concrete floor slabs;

d) *Low/mid rise residential* — In low to mid-rise residential buildings, precast concrete wall panels can be used with precast concrete floor slabs and beam-column combinations; and

e) *Design to cater for temporary loads during construction* — The structural design should cater for temporary loads during the construction phase, such as the weight of equipment and construction workers.

D-5 TYPES OF STRUCTURAL SYSTEMS

All semi or full precast concrete structural systems need clear consideration for stability. It may take one of the following forms:

a) *Skeletal frames* — Precast concrete components can be used to create skeletal frames, with columns and beams connected with precast framed connections;

b) *Load bearing walls* — Precast concrete wall panels can be used as load-bearing walls, supporting the weight of the floors and roof;

c) *Load bearing facade* — In a load-bearing facade system, the precast facade concrete panels bear the weight of the building and transfer the loads to the foundation independently to the core of the structure;

d) 3-*D boxes* — Precast concrete components can be used to create 3-D boxes, with precast walls, floors, and roofs forming the 3-D building unit;

e) *Mixed systems* — A combination of precast concrete components can be used to create mixed systems, such as precast concrete walls with cast-in-place concrete floors; and

f) *Checklists for good precast structural design* — Checklists can be used to ensure good precast structural design, covering aspects such as strength and durability, fire resistance, seismic design and ease of construction.

D-6 CONNECTIONS

Connection in precast concrete construction must be designed to take the forces derived in the structural modelling. To achieve work efficiency, the design approach should consider the following aspects:

a) *Standardized connections* — Standardized precast concrete connections are designed to be easily designed, manufactured and assembled on-site;

b) *Ease of erection* — Precast concrete connections should be designed with ease of erection in mind, to ensure that they can be quickly and safely assembled on-site;

c) *Simple and minimalistic* — Simple and minimalistic connections are preferred in precast concrete construction, as they are more efficient and cost-effective;

d) *Checklists for good connection systems* — Checklists can be used to ensure good precast concrete connection systems, covering aspects such as durability, strength, and ease of assembly; and

e) *Innovative connections* — Innovative precast concrete connections can be used to create unique and complex structures, such as hybrid steel and precast systems or lotus root precast systems. These connections can offer advantages such as improved structural performance, and reduced construction time.

D-7 DESIGN OF CONNECTIONS

Design methods for joints in precast construction have been covered by various international technical journals and published academic research papers. They briefly cover the connections listed below:

a) *Corbel-beam end joint* — A hidden mechanical connector can be used for the corbel-beam end joint, similar to hanger connections;

b) *Column/wall base mechanical connections* — Column shoes and wall shoes with anchor bolts can be used for mechanical connections at the base of columns and walls;

c) *Wall to wall connections* — Wire loops can be used for wall to wall connections;

d) *Beam to beam* — Steel hangers can be used for connecting precast concrete beams; and

e) *Rigid beam-column* — Top steel couplers and bottom steel welded connections can be used for rigid beam-column connections, ensuring that the connection is strong and can resist bending and shear forces.

D-8 CONNECTION DESIGN CONCEPT

This can cover the following:

a) Load paths — Diaphragm, slab to wall/column paths, slab-beam shear connection;

b) Frame behaviours;

c) Accidental loads, progressive collapse;

d) Tie design forces;

e) Tie continuity — Laps, tie with enclosed links; and

f) Tie anchorages with other ties.

D-9 DESIGN EXAMPLES

a) Beam half joint (dap connection);

b) Beam half joint (hanger/beam shoe connection);

c) Corbel (conventional);

d) Peikko corbel;

e) Column base — Splice sleeve/grouted couplers;

f) Column base — Shoe connection;

g) Wall base — Splice sleeve/grouted couplers;

h) Wall base — Shoe connection;

j) Wall —Wall joint – Shear keys only;

k) Wall — Wall joint – With loop reinforcement;

m) Beam steel hangers — Generic;

n) Beam steel hangers — Peikko;

p) Proprietary mechanical connections;

q) Column to base and column to column;

r) Beam to column — Moment connection;

s) Beam to column — Simply supported;

t) Beam to beam;

u) Wall to wall — Vertical and horizontal connections; and

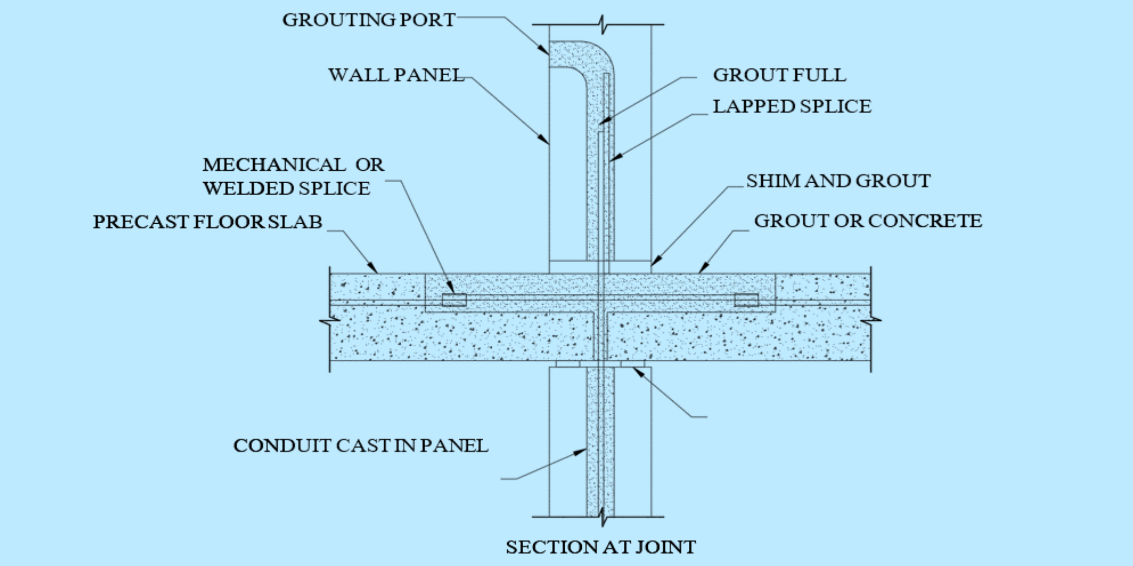
v) Landing slabs — TSS.

ANNEX E

(*Foreword and Clause* 8.3)

COMMON PRECAST CONNECTIONS

E-1 Typical figures of some common precast joint connections are given in Fig. 44 to Fig. 56.


GROUTING PORT
WALL PANEL
GROUT FULL
LAPPED SPLICE
MECHANICAL OR
WELDED SPLICE
SHIM AND GROUT
PRECAST FLOOR SLAB
GROUT OR CONCRETE
CONDUIT CAST IN PANEL
SECTION AT JOINT

NOTE: Overlapping bars in grout-filled conduit are extended full-height through the structural element

FIG. 44 LAPPED SPLICES IN LARGE CONDUIT

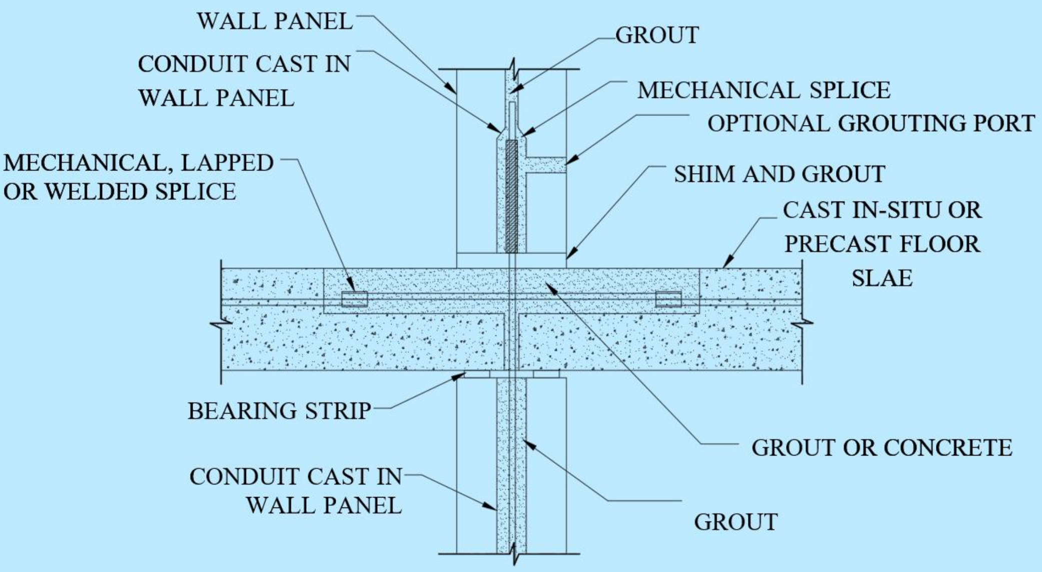

WALL PANEL
CONDUIT CAST IN
WALL PANEL
GROUT
MECHANICAL SPLICE
OPTIONAL GROUTING PORT
MECHANICAL, LAPPED
OR WELDED SPLICE
SHIM AND GROUT
CAST IN-SITU OR
PRECAST FLOOR
SLAE
BEARING STRIP
GROUT OR CONCRETE
CONDUIT CAST IN
WALL PANEL
GROUT

FIG. 45 MECHANICAL CONNECTION IN CONDUIT

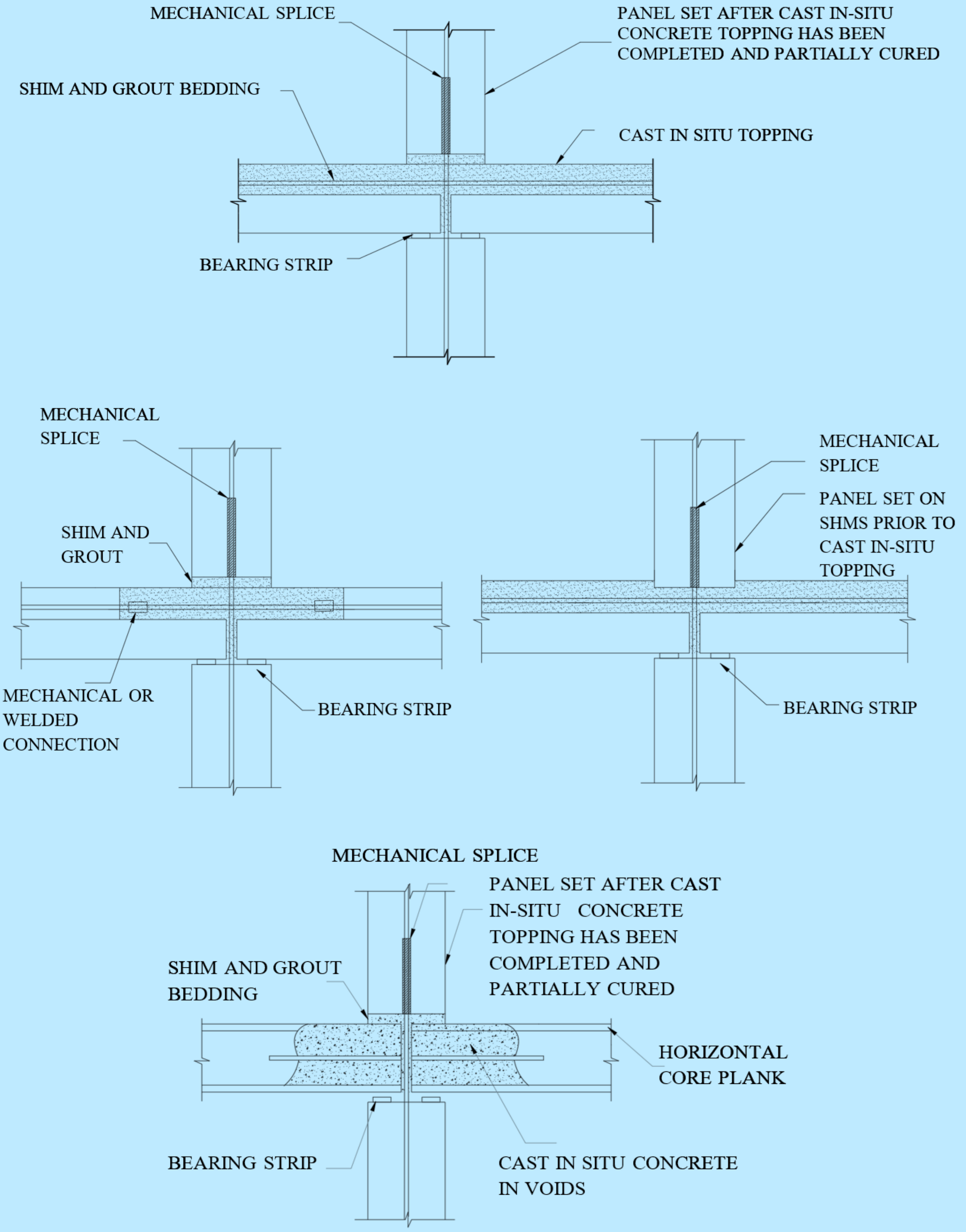

MECHANICAL SPLICE
PANEL SET AFTER CAST IN-SITU CONCRETE TOPPING HAS BEEN COMPLETED AND PARTIALLY CURED
SHIM AND GROUT BEDDING
CAST IN SITU TOPPING
BEARING STRIP
MECHANICAL SPLICE
SHIM AND GROUT
MECHANICAL OR WELDED CONNECTION
BEARING STRIP
MECHANICAL SPLICE
PANEL SET ON SHMS PRIOR TO CAST IN-SITU TOPPING
BEARING STRIP
MECHANICAL SPLICE
PANEL SET AFTER CAST IN-SITU CONCRETE TOPPING HAS BEEN COMPLETED AND PARTIALLY CURED
SHIM AND GROUT BEDDING
HORIZONTAL CORE PLANK
BEARING STRIP
CAST IN SITU CONCRETE IN VOIDS

Fig. 46 Different Types of Mechanical Splices for Connection of Various Configurations of Precast Wall and Floors

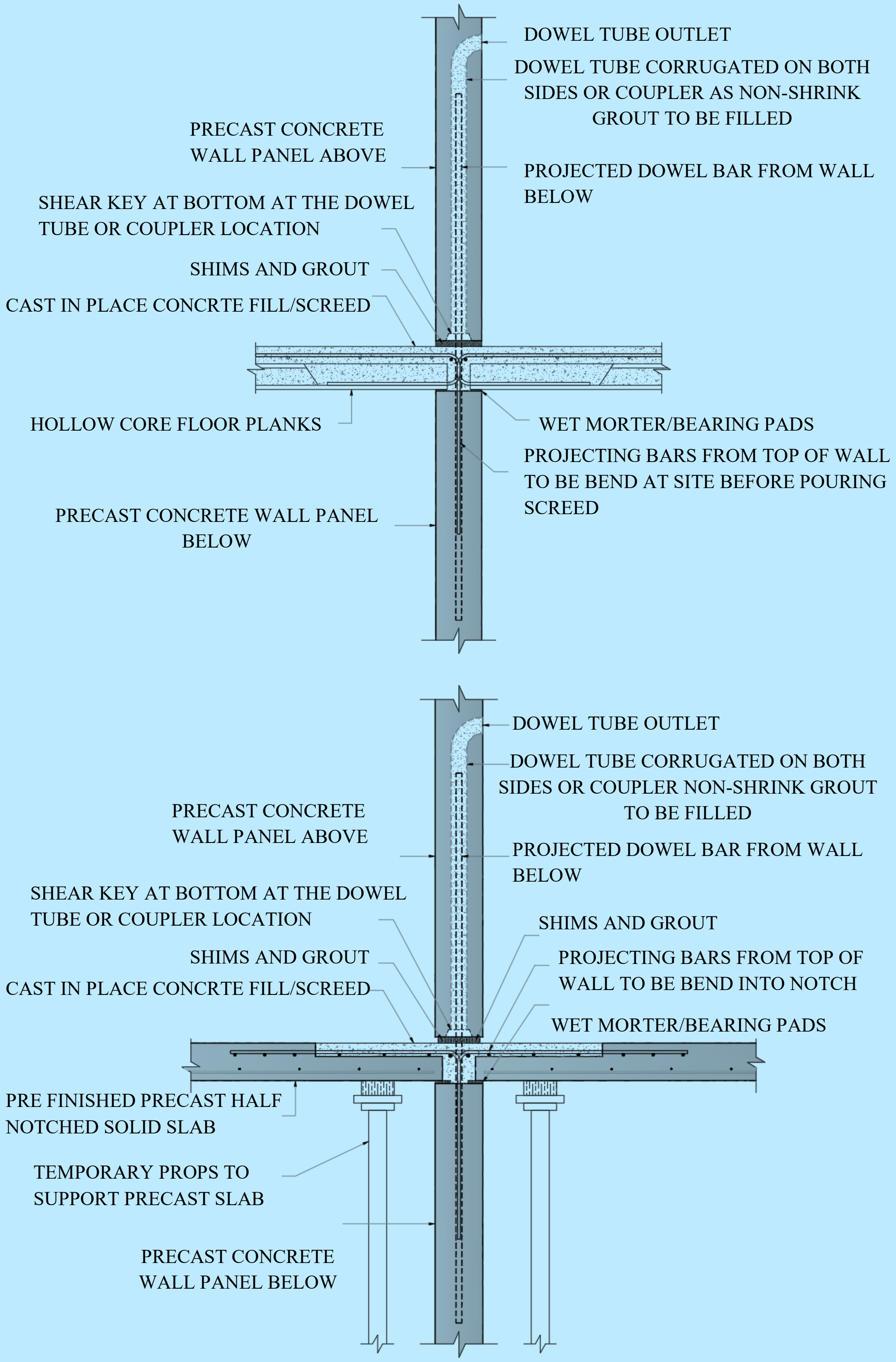

DOWEL TUBE OUTLET
DOWEL TUBE CORRUGATED ON BOTH SIDES OR COUPLER AS NON-SHRINK GROUT TO BE FILLED
PRECAST CONCRETE WALL PANEL ABOVE
PROJECTED DOWEL BAR FROM WALL BELOW
SHEAR KEY AT BOTTOM AT THE DOWEL TUBE OR COUPLER LOCATION
SHIMS AND GROUT
CAST IN PLACE CONCRTE FILL/SCREED
HOLLOW CORE FLOOR PLANKS
WET MORTER/BEARING PADS
PROJECTING BARS FROM TOP OF WALL TO BE BEND AT SITE BEFORE POURING SCREED
PRECAST CONCRETE WALL PANEL BELOW
DOWEL TUBE OUTLET
DOWEL TUBE CORRUGATED ON BOTH SIDES OR COUPLER NON-SHRINK GROUT TO BE FILLED
PRECAST CONCRETE WALL PANEL ABOVE
PROJECTED DOWEL BAR FROM WALL BELOW
SHEAR KEY AT BOTTOM AT THE DOWEL TUBE OR COUPLER LOCATION
SHIMS AND GROUT
SHIMS AND GROUT
PROJECTING BARS FROM TOP OF WALL TO BE BEND INTO NOTCH
CAST IN PLACE CONCRTE FILL/SCREED
WET MORTER/BEARING PADS
PRE FINISHED PRECAST HALF NOTCHED SOLID SLAB
TEMPORARY PROPS TO SUPPORT PRECAST SLAB
PRECAST CONCRETE WALL PANEL BELOW

FIG. 47 MECHANICAL SPLICES USING HIGH STRENGTH NON-SHRINK NON-METALLIC GROUT (CONTINUED)

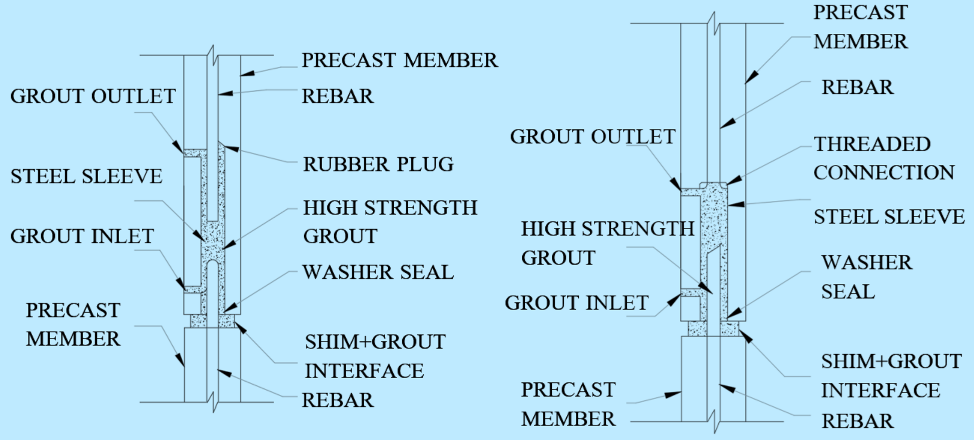

GROUT OUTLET
STEEL SLEEVE
GROUT INLET
PRECAST MEMBER
PRECAST MEMBER
REBAR
RUBBER PLUG
HIGH STRENGTH GROUT
WASHER SEAL
SHIM+GROUT INTERFACE
REBAR
PRECAST MEMBER
REBAR
GROUT OUTLET
THREADED CONNECTION
STEEL SLEEVE
HIGH STRENGTH GROUT
WASHER SEAL
GROUT INLET
SHIM+GROUT INTERFACE
PRECAST MEMBER
REBAR

FIG. 47 MECHANICAL SPLICES USING HIGH STRENGTH NON-SHRINK NON-METALLIC GROUT

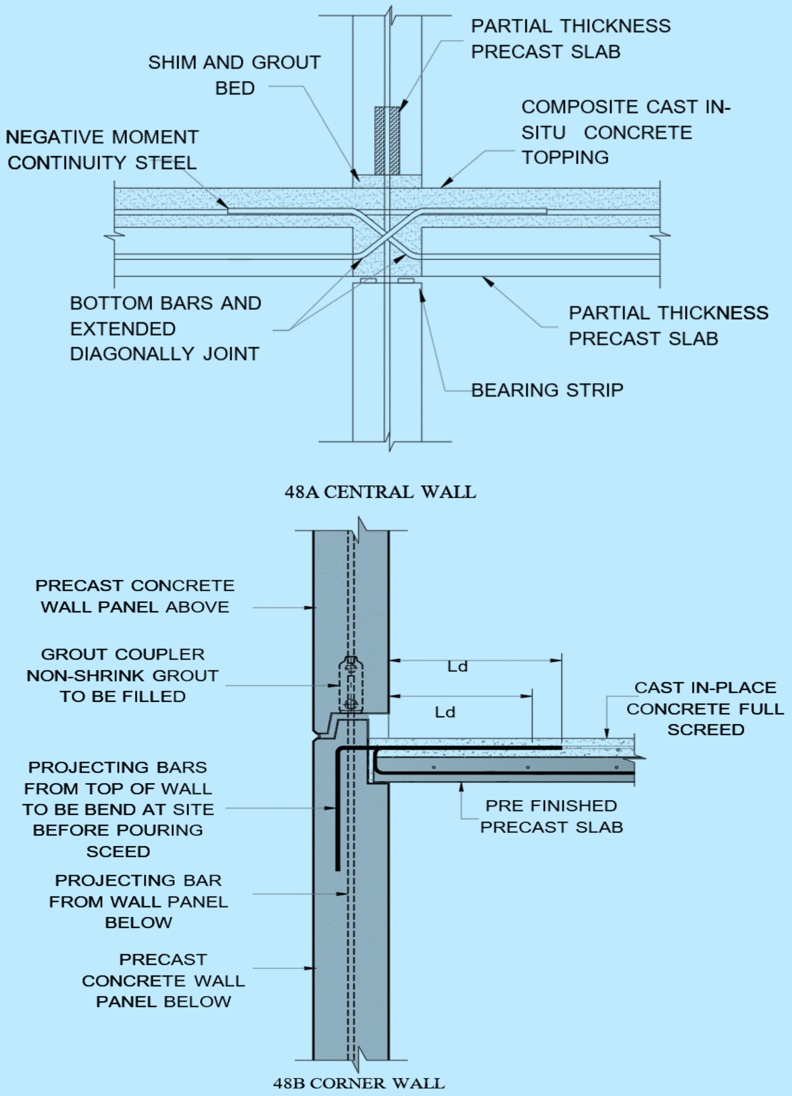
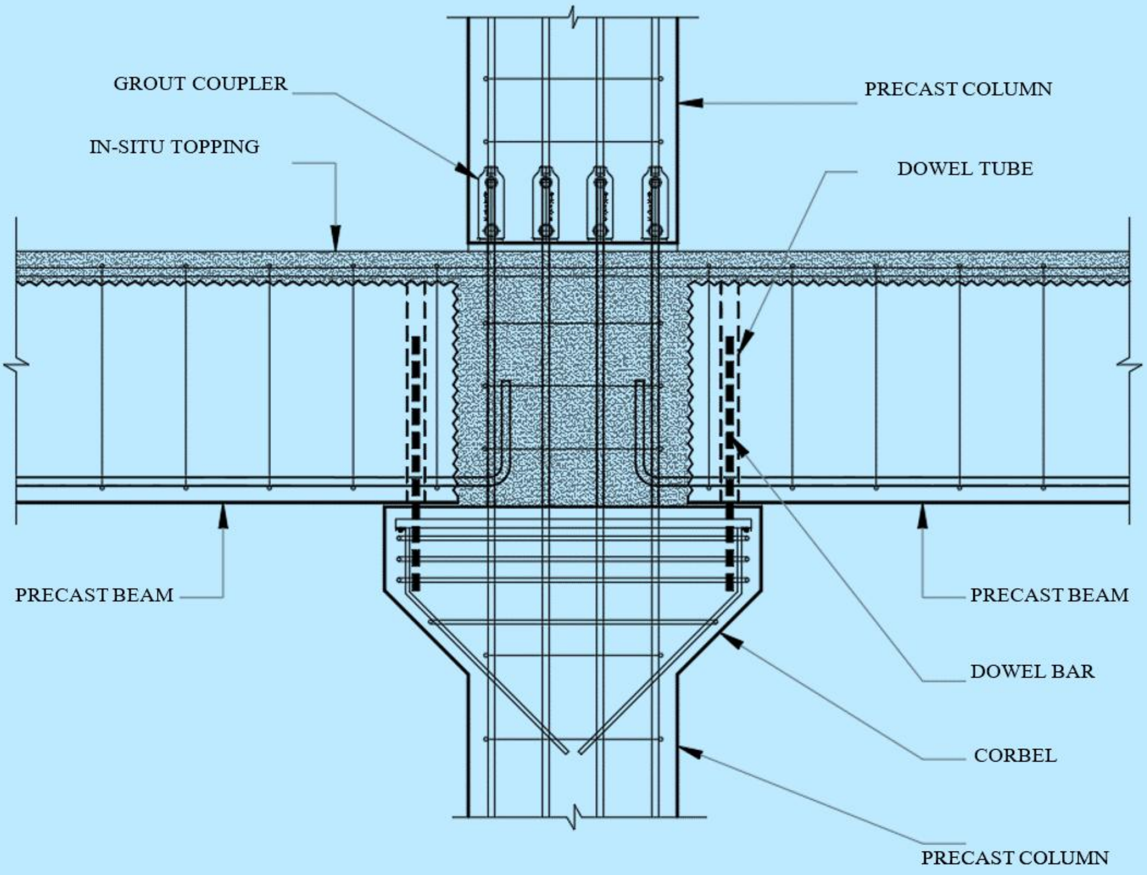
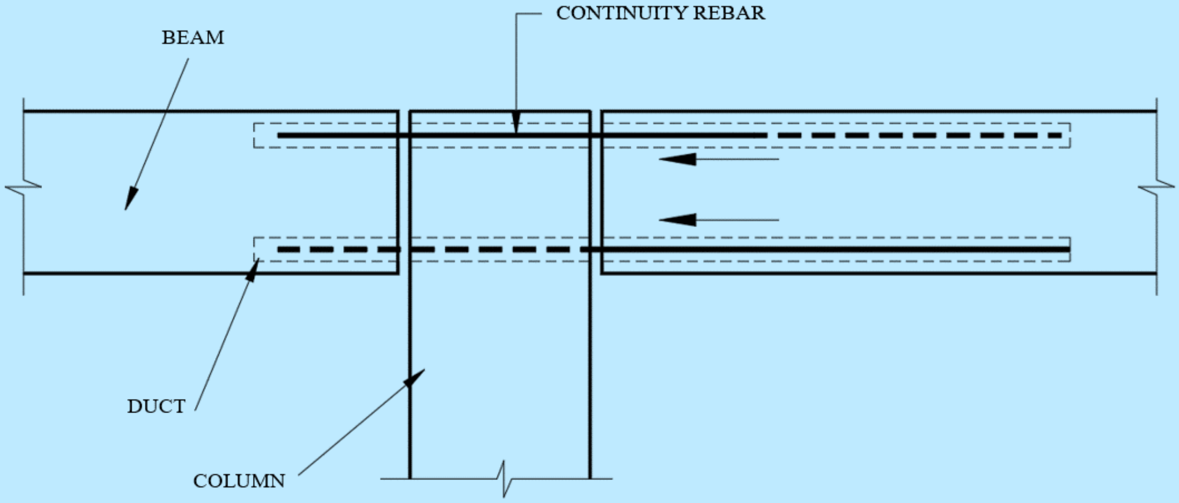

PARTIAL THICKNESS PRECAST SLAB
SHIM AND GROUT BED
COMPOSITE CAST IN-SITU CONCRETE TOPPING
NEGATIVE MOMENT CONTINUITY STEEL
BOTTOM BARS AND EXTENDED DIAGONALLY JOINT
PARTIAL THICKNESS PRECAST SLAB
BEARING STRIP
48A CENTRAL WALL
PRECAST CONCRETE WALL PANEL ABOVE
GROUT COUPLER NON-SHRINK GROUT TO BE FILLED
Ld
Ld
CAST IN-PLACE CONCRETE FULL SCREED
PROJECTING BARS FROM TOP OF WALL TO BE BEND AT SITE BEFORE POURING SCEED
PRE FINISHED PRECAST SLAB
PROJECTING BAR FROM WALL PANEL BELOW
PRECAST CONCRETE WALL PANEL BELOW
48B CORNER WALL

FIG. 48 FLOOR SLAB TO WALL DETAILS

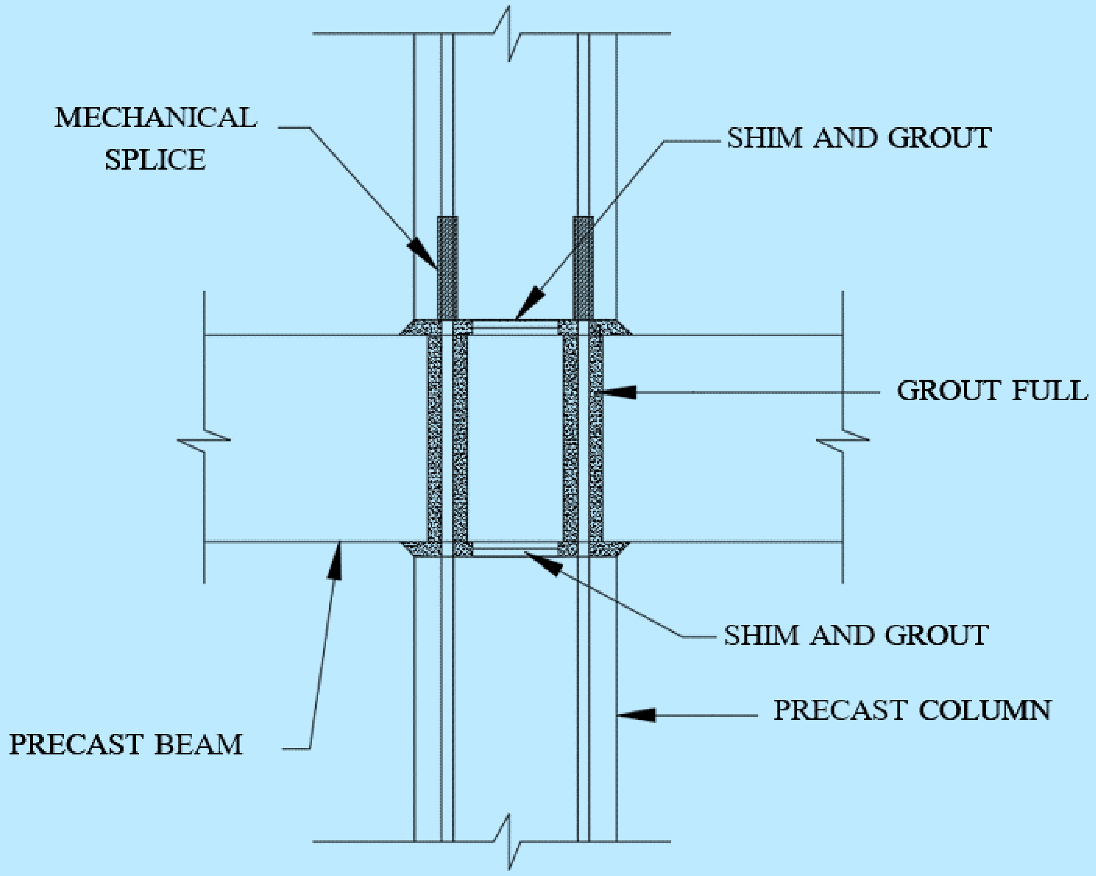

GROUT COUPLER
IN-SITU TOPPING
PRECAST COLUMN
DOWEL TUBE
PRECAST BEAM
PRECAST BEAM
DOWEL BAR
CORBEL
PRECAST COLUMN

49A WITH CIS JOINT


CONTINUITY REBAR
BEAM
DUCT
COLUMN

49B WITH GROUTED JOINT

FIG. 49 BEAM AND COLUMN


MECHANICAL SPLICE
SHIM AND GROUT
GROUT FULL
SHIM AND GROUT
PRECAST COLUMN
PRECAST BEAM

NOTE: Conduit diameter should be two to four times the bar diameter for tolerance in field erection

FIG. 50 COLUMN TO COLUMN THROUGH CONDUIT IN BEAM

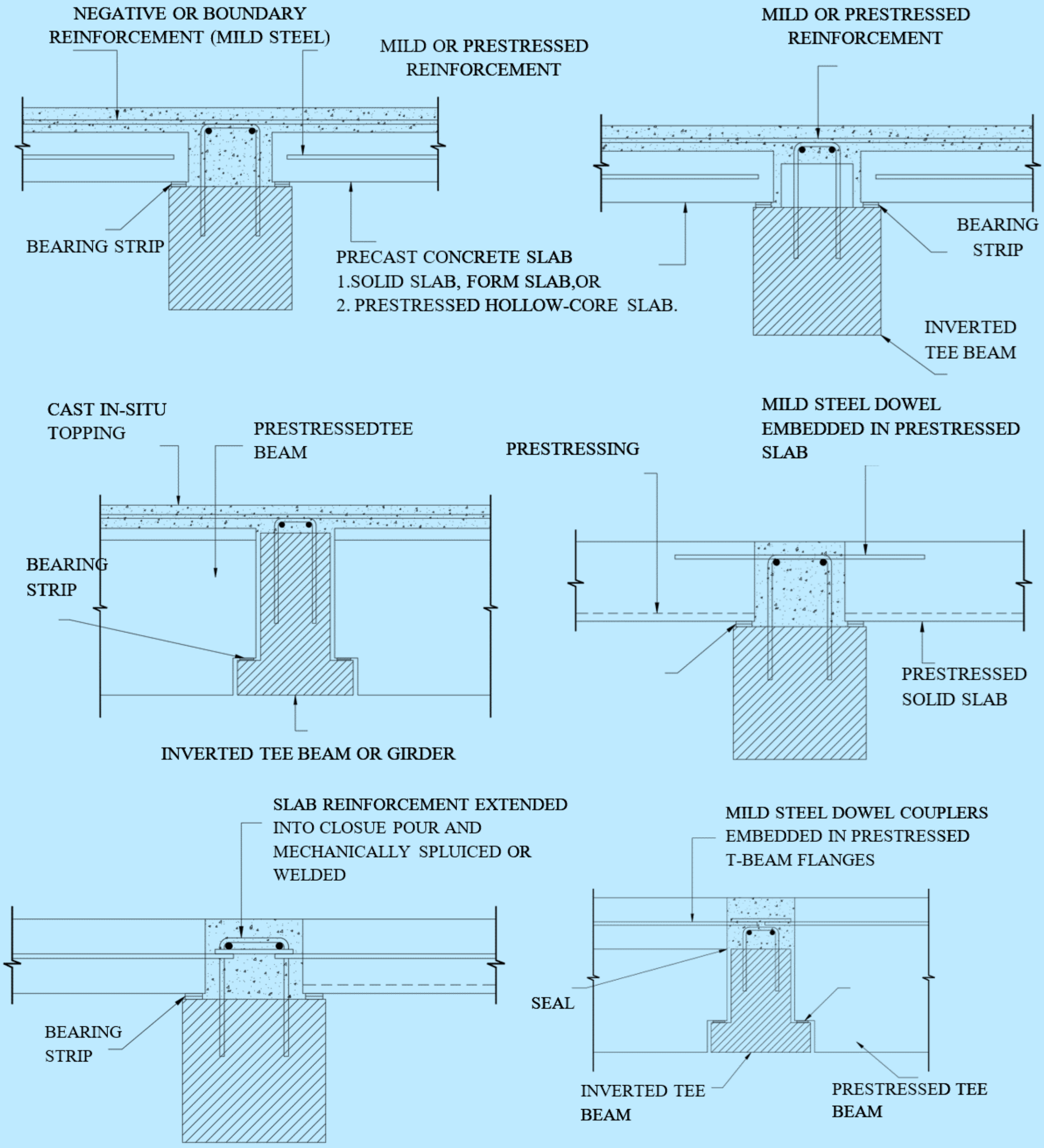

NEGATIVE OR BOUNDARY REINFORCEMENT (MILD STEEL)
MILD OR PRESTRESSED REINFORCEMENT
BEARING STRIP
PRECAST CONCRETE SLAB
1.SOLID SLAB, FORM SLAB,OR
2. PRESTRESSED HOLLOW-CORE SLAB.
MILD OR PRESTRESSED REINFORCEMENT
BEARING STRIP
INVERTED TEE BEAM
CAST IN-SITU TOPPING
PRESTRESSEDTEE BEAM
BEARING STRIP
INVERTED TEE BEAM OR GIRDER
PRESTRESSING
MILD STEEL DOWEL EMBEDDED IN PRESTRESSED SLAB
PRESTRESSED SOLID SLAB
SLAB REINFORCEMENT EXTENDED INTO CLOSUE POUR AND MECHANICALLY SPLUICED OR WELDED
BEARING STRIP
MILD STEEL DOWEL COUPLERS EMBEDDED IN PRESTRESSED T-BEAM FLANGES
SEAL
INVERTED TEE BEAM
PRESTRESSED TEE BEAM

FIG. 51 TYPICAL CONNECTIONS OF PRECAST FLOOR SLAB ELEMENTS

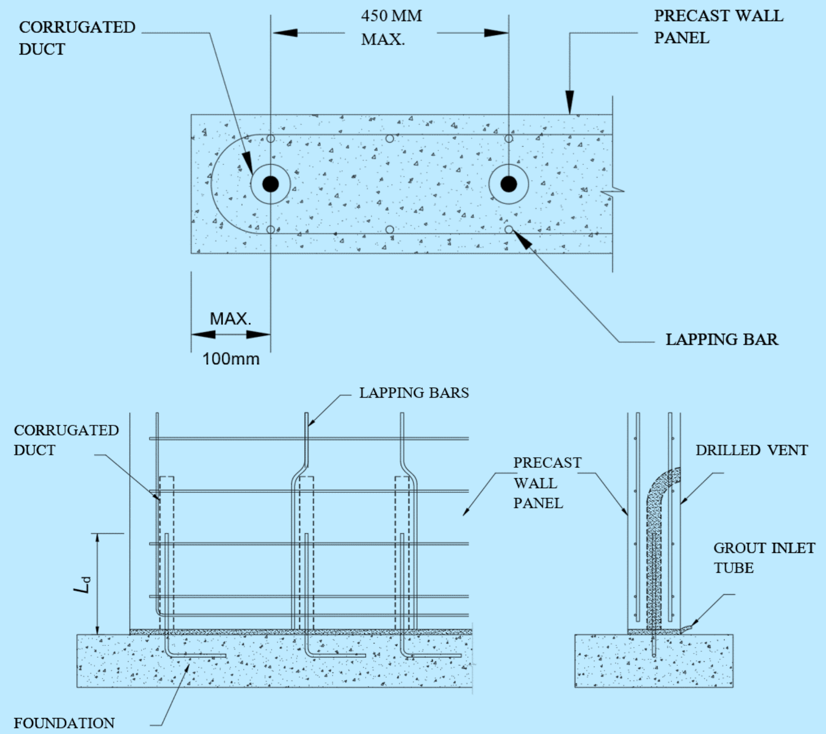

CORRUGATED DUCT
450 MM MAX.
PRECAST WALL PANEL
MAX.
100mm
LAPPING BAR
LAPPING BARS
CORRUGATED DUCT
L_d
PRECAST WALL PANEL
DRILLED VENT
GROUT INLET TUBE
FOUNDATION

FIG. 52 WALL TO FOUNDATION CONNECTION THROUGH GROUTED DUCT

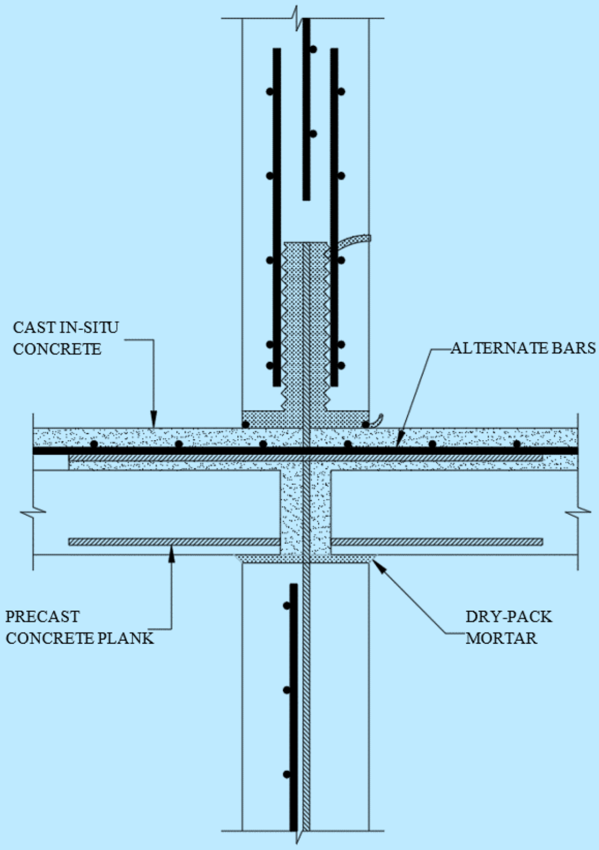

CAST IN-SITU CONCRETE
ALTERNATE BARS
PRECAST CONCRETE PLANK
DRY-PACK MORTAR

FIG. 53 WALL TO FLOOR SLAB CONNECTION

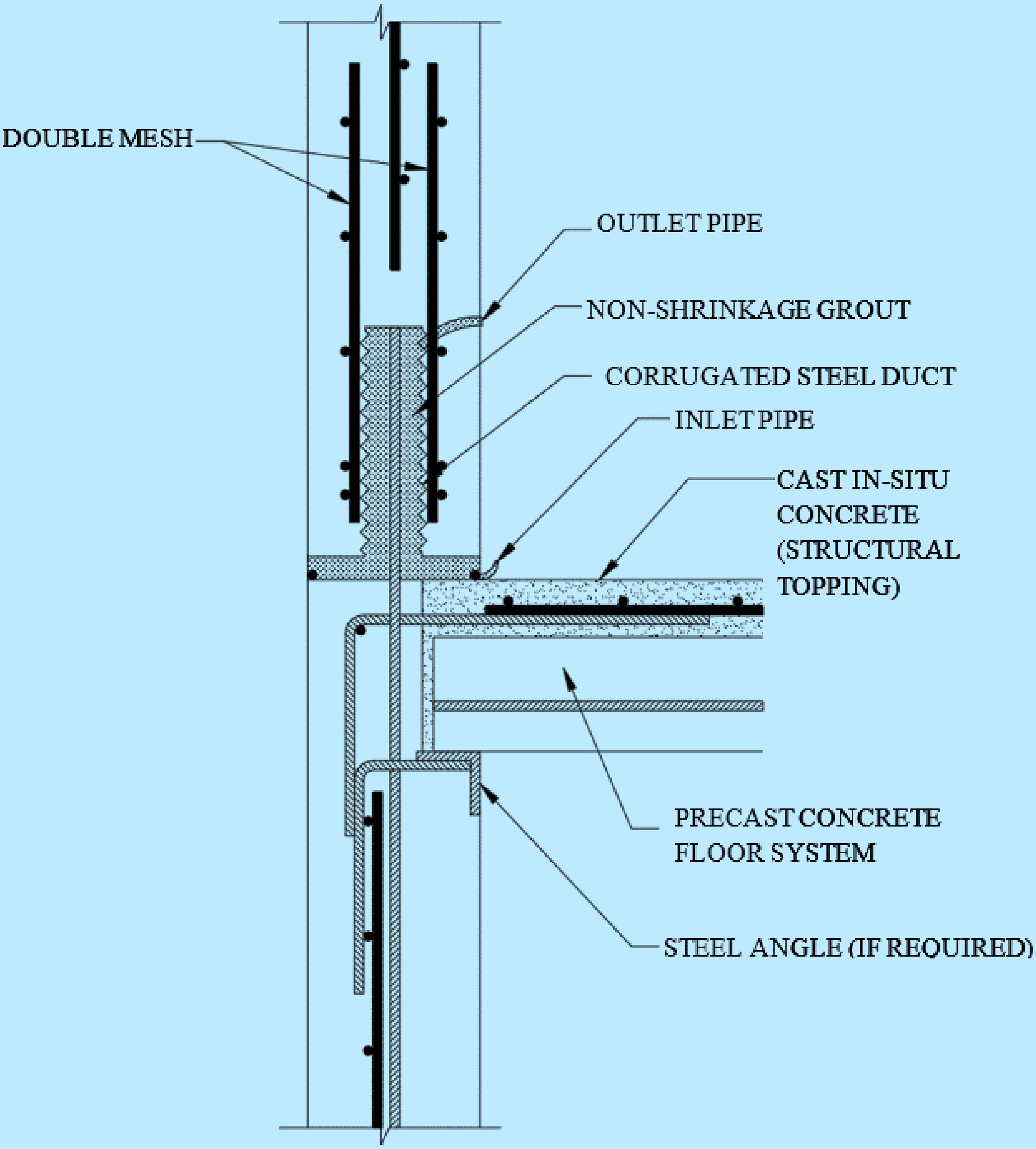
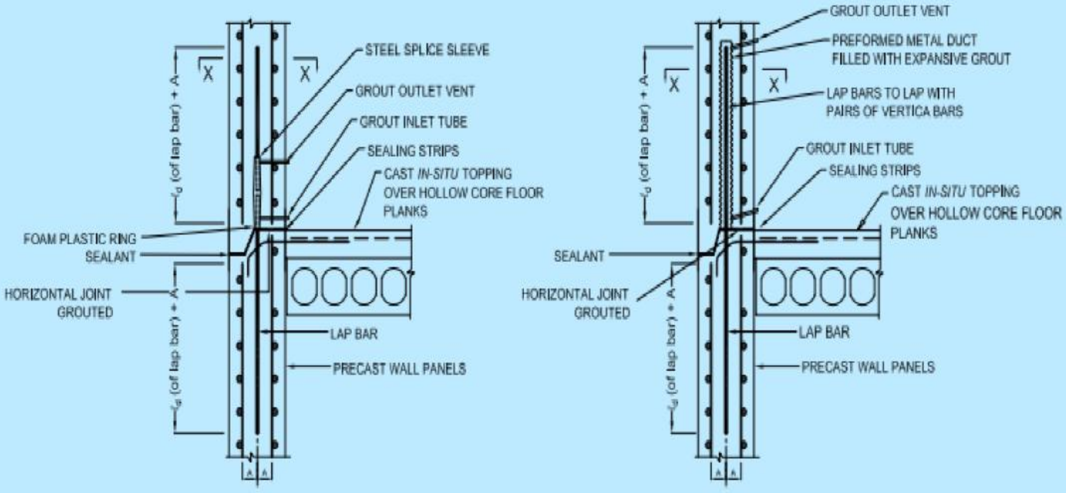
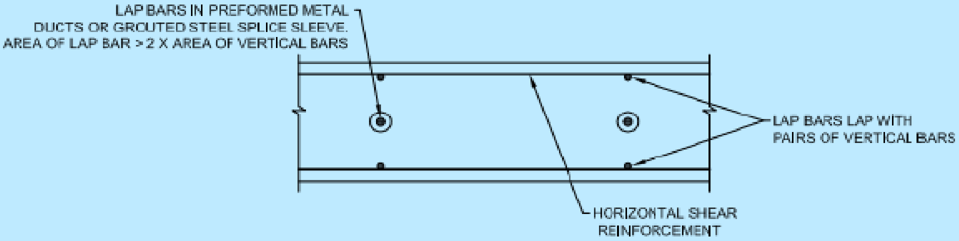

DOUBLE MESH
OUTLET PIPE
NON-SHRINKAGE GROUT
CORRUGATED STEEL DUCT
INLET PIPE
CAST IN-SITU CONCRETE (STRUCTURAL TOPPING)
PRECAST CONCRETE FLOOR SYSTEM
STEEL ANGLE (IF REQUIRED)

FIG. 54 EXTERIOR WALL TO FLOOR SLAB CONNECTION


STEEL SPLICE SLEEVE
GROUT OUTLET VENT
GROUT INLET TUBE
SEALING STRIPS
CAST IN-SITU TOPPING OVER HOLLOW CORE FLOOR PLANKS
FOAM PLASTIC RING
SEALANT
HORIZONTAL JOINT GROUTED
LAP BAR
PRECAST WALL PANELS
X
X
ℓd (of lap bar) + A
ℓd (of lap bar) + A
A
A
GROUT OUTLET VENT
PREFORMED METAL DUCT FILLED WITH EXPANSIVE GROUT
LAP BARS TO LAP WITH PAIRS OF VERTICA BARS
GROUT INLET TUBE
SEALING STRIPS
CAST IN-SITU TOPPING OVER HOLLOW CORE FLOOR PLANKS
SEALANT
HORIZONTAL JOINT GROUTED
LAP BAR
PRECAST WALL PANELS

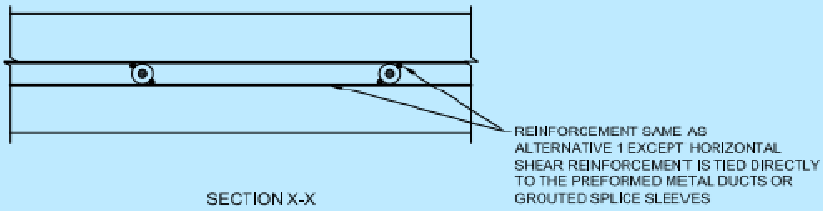
55A HORIZONTAL JOINT – TYPE A

55B HORIZONTAL JOINT – TYPE B


LAP BARS IN PREFORMED METAL DUCTS OR GROUTED STEEL SPLICE SLEEVE. AREA OF LAP BAR > 2 X AREA OF VERTICAL BARS
LAP BARS LAP WITH PAIRS OF VERTICAL BARS
HORIZONTAL SHEAR REINFORCEMENT

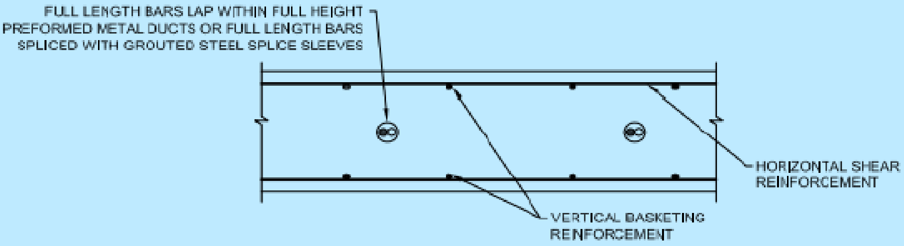
SECTION X-X

ALTERNATIVE 1


REINFORCEMENT SAME AS ALTERNATIVE 1 EXCEPT HORIZONTAL SHEAR REINFORCEMENT IS TIED DIRECTLY TO THE PREFORMED METAL DUCTS OR GROUTED SPLICE SLEEVES

SECTION X-X

ALTERNATIVE 2


FULL LENGTH BARS LAP WITHIN FULL HEIGHT PREFORMED METAL DUCTS OR FULL LENGTH BARS SPLICED WITH GROUTED STEEL SPLICE SLEEVES
HORIZONTAL SHEAR REINFORCEMENT
VERTICAL BASKETING REINFORCEMENT

SECTION X-X

ALTERNATIVE 3

FIG. 55 MONOLITHIC PRECAST WALL CONSTRUCTION

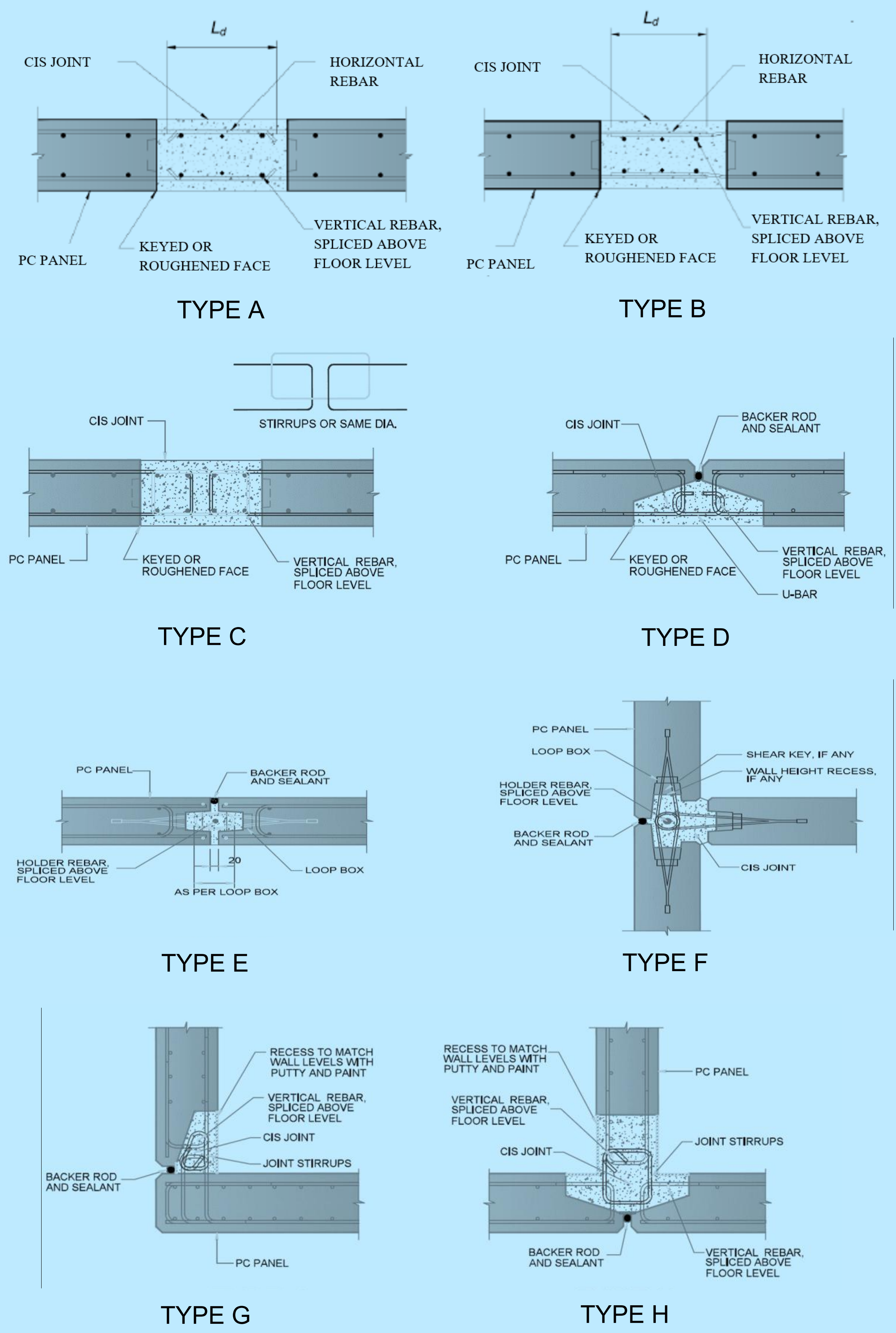
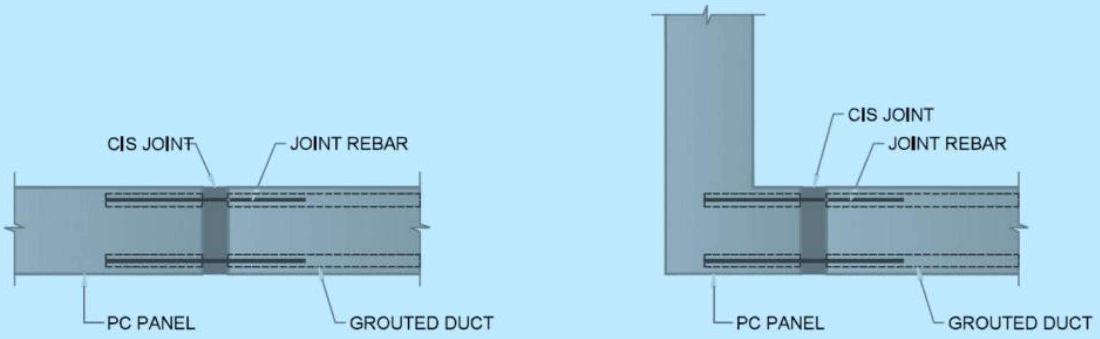

L_d
CIS JOINT
HORIZONTAL REBAR
PC PANEL
KEYED OR ROUGHENED FACE
VERTICAL REBAR, SPLICED ABOVE FLOOR LEVEL
TYPE A
L_d
CIS JOINT
HORIZONTAL REBAR
PC PANEL
KEYED OR ROUGHENED FACE
VERTICAL REBAR, SPLICED ABOVE FLOOR LEVEL
TYPE B
STIRRUPS OR SAME DIA.
CIS JOINT
PC PANEL
KEYED OR ROUGHENED FACE
VERTICAL REBAR, SPLICED ABOVE FLOOR LEVEL
TYPE C
CIS JOINT
BACKER ROD AND SEALANT
PC PANEL
KEYED OR ROUGHENED FACE
VERTICAL REBAR, SPLICED ABOVE FLOOR LEVEL
U-BAR
TYPE D
PC PANEL
BACKER ROD AND SEALANT
HOLDER REBAR, SPLICED ABOVE FLOOR LEVEL
20
AS PER LOOP BOX
LOOP BOX
TYPE E
PC PANEL
LOOP BOX
HOLDER REBAR, SPLICED ABOVE FLOOR LEVEL
BACKER ROD AND SEALANT
SHEAR KEY, IF ANY
WALL HEIGHT RECESS, IF ANY
CIS JOINT
TYPE F
RECESS TO MATCH WALL LEVELS WITH PUTTY AND PAINT
VERTICAL REBAR, SPLICED ABOVE FLOOR LEVEL
CIS JOINT
JOINT STIRRUPS
BACKER ROD AND SEALANT
PC PANEL
TYPE G
RECESS TO MATCH WALL LEVELS WITH PUTTY AND PAINT
VERTICAL REBAR, SPLICED ABOVE FLOOR LEVEL
CIS JOINT
PC PANEL
JOINT STIRRUPS
BACKER ROD AND SEALANT
VERTICAL REBAR, SPLICED ABOVE FLOOR LEVEL
TYPE H

FIG. 56 VERTICAL JOINT BETWEEN WALL TO WALL OR WALL TO COLUMN (CONTINUED)


CIS JOINT
JOINT REBAR
PC PANEL
GROUTED DUCT
CIS JOINT
JOINT REBAR
PC PANEL
GROUTED DUCT

TYPE I

TYPE J

FIG. 56 VERTICAL JOINT BETWEEN WALL TO WALL OR WALL TO COLUMN

ANNEX F

(*Clause* 11)

COMMON DEFECTS AND REMEDIES

F-1 As defects in precast concrete elements result in direct and indirect cost in terms of rectification and construction time, it is worthwhile to ensure that they are produced and handled in a way to avoid/reduce such incidences. Table 19 illustrates some of these common defects, their causes and preventive and remedial measures.

Table 19 List of Common Defects and Recommended Remedial Measures

(*Clause* F-1)

Sl No. (1)	Common Defects (2)	Possible Causes (3)	Recommendations (4)	Remedial Measures (5)
i)	*Dimensional deviation*: a) Variation in the dimension of precast elements would affect the joint alignment between these elements when erected; and b) Precast slab element may warp due to insufficient concrete strength at lifting or improper storage condition.	a) Mould forms may not be sufficiently rigid to maintain specified tolerances during concrete placement; b) Precast elements may not have gained sufficient concrete strength when demoulded; c) Top surface finish of precast elements may not be properly levelled and trowelled during production which result in differential thickness; and d) Precast elements (especially slender wall or slab panels) may be subjected to undue stress and deformation when they are not properly supported during storage.	a) Regular check on the dimensions and rigidity of mould forms before casting operations. As a general guide the recommended thickness for steel mould are: 1) 4.5 mm — Up to 50 castings; 2) 6 mm — Up to 100 castings; and 3) 9 mm — Up to 200 castings. Mould forms conditions will deteriorate with time and usage. They should be repaired, stiffened or replaced when needed. b) Cube tests should be conducted to ascertain the concrete strength of elements before demoulding;	a) For minor deviation, corrective measures such as surface grinding, trimming/ hacking and skim coat application can be appropriately used to remedy the situation; and b) Precast elements that are not within acceptable tolerance limits and have significant effects on the structural integrity or architectural performance should not be used.

Table 19 (*Continued*)

Sl No.	Common Defects	Possible Causes	Recommendations	Remedial Measures
(1)	(2)	(3)	(4)	(5)
			c) Spreading and levelling of concrete placement using appropriate tools such as structural screeder; and d) Precast elements should be properly stored and stacked at designated points using suitable support spacers and frame rack system.	
ii)	Cracks	a) Precast elements may not have gained sufficient concrete strength before demoulding; b) Cracks may have occurred during initial lifting due to friction between the elements and the casting mould forms; c) Thickness of the precast elements may be too thin (70 mm or less) for safe demoulding and handling; and d) Cracks may have occurred during erection due to lack of planning and provisions for the precast panel geometry, crane rigging configuration and location of openings.	a) Proper curing method, curing time and temperature should be maintained; b) Cube tests should be conducted to ascertain the concrete strength of elements before demoulding; c) Appropriate form release agents should be used and uniformly applied onto the mould surface to minimize friction; d) Sectional thickness of precast elements should be increased to accommodate demoulding and handling stresses; e) Proper handling techniques should be adopted; f) Sufficient lifting points should be used to minimize over-stressing on certain areas;	a) All cracks should be examined by a qualified engineer to determine if they present a structural problem; b) Depending on the locations and seriousness of the cracks, different repair methods can be used to make good the affected precast elements; and c) Hairline cracks (not more than design crack width) can be repaired by cutting V-groove of specified minimum depth along the crack-lines, followed by patching subject to location and length of the crack in relation to length of units and not having adverse effect on the structural strength of the unit. For surface cracks (more than design crack width) or through cracks, epoxy injection method should be used

Table 19 (*Continued*)

Sl No. (1)	Common Defects (2)	Possible Causes (3)	Recommendations (4)	Remedial Measures (5)
			g) Additional reinforcing bars should be placed around the opening and odd corners; and h) Temporary stiffeners for openings should be provided during erection.	to ensure that the cracks are completely bound and filled with epoxy.
iii)	Chip-off and damages	a) Chip-off at panel edges are usually caused by the hard bearing at support or excessive force exerted on the elements when handling; and 4) Improper storage method.	a) Precautions should be taken to avoid damaging the elements during placement on vehicle, travel to site and during the unloading operation. Bearing pads should be used to cushion the contact areas from damage; b) The storage area should be relatively flat and dry; c) Precast elements should be properly stored and stacked at designated points using suitable support spacers and frame rack system; d) The casting slab or mould form should be thoroughly cleansed, levelled to achieve a smooth surface; e) The coverage of form release agents should be adequate and applied uniformly onto the mould surface;	a) Remove all loose concrete and wash off any dust or dirt in the affected area; b) Apply bonding agent to affected concrete surface; c) Welded wire mesh can be included to provide support for the patch mix concrete or grout; d) Patch mix composition or grout should be consistent with the strength requirements of the adjacent concrete; e) Formwork should be placed whenever it is necessary to contain the patch mix or grout; and f) The affected area should be protected from any disturbance during the curing period.

Table 19 (*Continued*)

Sl No. (1)	Common Defects (2)	Possible Causes (3)	Recommendations (4)	Remedial Measures (5)
			f) Spacers of the correct sizes should be used and well secured to maintain the concrete cover required during casting; g) Lifting inserts and concrete strength of elements should be of adequate capacity for the intended lift. Proprietary products for safe and efficient handling may be used for this purpose; and h) Lifting inserts or hooks should be inspected for proper location. They should be fastened to specified depth prior to concrete placement.	
iv)	Honeycomb and excessive pinholes	a) Poor concrete compaction due to ineffective vibration or rebars congestion; annd b) Grout leakage along the perimeter of side forms due to: 1) Loose or missing bolts, fixing pins; 2) Damaged rubber gasket seal; 3) Mould part, if defective.	a) Proper compaction methods should be adopted and carried out; b) Concrete mix design and workability should bereviewed and adjusted when needed; c) Appropriate concrete vibrator such as clamp-on form vibrator may be used to attain better compaction; d) Rebar congestion can be alleviated by having larger size (that is, lesser number) rebars or by increasing the sectional	a) Remove all loose concrete and wash off any dust or dirt in the affected area; b) Apply bonding agent to affected concrete surface; c) Welded wire mesh may be included to provide support for the patch mix concrete or grout; d) Patch mix composition or grout should be consistent with the strength requirements of the adjacent concrete;

Table 19 (*Continued*)

Sl No.	Common Defects	Possible Causes	Recommendations	Remedial Measures
(1)	(2)	(3)	(4)	(5)
			dimensions of the elements where possible; e) Mechanical couplers or sleeves can be used to simplify the reinforcement layout and to minimize rebar congestion; and f) Defective mould forms and accessories should be repaired or replaced to prevent grout leakage during concrete.	e) Formwork is to be put up where it is necessary to contain the patch mix or grout; and f) The affected area should be protected from any disturbance during the curing period.
v)	*Missing or wrong details* — such as cast-in items, architectural nib and groove details, lifting hooks, reinforcement/starter bars/block- out/corrugated pipes.	a) Items may not have been included in the shop drawing; and b) Quality checks may not be properly in place.	a) All items should be reflected in the shop drawings for production. Any changes should be made known to the production team; and b) The use of checklists during inspection can help to ensure that all items specified in the drawing are included before casting.	a) Certain details such as missing starter bars/reinforcement and lifting hooks can be replaced by welding additional reinforcement bars after hacking off the concrete at the affected area; and b) Other items such as cast-in items, groove and block-out can be provided by chasing or chiselling out the face of the precast panels.
vi)	Strand slippage which exceed allowable design values (applicable to pre-stressed elements only) (Slippages of pre-stressing strands can be detected by visual inspection).	a) Insufficient bond strength between concrete and the pre-stressing strands; and b) Poor compaction of concrete around pre-stressed strands.	a) Required concrete strength of the precast elements should be attained and verified by cube test results before de-tensioning of strands; b) Proper compaction method should be adopted and carried out during casting;	a) It is not possible to rectify the elements from strand slippage; and b) Design verification should be carried out to ascertain the reduced capacity of the elements due to slippage, if adopted.

Table 19 (*Concluded*)

Sl No. (1)	Common Defects (2)	Possible Causes (3)	Recommendations (4)	Remedial Measures (5)
			c) Concrete mix design and workability should be reviewed and adjusted when needed; and b) Appropriate concrete vibrator to attain better compaction may be provided.	
vi)	Alignment	a) Inaccurate setting out and positioning of precast. elements during erection; and b) Deviation in the dimensions of the precast element.	a) Appropriate surveying and levelling equipment should be used to achieve better alignment; b) Required alignment and level should be confirmed before permanent jointing; and c) Critical dimensions of precast concrete elements should be verified before installation.	a) Minor adjustments of the element/panel alignment can be done during installation. However the effects on the final alignment and deviation of the building should be evaluated; b) For minor deviations, corrective measures such as surface grinding, trimming/ hacking and skim coat application can be appropriately used to rectify the precast elements before installation; and c) Precast elements that are not within acceptable tolerance limits and have significant effects on the structural integrity or architectural performance should not be used.

ANNEX G

(*Foreword*, *Clauses* 5, 7.1, 10.1.2, 10.9.1 *and* 11)

SUSTAINABILITY IN PRECAST CONCRETE CONSTRUCTION

G-1 GENERAL

This annex presents sustainable practices in precast concrete construction, emphasizing methods for reducing environmental impacts, promoting resource conservation and ensuring long-term viability. The following key sustainability factors can enables the adoption of greener and efficient solutions provided the challenges involved are appropriately addressed.

G-2 USE OF RECYCLED AGGREGATES IN PRECAST CONCRETE

G-2.1 Environmental Benefits

G-2.1.1 *Conservation of Natural Resources*

By reusing construction and demolition debris as recycled aggregates, the need for extracting virgin raw materials like sand and granite is significantly reduced, preserving ecosystems and minimizing environmental disruption.

G-2.1.2 *Reduction in Energy Use*

Recycled aggregates require less energy to process compared to natural aggregates, which leads to a lower carbon footprint during production. This also reduces the energy demand associated with quarrying, transportation and processing.

G-2.1.3 *Circular Economy Impact*

Incorporating recycled aggregates into precast concrete non-structural components-such as paving slabs, kerbs, and drainage of systems, etc, supports a circular economy, minimizing waste sent to landfills and promoting the reuse of construction materials.

G-2.2 Challenges and Innovations

G-2.2.1 *Ensuring Consistent Quality*

Recycled aggregates may exhibit variability in size and composition, potentially impacting concrete strength and durability. Innovations in sorting, crushing and refining technologies can improve the consistency and reliability of recycled aggregates.

G-2.2.2 *Efficient Use of Water*

In general, excessive water is required to be used while using recycled aggregate and can have negative environmental impacts. By adopting optimized mix designs and water-efficient technologies, the water demand for concrete production can be significantly reduced.

G-2.2.3 *Advancement in Sustainable Mixes*

New research into mix designs is focusing on achieving better integration of recycled aggregates without compromising the material’s strength or durability. This can lead to a more sustainable, high-performance concrete product.

G-3 ADOPTION OF RENEWABLE ENERGY SOURCES

G-3.1 Environmental Benefits

G-3.1.1 *Decarbonizing Operations*

Shifting precast concrete manufacturing facilities to renewable energy sources, such as solar, wind and hydropower, significantly reduces reliance on fossil fuels, helping to lower overall greenhouse gas emissions and mitigate climate change impacts.

G-3.1.2 *Electric and Hybrid Machinery*

By replacing conventional diesel-powered equipment with electric and hybrid alternatives, the precast concrete industry can reduce air pollution and carbon emissions associated with construction machinery.

G-3.2 Challenges and Innovations

G-3.2.1 *High Initial Costs*

The transition to renewable energy systems and low-emission machinery involves substantial initial investment. However, long-term operational savings, combined with available financial incentives for green technologies, can help offset the upfront costs.

G-3.2.2 *Energy Storage and Smart Grids*

Installing energy storage solutions, such as batteries, in conjunction with on-site renewable energy systems can help mitigate energy supply issues during periods of high demand or when renewable energy generation is low, further reducing dependence on the traditional energy grid.

G-4 REDUCING SITE POLLUTION AND WASTE

G-4.1 Environmental Benefits

G-4.1.1 *Waste Minimization*

Precast construction reduces on-site waste generation because most components are manufactured off-site in controlled factory settings. This reduces generation of waste and their dispersal at landfills and minimizes the potential for soil and water contamination and helps in achieving undisturbed site.

G-4.1.2 *Reduced Emissions and Noise Pollution*

Precast methods reduce the need for heavy on-site machinery and long construction timelines. As a result, there is less air pollution, noise pollution, and disturbance to nearby ecosystems or communities.

G-4.2 Challenges and Innovations

G-4.2.1 *Reducing Transportation Emissions*

Transporting precast components to construction sites can contribute to emissions, especially when distances are long. This can be minimized by optimizing transportation logistics, using hybrid or electric vehicles and focussing on the use of modular components that reduce transportation needs.

G-4.2.2 *On-Site Pollution Prevention*

During installation, on-site pollution, such as dust or runoff, can still occur. Simple practices like water misting to suppress dust and covering concrete surfaces to prevent runoff can significantly reduce the environmental impact of installation activities.

G-5 USE OF SUPPLEMENTARY CEMENTITIOUS MATERIALS (SCMs) AND OPTIMIZED CONCRETE MIXES

G-5.1 Environmental Benefits

G-5.1.1 *Low-Carbon Alternatives to Cement*

Replacing traditional Portland cement with supplementary cementitious materials (SCMs) such as fly ash, slag, or natural pozzolans can drastically reduce the carbon footprint of concrete production by minimizing the need for energy-intensive cement manufacturing.

G-5.1.2 *Efficient Resource Use*

Advanced mix designs, including high-performance concrete (HPC) and ultra-high-performance concrete (UHPC), allow for the reduction of material consumption without sacrificing strength or durability. These innovations help to optimize the use of raw materials, ensuring sustainability in production.

G-5.2 Challenges and Innovations

G-5.2.1 *Durability and Performance*

While reducing cement content or using alternative binders can lower the carbon footprint, it is essential to ensure the long-term durability and performance of the concrete.

G-5.2.2 *Geopolymer Concrete*

Geopolymer concrete, made from industrial by-products has a lower carbon footprint compared to traditional cement-based concrete and can be used in precast applications without compromising strength and durability.

G-6 SUSTAINABLE DESIGN AND PRODUCTION OPTIMIZATION

G-6.1 Environmental Benefits

G-6.1.1 *Material Efficiency through Design*

Precast elements can be optimised for material efficiency by carrying out optimum design. Building information modelling (BIM) allows for detailed digital models that reduce waste during both the design and construction phases.

G-6.1.2 *Modular and Prefabricated Systems*

The use of modular designs with standardization in precast construction can reduce material waste, reducing production time, reuse of mould and optimize the process of precasting.

G-6.2 Challenges and Innovations

G-6.2.1 *Customization versus Standardization*

While standardization helps reduce waste and increase efficiency, some projects require customised solutions. The challenge lies in finding a balance between benefits of standardized components and the need for bespoke, project-specific designs.

G-6.2.2 3*D Printing and Additive Manufacturing*

Emerging technologies like 3D printing could revolutionise precast construction (*refer* Annex B). By using digital fabrication techniques, custom shapes and optimized designs can be produced efficiently, with less material wastage.

G-7 TRANSPARENCY, CERTIFICATION AND ETHICAL PRACTICES

G-7.1 Sustainability Governance

G-7.1.1 *Environmental Certifications*

Precast manufacturers and construction companies can pursue certifications such as environmental management systems, to demonstrate their commitment towards achieving sustainability. These certifications set a global benchmark for eco-friendly practices in construction.

G-7.1.2 *Ethical Sourcing and Labour Practices*

Sustainable construction practices require ethical sourcing of materials, ensuring that raw materials are extracted responsibly and workers are treated fairly. This also includes adherence to applicable labour and governance standards/practices.

G-7.2 Challenges and Innovations

G-7.2.1 *Data Transparency*

As consumer and regulatory demand for sustainability data increases, companies are under pressure to disclose their environmental impacts. Technologies like block-chain offer innovative solutions for ensuring transparency and accountability in reporting environmental performance.

G-7.2.2 *Community and Stakeholder Engagement*

Actively engaging with local communities, government bodies, and customers to ensure that sustainability goals align with the social expectations and needs of stakeholders.

ANNEX H

(*Clause* 7.9.4.8)

DESIGN AND DETAILING GUIDELINES FOR PRECAST STRUCTURES WITH HOLLOW CORE SLABS

H-1 GENERAL

This annex presents the design guidelines and detailing parameters essential for structures using hollow core slabs as the flooring system. This annexure ensures that all parameters pertaining to structural stability and end user safety of hollow core slab systems are attended to.

H-2 DESIGN GUIDELINES

H-2.1 Hollow core slabs are to be designed as a simply supported slab system. The use of hollow core slabs is not permitted as a continuous flooring system.

H-2.2 Hollow core slabs are to be mandatorily designed using structural topping as mentioned in **6.3.6.1**. This topping shall be considered acting composite with the hollow core slab provided conditions mentioned in **6.3.6.3** are met.

H-2.3 For flooring systems consisting of hollow core slabs, only the structural topping shall be considered as part of the diaphragm as noted in **6.3.6.3**. No part of the hollow core slab shall be considered as part of diaphragm or considered participating in lateral load transfer. Structural topping design to follow guidelines as prescribed in **7.10.8**.

H-2.4 The design engineer is to assess the torsional rotation of the hollow core slab caused by the differential settlement of the slab supports. Special attention is to be undertaken by the structural engineer since hollow core slabs have limited torsional resistance capacity.

H-3 DETAILING PARAMETERS

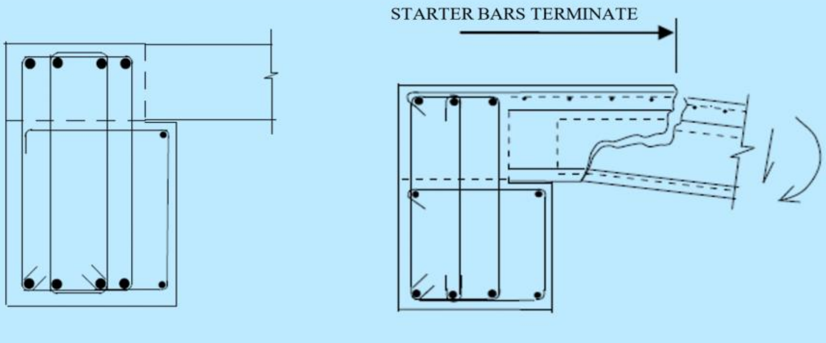
H-3.1 Low friction bearing shims or strips are to be placed under the hollow core slabs to mitigate the formation of flexural crack close to the support in the hollow core element and to mitigate spalling of support ledge concrete.

H-3.2 Concrete ledges to be used as bearing support for hollow core slabs must have the ledge reinforcement tied with the primary supporting beam or wall as shown in Fig. 57A.

H-3.3 Hollow core slabs to have minimum bearing of 80 mm to mitigate loss of support due to spalling and relative movement of the slabs.

H-3.4 Nominal starter bars must extend for a length of 600 mm from the face of the supporting members and tied to the structural topping reinforcement to mitigate failure due to negative moments close to the support during seismic events as shown in Fig. 57B. Starter bar reinforcement diameter may be 8 mm for slabs up to 300 mm depth and 10 mm for slabs over 300 mm depth at a spacing not more than 250 mm.

H-3.5 Structural topping to be preferably reinforced with reinforcement with elongation more than 14.5 percent to mitigate brittle failure of topping. Welded mesh may be permitted as topping reinforcement provided the mesh is fabricated from reinforcement having elongation more than 14.5 percent.

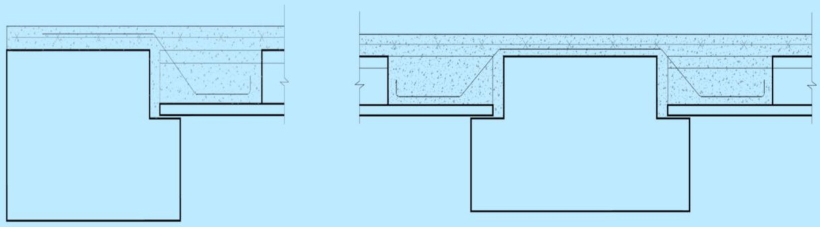


57A) LEDGE REINFORCEMENT TIED TO SUPPORTING MEMBER

57B) NEGATIVE FLEXURAL MOMENT FAILURE NEAR TO SUPPORT FACE

FIG. 57 DETAILING FOR HOLLOW CORE SLAB AND SUPPORTING ELELMENTS

H-3.6 A minimum of 2 cores to be opened for a length of 600 mm at both span ends of the hollow core slab, they are to be reinforced with 8 mm reinforcement for slabs up to 300 mm depth and 10 mm for slabs over 300 mm depth and filled simultaneously with the structural topping concrete. Figure 58 elaborates on the detailing that may be adopted at open core locations.

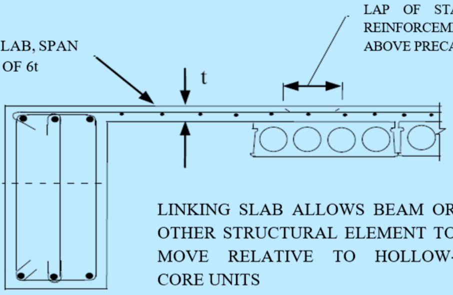


58A) OPEN CORE REINFORCEMENT AT END SPAN

58B) OPEN CORE REINFORCEMENT AT INTERMEDIATE SPAN

FIG. 58 DETAILING FOR HOLLOW CORE SLAB AT OPEN CORE LOCATION

H-3.7 Linking slabs to be provided to connect structural members to non-bearing ends of hollow core slabs. The length of the linking slab to be a minimum of 6 times the structural topping thickness as described in Fig. 59. The depth of the linking slab will be as per structural or load requirements.



LINKING SLAB, SPAN MINIMUM OF 6t

LAP OF STARTER BARS TO REINFORCEMENT IN TOPPING ABOVE PRECAST UNIT

LINKING SLAB ALLOWS BEAM OR OTHER STRUCTURAL ELEMENT TO MOVE RELATIVE TO HOLLOW-CORE UNITS

FIG. 59 DETAILING FOR LINKING SLAB AT HOLLOW CORE SLAB AND STRUCTURAL MEMBER

LIST OF STANDARDS

The following list records those standards which are acceptable as 'good practice' and 'accepted standards' in the fulfilment of the requirements of this NBCS. The latest version of a standard shall be adopted at the time of enforcement of this NBCS. The standards listed may be used as a guide in conformance with the requirements of the referred clauses in this NBCS.

In the following list, the number appearing in the first column within parentheses indicates the number of the reference in this Section.

	IS No.	*Title*
(1)	IS 13920 : 2016	Ductile design and detailing of reinforced concrete structures subjected to seismic forces — Code of practice (*first revision*)
(2)	IS 456 : 2000	Plain and reinforced concrete — Code of practice (*fourth revision*)
(3)	IS 1343 : 2012	Prestressed concrete — Code of practice (*second revision*)
(4)	IS 383 : 2016	Coarse and fine aggregate for concrete — Specification (*third revision*)
	IS 456 : 2000	Plain and reinforced concrete — Code of practice (*fourth revision*)
(5)	IS 9103 : 1999	Concrete admixtures — Specification (*first revision*)
	IS 456 : 2000	Plain and reinforced concrete — Code of practice (*fourth revision*)
(6)	IS 10262 : 2019	Concrete mix proportioning — Guidelines (*second revision*)
(7)	IS 1199 : 1959	Methods of sampling and analysis of concrete
(8)	IS 10262 : 2019	Concrete mix proportioning — Guidelines (*second revision*)
	IS 1199 : 1959	Methods of sampling and analysis of concrete
(9)	IS 9417 : 2018	Welding of high strength steel bars for reinforced concrete construction — Recommendations (*second revision*)
(10)	IS 16172 : 2023	Reinforcement couplers for mechanical splices of steel bars in concrete — Specification (*first revision*)
(11)	IS 18256 : 2023	Solid round glass fibre reinforced polymer (GFRP) bars for concrete Reinforcement — Specification
(12)	IS 1566 : 1982	Specification for hard-drawn steel wire fabric for concrete reinforcement (*second revision*)
(13)	IS 14343 : 1996	Choice of grouting, materials for alluvial grouting — Guidelines
(14)	IS 4671 : 2018	Expanded polystyrene for thermal insulation purposes — Specification (*second revision*)
(15)	IS 8183 : 2024	Bonded mineral wool — Specification (*second revision*)
(16)	IS 6598 : 2018	Cellular concrete for thermal insulation — Specification (*first revision*)
(17)	IS 10297 : 1982	Code of practice for design and construction of floors and roofs using precast reinforced/prestressed concrete ribbed or cored slab units
(18)	IS 16700 : 2023	Criteria for structural safety of tall concrete buildings (*first revision*)

	IS No.	*Title*
(19)	IS 1641 : 2013	Fire safety of buildings (general): General principles of fire grading and classification — Code of practice (*second revision*)
	IS 1642 : 2013	Fire safety of buildings (general): Details of construction — Code of practice (*second revision*)
(20)	IS 4326 : 2013	Earthquake resistant design and construction of buildings — Code of practice (*third revision*)
(21)	IS 4082 : 1996	Stacking and storage of construction materials and components at site — Recommendations (*second revision*)
(22)	IS 11384 : 2022	Composite construction in structural steel and concrete — Code of Practice (*first revision*)
(23)	IS 3201 : 1988	Criteria for design and construction of precast concrete trusses and purlins (*first revision*)
(24)	IS 6332 : 1984	Code of practice for construction of floor and roofs using precast doubly-curved shell units
	IS 10297 : 1982	Code of practice for design and construction of floors and roofs using precast reinforced/prestressed concrete ribbed or cored slab units
	IS 10505 : 1983	Code of practice for construction of floors and roofs using precast concrete waffle units
	IS 13994 : 1994	Design and construction of floor and roof with precast reinforced concrete planks and joists — Code of practice
	IS 14142 : 1994	Design and construction of floors and roofs with prefabricated brick panel — Code of practice
	IS 14215 : 1994	Design and construction of floors and roofs with precast reinforced concrete channel units — Code of practice
	IS 14242 : 1995	Design and construction of roofs using precast reinforced concrete L-Panels — Code of practice
(25)	IS 6061	Code of practice for construction of floor and roof with joists and filler blocks:
	(Part 1) : 1971	With hollow concrete filler blocks
	(Part 2) : 1981	With hollow clay filler blocks (*first revision*)
	(Part 3) : 1981	With precast hollow clay block joists and hollow clay filler blocks
	(Part 4) : 1981	With precast hollow clay block slab panels
(26)	IS 14687 : 1999	Falsework for concrete structures — Guidelines
(27)	IS 2185 (Part 1) : 2005	Concrete masonry units — Specification: Part 1 Hollow and solid concrete blocks (*third revision*)
(28)	IS 3952 : 2013	Burnt clay hollow bricks and blocks for walls and partitions — Specification (*third revision*)
(29)	IS 2185 (Part 3) : 1984	Specification for concrete masonry units: Part 3 Autoclaved cellular (Aerated) concrete blocks (*first revision*)

	IS No.	*Title*
(30)	IS 4101 (Part 2) : 1967	Code of practice for external facings and veneers: Part 2 Cement concrete facing
(31)	IS 1950 : 1962	Code of practice for sound insulation of non-industrial buildings
(32)	IS 3483 : 1965	Code of practice for noise reduction in industrial buildings
	IS 2526 : 1963	Code of practice for acoustical design of auditoriums and conference halls
(33)	IS 1904 : 2021	General requirements for design and construction of foundations in soils — Code of practice (*fourth revision*)
(34)	IS 516 (Part 1/Sec 1) : 2021	Hardened concrete — Methods of test: Part 1 Testing of strength of hardened concrete, Section 1 Compressive, flexural and split tensile strength (*first revision*)
(35)	IS 3414 : 1968	Code of practice for design and installation of joints in buildings
(36)	IS 1786 : 2008	High strength deformed steel bars and wires for concrete reinforcement — Specification (*fourth revision*)
(37)	SP 30 : 2023	National Electrical Code of India 2023 (*second revision*)
	IS 732 : 2019	Code of practice for electrical wiring installations (*fourth revision*)
(38)	IS/IEC 62305-1 : 2010	Protection against lightning: Part 1 General principles
(39)	IS 2065 : 1983	Code of practice for water supply in buildings (*second revision*)
	IS 1742 : 1983	Code of practice for building drainage (*second revision*)
(40)	IS 1742 : 1983	Code of practice for building drainage (*second revision*)
	IS 12183 (Part 1) : 1987	Code of practice for plumbing in multi-storeyed buildings: Part 1 Water supply

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART C STRUCTURAL DESIGN

SECTION 8 GLASS AND GLAZING

BUREAU OF INDIAN STANDARDS

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National Building Code Sectional Committee, CED 46

FOREWORD

This NBCS (Part C/Section 8) deals with the use of glass in buildings. Glazing has become an important item in building construction. Glass, the primary glazing element has to be selected to cater to several requirements and the glazing has to be designed to meet various engineering requirements. Fixing of glass, a specialized operation, when properly done, will avoid the hazards of broken glass. Growing trend in resorting to glazed windows/doors in buildings and structures has considerably increased the importance of glazing and the need for proper workmanship. Considering all these, this Section was introduced in the third revision of the Code in 2016 as part of the National Building Code of India.

This Section provides guidance in the selection of appropriate glazing for various types for building construction; guidance on the energy and light aspects while choosing glazing; guidance on determining the appropriate thickness of glass used in building glazing and guidance with respect to human impact safety while using glazing in buildings.

Use of organic coated films including safety films on glass shall not classify the glass as safety glass as per this NBCS, and hence users should exercise caution in choosing their options.

Information on installation of glass mirrors and glass railings are given in the informative Annex H and Annex J, respectively.

A conformity assessment sheet for evaluating the compliance of glass and glazing systems with the requirements of this Section has been included in informative Annex K.

This Section was introduced in the Code in 2016 as part of the National Building Code of India. As a result of experience gained in implementation of 2016 version of this Section, feedback received as well as in view of formulation of new standards in the field of glass and glazing and revision of some existing standards, a need to revise this Section was felt. This revision was, therefore, prepared to take care of these aspects.

In this revision, this publication has been renamed as National Building Construction Standards (NBCS).

The significant changes incorporated in this revision include:

a) Definitions of various existing terms have been reviewed and updated, wherever required;

b) Provisions related to the requirements for laminated safety glass, toughened (tempered) safety glass and heat strengthened glass in **4** have been updated;

c) Clause **5** on energy and light has been reviewed and updated, and new provisions on energy design considerations and window design guidelines for non-conditioned/mixed mode buildings have been included;

d) The types of glass permitted for fire-resistant glazing within the scope of the Section in **6** have been updated;

e) Inclusion of provisions for determining the fire resistance performance of perimeter fire barrier joint systems, thereby enhancing fire safety measures;

f) New provisions addressing anti-fallout features, window restrictors for child safety, and dynamic wind restraint mechanisms, have been included in **7.2**, **7.3** and **7.4** respectively;

g) A new clause **9** on security glass has been introduced, covering glass for security applications such as bullet resistance, burglary resistance, and blast resistance;

j) Incorporation of provisions for assessing curtain walls and storefront systems under inter-storey drift conditions in Annex A;

h) Provisions related to railings with glass infill panels and free-standing glass protective railings have been modified in Annex J;

k) Addition of a conformity assessment sheet to evaluate the compliance of glass and glazing systems with the requirements outlined in this Section in Annex K; and

m) References to all the concerned Indian Standards have been updated.

The information contained in this Section is largely based on the following Indian Standards:

IS No.	*Title*
IS 16231	Use of glass in buildings — Code of practice:
(Part 1) : 2019	General methodology for selection (*first revision*)
(Part 2) : 2019	Energy and light (*first revision*)
(Part 3) : 2019	Fire and loading (*first revision*)
(Part 4) : 2019	Safety related to human impact (*first revision*)

Assistance has also been derived from the following publications in the formulation of this Section:

ISO 9845-1 : 2022	Solar energy — Reference solar spectral irradiance at the ground at different receiving conditions — Part 1: Direct normal and hemispherical solar irradiance for air mass 1,5
ISO 10291 : 1994	Glass in building — Determination of steady-state U values (thermal transmittance) of multiple glazing — Guarded hot plate method
ISO 10292 : 1994	Glass in building — Calculation of steady-state U values (thermal transmittance) of multiple glazing
ISO 10293 : 1997	Glass in building — Determination of steady-state U values (thermal transmittance) of multiple glazing — Heat flow metre method

All standards, whether given herein above or cross-referred to in the main text of this Section, are subject to revision. The parties to agreement based on this Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

As the regulation of land development and buildings is a State subject and is dealt by the States and local bodies such as urban local bodies within their jurisdiction through building regulatory documents like building regulations, building byelaws, and fire regulations, this document is voluntary in nature and is non-binding. The implementation depends on adoption by concerned parties or stipulations in a contract or by appropriate adoption by the concerned authorities.

For the purpose of deciding whether a particular requirement of this Section is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with in the rounded off value should be the same as that of the specified value in this Section.

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Important Explanatory Note for Users of this NBCS

In any Part/Section of this NBCS, where reference is made to **'good practice'** in relation to design, constructional procedures or other related information, and where reference is made to **"accepted standard"** in relation to material specification, testing, or other related information, the Indian Standards listed at the end of the Part/Section shall be used as a guide to the interpretation.

At the time of publication, the editions indicated in the standards were valid. All standards are subject to revision and parties to agreements based on any Part/ Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

In the list of standards given at the end of a Part/Section, the number appearing within parentheses in the first column indicates the number of the reference of the standard in the Part/Section. For example:

a) Accepted standards [C-8(1)] refers to the Indian Standards given at serial number (1) of the list of standards given at the end of this Part C/Section 8, that is, IS 14900 : 2018 'Specification for transparent float glass (*first revision*)' and IS 2553 (Part 1) : 2018 'Specification for safety glass: Part 1 Architectural, building and general uses' (*fourth revision*).

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART C STRUCTURAL DESIGN

SECTION 8 GLASS AND GLAZING

1 SCOPE

1.1 This NBCS (Part C/Section 8) covers,

a) selection and application of glass in buildings, different types of glass, their requirements and associated glazing materials;

b) guiding provision for glazing in buildings with respect to their effect on energy, visual (light) and solar environments in the building;

c) selection of glass in buildings, subject to wind loading, seismic loading and special considerations for fire rated glass and related materials;

d) provisions for the selection and manifestation of glass in buildings, subject to safety with respect to human impact of the occupants;

e) provisions relating to glazing systems such as selection, design, fabrication, installation, testing and maintenance; and

f) requirement and selection criteria for security glass in buildings.

1.2 This Section does not cover patent glazing.

NOTE — The provision of this Section pertains to glass and installation thereof. However, parties, as per their mutual agreement, may appropriately utilize the relevant provisions for installation of alternative sheeting materials used for similar purposes such as plastic glazing sheets/polycarbonate sheets taking also into account requirements of safety issues as applicable with the specific material.

1.3 The provisions in respect of sustainable use of glass in buildings are covered in relevant guidelines/best practices (Handbook on 'Sustainability in Buildings').

2 TERMINOLOGY

For the purpose of this Section, the following definitions shall apply, and for other terms those given in accepted standards [C-8(1)] shall apply.

2.1 Annealed Glass (*see* **Glass**) — Also known as 'normal' glass, which has not been subjected to toughening, lamination and heat strengthening. It is the product obtained from the process of slow and steady cooling of hot glass in order to relieve internal stresses or thermal induced stresses.

NOTE — This term is most commonly used for flat glass.

2.2 Annealed Fire Resistant Glass — Type of glass which is made out of annealed glass combination and is tested for the required duration and satisfies the intended criteria of fire resistance. These types of glasses may not possess the best of the impact resistance characteristics and may be used as vision panels.

2.3 As-Cut Finished Sizes — Finished panes of flat glass cut from stock/standard sizes. They may be subject to further processing, such as edge working, drilling, face decoration, etc.

2.4 Aspect Ratio — The ratio of a longer side of glass pane to its shorter side.

2.5 Balustrade — A low barrier forming a parapet to a stair, ramp, balcony, raised level or a change in level.

2.6 Beads or Glazing Beads — A strip of wood, metal or other suitable material attached to the rebate to retain the glass in position in the frame.

2.7 Bite — The minimum distance by which the inner edge of a frame (or a stop) overlaps the edge of the glass panel.

2.7.1 *Glazing Bite* — The dimension by which the framing system overlaps the edge of the glazing infill. Minimum glazing bite shall be 10 mm for non-structural sealant applications.

2.8 Block (Setting Block) — A small piece of wood, plastic, rubber or other suitable material used between the edges of the glass (generally the bottom edge only) to centralize the glass in the frame (frequently called a setting block).

2.9 Chair Rail — A fixed rigid bar that provides protection from human impact.

2.10 Clear Glass — A transparent glass with neutral/near colourless appearance.

2.11 Coefficient of Linear Expansion — It is expressed as the strain (change in length per unit length) per unit variation of temperature of a material.

2.12 Combustible Material — The material which when burnt adds heat to a fire when tested for combustibility in accordance with accepted standard [C-8(2)].

2.13 Corridor — A common passage or circulation space including a common hall.

2.14 Coupled Glazing (also known as Secondary Glazing) — Two panes of glazing spaced apart in an opening, either in the frame or glazed separately, to form an unsealed cavity.

2.15 Curtain Wall — Non-load bearing structure/partition of glass attached to the building frame, usually on the exterior face. Curtain wall vertical framing members run past the face of floor slabs, and provision for anchorage is typically made at vertical framing members only.

NOTE — In contrast to combination assemblies and composite units, curtain wall systems often need to meet additional performance requirements for inter-storey differential movement, seismic drift (*see* Annex A), dynamic water infiltration, etc. Operating vents and entrance doors are provided as separate inserts.

2.16 Curtain Wall Assembly — A fire rated or non-fire rated, non-load bearing exterior wall assembly secured to the structural members of the building.

2.17 Distance Piece — A small piece of wood or other suitable material used to locate the glass between the bead and the back of the rebate to prevent lateral movement.

2.18 Door or Shutter Assembly Door-Set — A pedestrian door-set or industrial type door-set including any frame or guide, door leaf or leaves, rolling or folding curtain, etc, which is provided to give a fire resisting capability when used for the closing of permanent openings in fire resisting separating elements, which includes any side panel(s), vision panel(s), flush over panel(s) and/or transom panel(s) together with the building hardware and any seals (whether provided for the purpose of fire resistance or smoke control or for other purposes such as draught or acoustics) which form the assembly.

2.19 Double Glazed Fire Resistant Glass — A fire resistant glass that is used in a double glazed unit.

NOTE — These shall be tested as a complete Double Glazed Unit (DGU) or other multiple glazed units as the case may be. Double glazed fire resistant glass can be a combination of intumescent laminated fire rated or tempered fire resistant glass. Fire resistant glass cannot be combined with another glass and used as a DGU unless the combined double glazed or multiple glazed units are also tested.

2.20 Double Glazing — Glazing formed by an assembly of two glass panes separated by a spacer and the gap may be filled by vacuum, air or inert gases and hermetically sealed along the periphery to improve the thermal insulation.

2.21 Edge Deterioration — The discolouration of the reflective coating at the edge of the silvered glass.

2.22 Edge Faults — The faults that affect the as-cut edge of the glass. They may include entrant/emergent faults, shelling, corners on/off and vents.

2.23 Edge Polished — It is usually applied to flat glass, the edges of which have been polished after cutting.

2.24 Edging — Grinding the edge of flat glass, to a desired shape or size.

2.25 Exposed Edge — A glass panes' edge that is not covered.

2.26 Facade — It is the front or face of the building which is part of framed or frameless system.

2.27 Faceted Glazing — It is a type of glazing in which flat panes of glass are installed vertically at an angle to each other to form a faceted surface.

2.28 Fenestration — All area (including frame) in the building envelope that let in light, including window, plastic panels, clerestories, skylight, fanlight and glass doors that are generally more than one-half the floor height, and glass block walls.

2.29 Fin — A piece of glass positioned and fastened to provide lateral support.

2.30 Fire Separation — The shortest distance, in metre, measured from the external wall of the building concerned to the external wall of any other building on the site, or from other site, or from the opposite side of street or other public space for the purpose of preventing the spread of fire.

2.31 Float Glass — Flat, transparent, clear or tinted soda-lime silicate glass having parallel and polished surfaces obtained by continuous casting and floatation on a metal bath.

NOTE — Flat glass is a general term covering sheet glass, float glass and various forms of rolled and plate glass in which shape of the glass is flat and commonly used for windows, glass doors, transparent walls and other architectural applications.

2.32 Flush Over Panel — A panel which is incorporated within a door-set or openable window and fitted above the leaf or leaves within the frame head and the jambs and with no transom.

2.33 Frame — An element made of timber/metal/aluminium or other durable material/combinations of materials, such as glass fins and structural sealant, supporting the full length of a glazed panel edge.

2.34 Frameless Glazing — An unframed glazing which maintains the integrity through pointed support structures.

2.35 Front Putty — The compound forming a triangular fillet between the surface of the glass and the front edge of the rebate.

2.36 Fully Framed Glazing — The glazing whose panels have all its four edges framed.

2.37 Gap — A clearance between two adjacent surfaces and/or edges, for example between the edge of the leaf and the reveal of the frame or between the face of the leaf and the frame stop.

2.38 Glass — An inorganic product of fusion which has cooled to a rigid condition without crystallizing. It is typically hard and brittle, and has a conchoidal fracture. It may be colourless or tinted and transparent to opaque. The term glass refers to monolithic glass unless specified otherwise.

2.39 Glass Appearance Faults — Faults such as spot and/or linear and/or enlarged area faults which alter the visual quality of glass.

2.40 Glazing — Act of securing of glass or other glazing material into a building in prepared openings in windows, door panels, partitions, etc.

2.41 Guard Rail — A permanent physical barricade used to prevent human impact on glass/glazing.

2.42 Hairline Scratch — Very fine scratch that can hardly be seen with naked eye and is associated with glass cleaning techniques.

2.43 Halo — It is the distortion zone around a spot fault.

2.44 Heat Soaking — It is done on toughened/tempered glass by reheating to a temperature of 290 ºC and keeping it at this temperature for 8 h and cooling it gradually. The glass can break spontaneously and without provocation due to possible impurity of nickel sulphide in basic glass used for toughening/tempering. This risk of spontaneous breakage can be minimised by heat soaking process by forcing such glasses to break during the test itself.

2.45 Heat Strengthened Glass — A single piece of glass within which a permanent surface compressive stress, additionally to the basic mechanical strength, has been induced by a controlled heating and cooling process in order to give it increased resistance to mechanical and thermal stress and prescribed fracture characteristics {*see* **6.1.5** of accepted standard [C-8(3)]}.

2.46 Hermetic Seal — A complete seal (especially against the escape or entry of air which is impervious to outside interference or influence) done on insulating glass units.

2.47 High Activity Area — An area where multiple and major human activity takes place.

2.48 High Risk Area — An area prone to human injury and casualty.

2.49 Infill Balustrades — The balustrades in which the supported glass resists an infill pressure and/or point load applied to the glass panel.

2.50 Insulating Glass Unit (IGU) — An assembly consisting of at least two panes of glass, separated by one or more spaces, hermetically sealed along the periphery, mechanically stable and durable.

2.51 Interlayer — Layer or material acting as an adhesive and separator between plies of glass and/or plastic glazing sheets.

NOTE — It can be designed to give additional performance to the finished product, for example impact resistance, fire resistance, solar control and acoustic insulation.

2.52 Internal Partition — An interior dividing wall or such portion of an interior dividing wall that is not a door, side panel, shop front or atrium wall.

2.53 Light Transmission — It is the measure of light passing through a transparent or a translucent material.

2.54 Light Transmittance — It is the measure of percent of visible light transmitted through glass pane which depends on type of body substrate and coating done on glass.

2.55 Linear Defects — They are the scratches and extended spot faults on the glass.

2.56 Manifestation — Any technique for enhancing a person's awareness of the presence of transparent glass.

2.57 Maximum Thickness — The thickness of a pane of glass at the maximum thickness tolerance.

2.58 Minimum Thickness — The thickness of a pane of glass at the minimum thickness tolerance.

2.59 Modulus of Elasticity (Young's Modulus) — This modulus expresses the tensile force that theoretically has to be applied to a glass specimen to stretch it by an amount equal to its original length. It is expressed as a force per unit area (for glass, $E = 0.7 \times 10^5$ N/mm^2 = 70 GPa).

2.60 Monolithic Glass — A single sheet of flat glass which could be either annealed, toughened or heat strengthened.

2.61 Mullion — Vertical framing member supporting the edge or surface of the glass. It is responsible for transferring loads to the sub-structure.

2.62 Nominal Thickness — A numeric designation that indicates the approximate thickness of glass.

2.63 Non-Combustible Material — A material not liable to burn itself or to add heat to a fire when tested for combustibility in accordance with good practice [C-8(2)].

2.64 Organic Coated Glass — A sheet of glass coated on one or both sides with an applied organic coating or sheeting.

2.65 Pane — A single piece of glass or plastic glazing sheet material in a finished size ready for glazing.

2.66 Panel — An assembly containing one or more panes of glass.

2.67 Partition — It means an interior non-load bearing divider, one storey in height or part.

2.68 Partly Framed or Unframed Glazing — The panels that have one or more edges unframed.

2.69 Passive Solar Gain — The solar radiation in the form of energy and light which is transmitted through the glazing into the building and which can be utilized as a source of energy to reduce the need for artificial lighting.

2.70 Patterned Glass — A rolled glass having a distinct pattern on one or both surfaces.

2.71 Perimeter Fire Barrier — The perimeter joint protection that provides resistance to prevent the passage of fire and/or smoke from floor to floor within the building at the opening between the exterior wall assembly and the floor assembly (*see also* **6.4.3.7**).

2.72 Protective Coating(s) Faults — The faults where the metallic layer is exposed. They can be scratches or loss of adhesion of the protective coating(s).

2.73 Rebate — The part of a surround; the cross-section of which forms an angle into which the edge of the glass is received.

2.74 Reflective Coated Glass — It is a glass with reflective coating which uses the principle of increasing the direct reflection to maximize solar energy attenuation. In comparison with clear glass, its absorption of solar energy is also increased.

NOTE — In comparison with float glass surface, these reflecting coatings (due to their composition) exhibit lower level of emissivity which improves their *U*-value.

2.75 Reflective Silver Coating Faults — It is the fault on reflective silver layer which shall alter the appearance of the silvered glass. They consist of scratches, stains, colour spots and edge deteriorations.

2.76 Residual Protection — It is the protection provided to avoid the human impact on glass. It is provided on the side of glass where there are chances of human impact. It can be achieved by providing a sill structure or a grill inside.

2.77 Safety Glass

2.77.1 *Laminated Safety Glass* — Two or more pieces of glass held together by an interleaving layer or layers of plastic sheet material. The laminated safety glass will crack and break under sufficient impact, but the pieces of glass tend to adhere to the plastic and do not fly.

NOTE — The railing and overhead glazing shall consist exclusively of laminated safety glass.

2.77.2 *Toughened* (*Tempered*) *Safety Glass* — A single piece of specially heat treated glass, with a stress pattern such that the piece when fractured reduces to numerous granular fragments, with no large jagged edges.

2.78 Shading Coefficient — The ratio of the rate of solar heat gain through a specific unit assembly of glass to the solar heat gain through a single light of 3 mm clear glass in the same environment.

2.79 Sheet Glass — Glass made in large sheet directly from furnace or by making a cylinder and then flattening it.

NOTE — These transparent glass have a glossy, fire-finished, apparently plane and smooth surfaces, but having a characteristic waviness of surface.

2.80 Skylight — A fenestration surface having a slope of less than 60º from the horizontal plane. Other fenestration, even if mounted on roof of a building is considered as either a vertical glazing or sloped glazing depending upon the angle of the glazing.

2.81 Sloped Overhead Glazing — A glazing that is inclined at less than 75º to the horizontal and located, wholly or partially, directly above an area that may be used by people.

2.82 Solar Energy Absorption — The percentage of the solar spectrum energy (ultraviolet, visible, and near-infrared) from 300 nm to 2 500 nm that is absorbed by a glass product.

2.83 Solar Energy Transmittance (Direct) — The percentage of energy in the solar spectrum, ultraviolet, visible, and near-infrared energy, 300 nm to 2 500 nm, that is directly transmitted through the glass.

2.84 Solar Heat Gain Coefficient (SHGC) — The SHGC is the fraction of incident solar radiation admitted through a fenestration, both directly transmitted, and absorbed and subsequently released inward through conduction, convection and radiation.

2.85 Spandrel — A non-vision portion of the exterior wall of a building.

2.86 Spot Faults — The nuclei (solid or gaseous inclusions), deposits, crush marks, etc, in the glass. In certain instances, spot faults are accompanied by a distortion zone called 'halo'. The nucleus of the spot fault is measurable.

2.87 Stain — An alteration of the reflective coating characterized by a more or less brownish, yellowish or greyish colouration of zones which can sometimes cover the whole reflective surface.

2.88 Stock/Standard Sizes — The panes of flat glass such as coated, mirror, enamelled glass, etc supplied with as-cut edges which are intended for further processing. These are generally corresponded with manufacturer’s production size.

2.89 Tempered Fire Resistant Glass — A single piece of specially thermally-treated or chemically treated glass, tested for fire resistance for the required duration and having such a stress pattern that the piece when fractured, reduces to numerous granular fragments, with no large jagged edges.

2.90 Test Assembly — The complete assembly of the test specimen together with the test apparatus.

2.91 Thermal Transmittance (*U*) — Thermal transmission through unit area of the given building unit divided by the temperature difference between the air or other fluid on either side of the building unit in steady state conditions. It is also called as *U*-value. Its unit is W/m^{2}K.

NOTES

1 Thermal transmittance differs from thermal conductance insofar as temperatures are measured on the two surfaces of a building unit in the latter case and in the surrounding air (or other fluid) of the material on the two sides, in the former case. Thermal conductance is a characteristic of the building unit whereas thermal transmittance depends on conductance and surface coefficients of the building unit under the conditions of use.

2 In the case of glazing, thermal transmission is taken through the central part of the glazing, that is, without edge effects.

2.92 Through Component/Connection — The internal spacer or fixing that either penetrates through the door-set or openable window from one face to another or directly connects the faces of one to the other.

2.93 Tinted Glass — A normal flat glass to which colourants (normally metal oxides) are added during manufacturing process to achieve tinting and solar radiation absorption properties. It is also referred to as body tinted glass {*see* accepted standard [C-8(4)]}.

2.94 Transom — A horizontal cross bar connecting two vertical members in a glazing frame.

2.95 Unframed Glazing — A glazing with one or more edges unframed.

2.96 UV Transmittance — The percentage of energy in the ultraviolet (UV) spectrum from 300 nm to 380 nm that is directly transmitted through the glass.

2.97 Vertical Fenestration — All fenestration other than skylights. Trombe wall assemblies, where glazing is installed within 300 mm of a mass wall are considered walls and not fenestration.

2.98 Wired Glass — It is a type of glass into which a wire mesh is embedded during production. Wired glass has an impact resistance similar to that of normal glass, but in case of breakage, the mesh retains the pieces of glass.

3 APPLICATION

The type of glass chosen shall satisfy the following criteria:

a) For a given application, the type and thickness of glass selected shall be in accordance with the requirements provided herein and the thickness calculation as subjected to wind load shall also satisfy requirements for human impact safety;

b) Installation of glass to the building is done in accordance with the various provisions available in this Section and in the absence of any specific provisions the same shall be as per manufacturer's instructions;

c) Optical, solar, thermal performance of glazing (clear/tinted/coated reflective glass) shall have the characteristic performances, such as:

    1) spectral transmittance, external and internal spectral reflectance;
    2) light transmittance, external and internal light reflectance;
    3) solar direct transmittance and reflectance;
    4) UV transmittance; and
    5) better thermal transmittance (*U*-value).

4 GENERAL METHODOLOGY FOR SELECTION

4.1 Selection

4.1.1 Right from the initial project evaluation stage, a suitable methodology that incorporates the implications of use of glass materials and their influence on performance of the building shall have to be looked into. A typical flowchart outlining such a methodology is provided (*see* Fig. 1).

It is assumed that,

a) the location of area to be glazed and its preliminary size/shape have been decided as part of normal building design process,

b) the designer has gained information on glass/and plastic glazing sheet materials used in similar circumstances, and

c) the designer is cognizant of implications of any innovation in design.

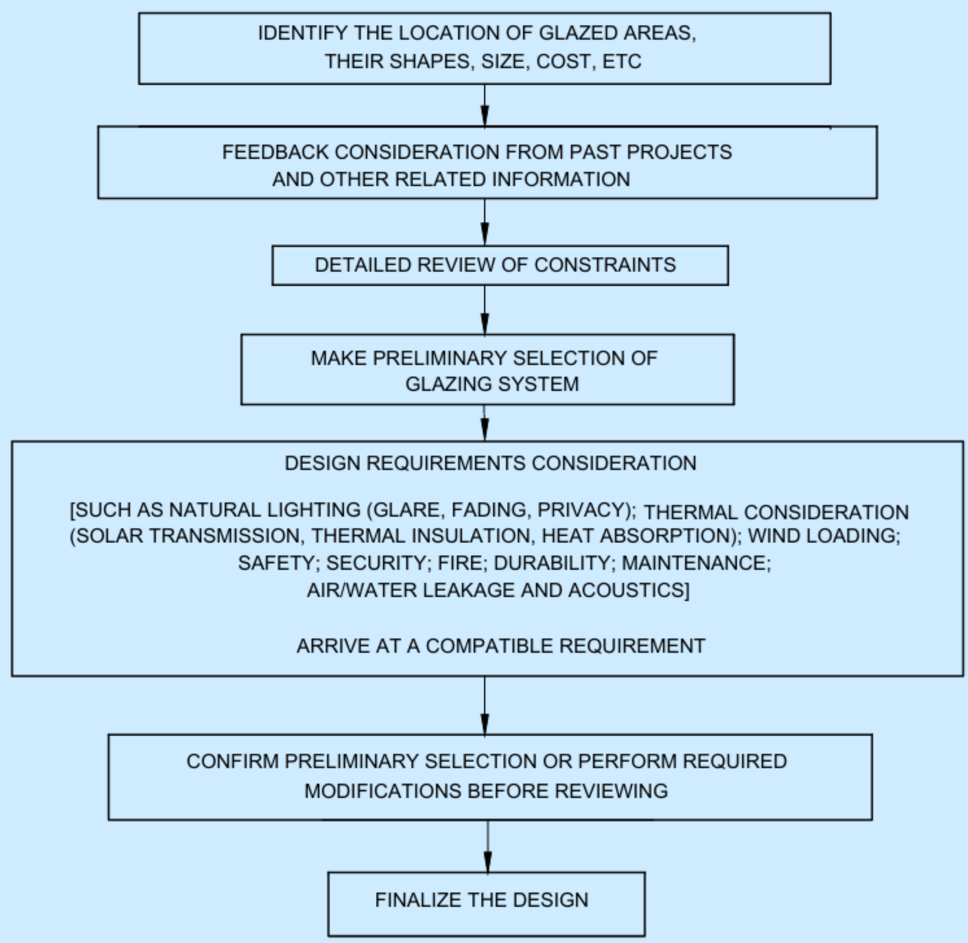

IDENTIFY THE LOCATION OF GLAZED AREAS, THEIR SHAPES, SIZE, COST, ETC
FEEDBACK CONSIDERATION FROM PAST PROJECTS AND OTHER RELATED INFORMATION
DETAILED REVIEW OF CONSTRAINTS
MAKE PRELIMINARY SELECTION OF GLAZING SYSTEM
DESIGN REQUIREMENTS CONSIDERATION
[SUCH AS NATURAL LIGHTING (GLARE, FADING, PRIVACY); THERMAL CONSIDERATION (SOLAR TRANSMISSION, THERMAL INSULATION, HEAT ABSORPTION); WIND LOADING; SAFETY; SECURITY; FIRE; DURABILITY; MAINTENANCE; AIR/WATER LEAKAGE AND ACOUSTICS]
ARRIVE AT A COMPATIBLE REQUIREMENT
CONFIRM PRELIMINARY SELECTION OR PERFORM REQUIRED MODIFICATIONS BEFORE REVIEWING
FINALIZE THE DESIGN

FIG. 1 TYPICAL SEQUENCE OF DESIGN EVALUATION FOR GLAZED AREAS

4.1.2 Design requirement including aesthetic considerations and client specified requirements such as security and maintenance are to be considered.

4.1.3 Effect of design on cost such as initial cost of glazing (specification of glass/plastic sheeting material; glazing method; access for initial glazing; work schedule; protection during construction); effect of glass/plastic sheeting material on capital/running cost related to building heating/cooling, lighting and ventilation; and maintenance cost of glazed areas (access for cleaning and reglazing) should be considered.

4.1.4 Selection of appropriate glass may be done considering the cost benefit analysis in respect of the benefit accrued against the alternatives available. Also, the comparative cost of glazing materials should be considered together with their life expectancy and probability of need for maintenance. In the context of selection of glass, the provisions given in the relevant guidelines/best practices (Handbook on 'Sustainability in Buildings') may also be considered in addition to the cost benefit analysis on the use of glass *vis-a-vis* use of other alternatives.

4.2 Types of Glass

4.2.1 The soda lime silicate glass is classified based on the type of internal stress which determines the strength of the glazing towards breakage, design and installation procedure and based on application. Table 1 gives the typical properties of various types of glass.

4.2.2 *Normal* (*Annealed*) *Glass*

Normal (Annealed) glass shall be as per accepted standard [C-8(5)] for flat transparent sheet glass or as per accepted standard [C-8(6)] for transparent float glass.

4.2.3 *Laminated Safety Glass*

Two or more pieces of glass held together by an interleaving layer or layers of plastic sheet material. The laminated safety glass will crack and break under sufficient impact, but the pieces of glass tend to adhere to the plastic and do not fly. For requirements of laminated safety glass, accepted standard [C-8(7)] shall be referred.

Table 1 Typical Properties of Various Types of Glass

(*Clause* 4.2.1)

Sl No. (1)	**Properties** (2)	**Annealed Glass** (3)	**Float Glass** (4)	**Annealed Laminated Glass** (5)	**Tempered or Toughened Glass** (6)
i)	Modulus of rupture	40 N/mm^2	40 N/mm^2	40 N/mm^2	120 N/mm^2 to 200 N/mm^2
ii)	Thickness	As per accepted standard [C-8(5)]	As per accepted standard [C-8(6)]	6.38 mm to 19 mm	3 mm to 19 mm
iii)	Density (approximate)	← 2 400 kg/m^3 to 2 550 kg/m^3 →			
iv)	Modulus of elasticity	← 70 GPa →			
v)	Coefficient of linear expansion	← 9×10^{-6} m/m K →			
vi)	Compressive strength	← 1 000 N/mm^2 →			

NOTE — Conventionally, the following types of glass exist:

a) Annealed (clear) glass;
b) Extra clear glass;
c) Body tinted glass;
d) Coated glass (including Lacquered glass); and
    1) Online coated glass; and
    2) Offline coated glass.
e) Processed glass — Each of the glasses (a) to (e) above can be subjected to further processing to produce the following types:
    1) Heat strengthened;
    2) Toughened or tempered;
    3) Double glazed unit;
    4) Laminated glass (single laminated);
    5) Laminated double glass unit;
    6) Ceramic/screen printed fritted glass (patterned glass); and
    7) Fire safety glass.

4.2.4 *Toughened* (*Tempered*) *Safety Glass*

A single piece of specially heat treated glass, with a stress pattern such that the piece when fractured reduces to numerous granular fragments, with no large jagged edges. For requirements of toughened safety glass, accepted standard [C-8(7)] shall be referred.

4.2.5 *Heat Strengthened Glass*

A single piece of glass within which a permanent surface compressive stress, additionally to the basic mechanical strength, has been induced by a controlled heating and cooling process in order to give it increased resistance to mechanical and thermal stress and prescribed fracture characteristics {*see* **6.1.5** of accepted standard [C-8(3)]}. Heat strengthened glass shall have a surface compression between 31 MPa and 52 MPa (4 500 and 7 500 psi) when tested as prescribed in **6.5** of accepted standard [C-8(3)]. For requirements of heat strengthened glass, accepted standard [C-8(8)] shall be referred.

NOTE — Heat strengthened glass is not a safety glass.

4.2.6 *Coated Glass*

A metallic coating is applied to one side of the glass in order to significantly increase the amount of reflection by the glass of both the visible and infrared (light and heat) ranges of the electromagnetic spectrum. This metallic coating can be applied to clear or body tinted glass, without adversely affecting the transparency of the glass. The reflective glass imparts an enhanced appearance to the exterior of buildings due to the coating of metal oxides on the glass. It is widely applied as an aesthetic and energy efficient product in buildings for its highly reflective surface and wide palette of colours. It reduces heat gain and glare from the exterior and allows optimum visible light transmission to the interior. If designed/used properly, reflective glass can aid in reducing the air conditioning load of buildings.

NOTE — Highly reflective glass should be avoided, especially in internal environments. The reflections from these surfaces can be particularly confusing for persons with vision impairment.

4.2.7 *Insulating Glazing Unit*

Insulating glazing units are two or more panels of glass spaced apart and hermetically sealed to form a single unit with air or inert gas filled space between the panels. The spacer is made of aluminium that is either mill-finished or painted/anodized in different colours or finishes, or an equivalent alternative material. Desiccants are filled inside the spacer framework to prevent condensation inside the unit. The primary sealant acts as a barrier to moisture and vapour penetration. The secondary sealant provides structural integrity to the unit. For requirements of insulating glazing unit, accepted standard [C-8(9)] shall be referred.

NOTE — Moisture penetration test and argon/krypton gas level test are typically carried out to determine the characteristic of IGUs.

4.2.8 *Rolled Glass — Patterned*, *Extra Clear Patterned*, *Wired and Wired-Patterned Glass*

The general requirements including thickness, dimensional tolerance and tests for wired glass as specified in accepted standard [C-8(10)] are valid.

4.2.9 *Glass Fins*

When glass fins are used as a decorative member, it can be either toughened (tempered) or laminated glass.

When glass fins are used as a structural member, it shall be toughened and laminated. The depth and thickness may vary as per elevation and wind load requirements. Design should also accommodate movements and verified for lateral torsional buckling. It is recommended to use finite element analysis to determine the appropriate glass fin sizes.

4.3 Application

Glass can be designed/suited to use in building occupancies such as in residential, assembly and mercantile in elements such as facades, windows, doors, partitions, display units, shop fronts, greenhouses (where plants are grown) and atrium. Different types of glass are selected based on requirements. For safety against accidental breakage and strength requirement (mechanical and thermal), toughened glass or laminated glass may be considered over annealed glass. For increased high security requirements, acoustic insulation, sloped glazing and skylights, laminated glass may be considered.

4.4 Associated Glazing Materials

4.4.1 *Structural Sealant*

The structural sealant could be of silicone type with requirements meeting the design criteria. Structural sealant shall be shelf-stable, natural-cured, elastomeric adhesive exhibiting the desired adhesion to building substrates. The structural sealant may require cleaning and/or priming to get good adhesion for structural glazing application. For laminated glass applications where glass edges are sealed with a sealant, compatibility shall be ensured with the interlayer to avoid delamination.

Structural sealant shall be as per accepted standard [C-8(11)].

4.4.2 *Gaskets*

Gasket is a mechanical seal that fills the space between two mating surfaces, to prevent leakage from or into the joined objects and will be able to deform while under compression and tightly fills the space it is designed for, including any slight irregularities. Gaskets shall be as per **5.10** of accepted standard [C-8(12)].

4.4.3 *Preformed Tape*

Typical requirements of preformed butyl and foam tapes shall be as given in Table 2.

4.4.4 *Setting Blocks, Location Blocks and Distance Pieces*

Setting blocks, location blocks, and distance pieces shall be designed in accordance with **6** which are:

a) resilient, load-bearing, non-absorbent and rot-proof materials; and

b) compatible with all other materials that may come in contact with them.

4.5 General Requirements

4.5.1 Glazing and associated materials used for the proper installation shall satisfy the minimum dimensional and framing requirements in accordance with the procedures given in this Section. The dimensional and thickness tolerance of the glass used in exterior and interior is determined from the provisions given hereunder.

4.5.2 *Dimensional Requirement*

4.5.2.1 The dimensions for edge clearance, edge cover, and front and back clearance, as defined in Fig. 2, shall be not less than the values given in Table 3.

NOTE — For glazing systems where the framing member is aluminium or steel and gaskets are used to capture the glazing, minimum glazing bite of 12.7 mm is recommended for architectural glazing.

4.5.2.2 *Front putty width*

The front putty width shall be not less than 10 mm for panels up to 1 m^2, and not less than 12 mm for panels between 1 m^2 and 2 m^2.

Table 2 Typical Properties of Preformed Tapes

(*Clause* 4.4.3)

Sl No. (1)	Properties (2)	Requirement (3)
i)	Low temperature flex	No cracks at – 23 °C
ii)	Weight loss	2 percent, *Max*
iii)	Vehicle migration	1 paper stained maximum and this stain shall be no more than 3.2 mm from edge of sample maximum

Table 2 (*Concluded*)

Table 2 Typical Properties of Preformed Tapes

(*Clause* 4.4.3)

Sl No. (1)	Properties (2)	Requirement (3)
iv)	Backing removal	No transfer of tape compound to the paper
v)	Yield strength	41.4 kPa, *Min*
vi)	Compression/Recovery	Compression index, 1.22 N/mm^2, *Max*
vii)	Water absorption	Weight gain maximum after boiling, 40 kg/m^3
viii)	Flow test	Loss of height, 60 percent, *Max*

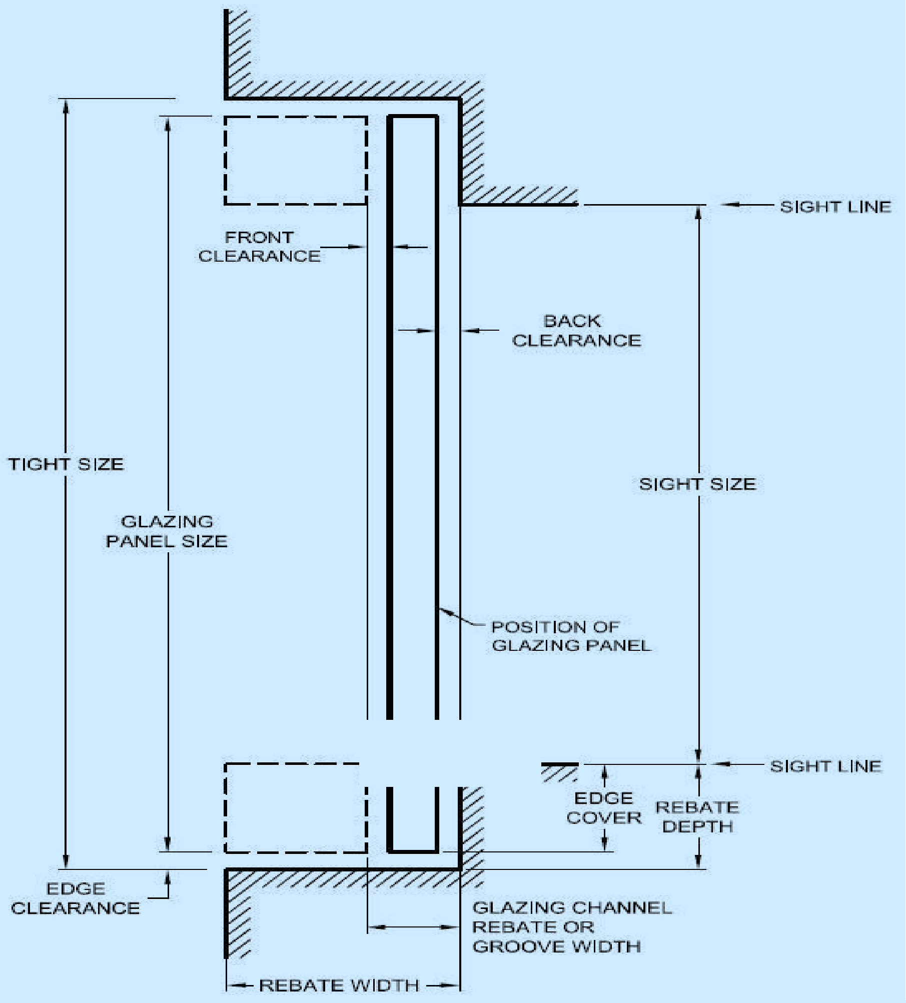

SIGHT LINE
FRONT CLEARANCE
BACK CLEARANCE
TIGHT SIZE
SIGHT SIZE
GLAZING PANEL SIZE
POSITION OF GLAZING PANEL
SIGHT LINE
EDGE COVER
REBATE DEPTH
EDGE CLEARANCE
GLAZING CHANNEL REBATE OR GROOVE WIDTH
REBATE WIDTH

FIG. 2 SIZES AND REBATES

4.5.2.3 *Dimensions of rebates and grooves* (*width and depth*)

Dimensions of rebates and grooves shall accommodate the requirements of Table 3 and allow for the appropriate setting and location blocks (*see* **6**).

4.5.2.4 *Glass dimensional tolerance*

The tolerance for dimensions shall be as per those in the respective Indian Standards.

4.6 Frame Requirements

4.6.1 When completely assembled and glazed, the secondary design action effects due to deflection of the frame member supporting the edge of the glass shall be allowed for.

4.6.2 *Deflection Limits*

The frame deflection limits under serviceability loading shall satisfy the conditions for four sided frames as given in **6.3.6.2**(c).

NOTE — In framing members, where reinforcement/fixing brackets are required to meet the deflection/stress criteria, it may be of aluminium or steel. When steel is used, proper dielectric galvanic separation shall be used. The material chosen for reinforcement shall be in close proximity in the galvanic series, to ensure dielectric separation.

4.6.3 *Panels Glazed into the Building Structure*

A panel glazed directly into a building structure by means of appropriate beads or stops shall be considered to be framed, provided the assembly complies with the deflection requirements of **4.6.2**.

4.6.4 *Mixed Framing*

Glass supported along the top and bottom edges by one means and along the vertical edges by another means shall be considered to be framed provided each frame member of the assembly complies with the deflection requirements of **4.6.2**.

4.7 Glass Dimensions

4.7.1 The actual thickness for each pane of glass shall be measured using screw calliper as per **4.3** of accepted standard [C-8(6)].

The actual thickness of glass, rounded to the nearest 0.1 mm shall not vary from the nominal thickness by more than the tolerances specified in respective Indian Standard or the values provided in this Section (where Indian Standard specifications are not available).

The minimum thickness allowed in insulated glazing unit (IGU) should be the sum of minimum thickness allowed of two panes as per accepted standard [C-8(6)] plus thickness of air-gap.

As per the accepted standard [C-8(7)], the nominal thickness of laminated safety glass shall be the sum of the nominal thickness of constituent panes of glass and interlayer material. The limit deviation of the interlayer shall not be taken into account if the total interlayer thickness is < 2 mm.

If the total interlayer thickness is > 2mm, a limit deviation of ± 0.2 mm shall apply. For plastic glazing sheet material, the limit of deviation on thickness shall be the same as applicable to a float glass of the same nominal thickness.

The limit deviations on thickness of laminated glass shall not exceed the sum of the limit deviations of the constituent glass panes as specified in accepted standard [C-8(6)].

Table 3 Minimum Dimensions for Glazing Material

(*Clauses* 4.5.2.1 *and* 4.5.2.3)

All dimensions in millimetres.

Sl No.	**Nominal Thickness**	**Front and Back Clearance**			**Edge Clearance**	**Edge Cover**	**Rebate Depth**
		Type A (*See* Note 1)	Type B (*See* Note 2)	Type C (*See* Note 3)			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	3 (for pane area up to 0.1 m^2)	2	—	—	2	4	6
ii)	3 (for pane area > 0.1 m^2)	2	—	—	3	6	9
iii)	3	—	2	1	3	6	9
iv)	4	2	—	—	2	6	8
v)	4	—	2	1	3	6	9
vi)	5	2	2	2	4	6	10
vii)	6	2	2	2	4	6	10
viii)	8	—	3	2	5	8	13
ix)	10	—	3	2	5	8	13
x)	12	—	3	2	6	9	15
xi)	15	—	5	4	8	10	18
xii)	19	—	5	4	10	12	22
xiii)	25	—	5	4	10	15	15

NOTES

1 Type A applies to linseed oil and metal casement putties.

2 Type B applies to non-setting glazing compounds, plastic glazing compounds, two-part rubberizing compounds, sealants and preformed strip materials.

3 Type C applies to gaskets made from extruded materials such as butyl strip, PVC, neoprene and sanoprene held in position by pressure upon the glass.

4 For non-standard glass thicknesses the nearest values of nominal thickness, shall be used.

5 Timber and PVC frames may not require the specified front and back clearances provided the waterproofing performance requirements are met.

6 The dimensions are the minimum necessary for the structural integrity of glass only but do not apply to insulating glass units.

4.7.2 Length and width are defined with reference to the direction of draw of the flat glass ribbon (*see* Fig. 3).

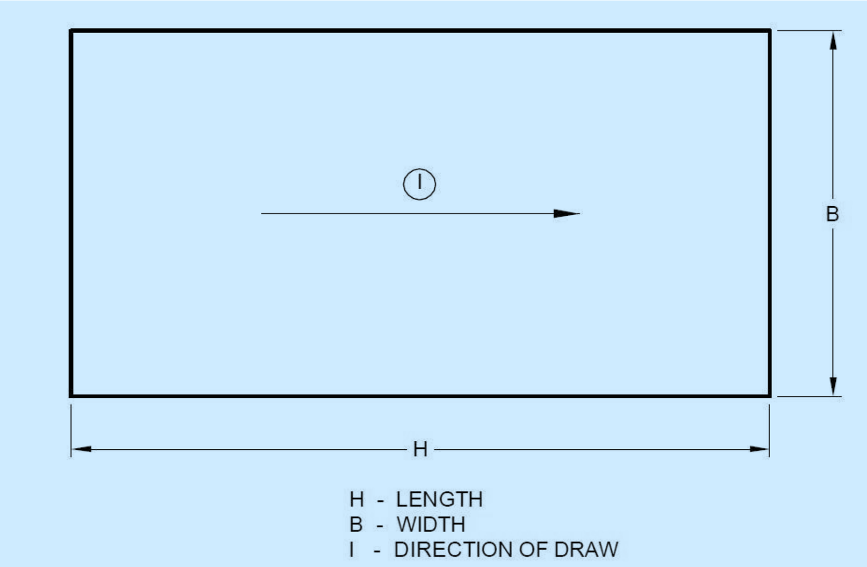


FIG. 3 REPRESENTATION OF LENGTH, WIDTH AND DIRECTION OF DRAW

4.7.3 *Jumbo Sizes*

Glass is available commonly in the following sizes, nominal length (H) 4 500 mm to 6 000 mm and nominal width, (B) 3 660 mm or 3 210 mm.

NOTE — The usual width is 3 660 mm or 3 210 mm. Other sizes may be mutually agreed to between the manufacturer and the user based on their requirement.

4.7.4 *Stock Size*

Glass is available commonly in the following sizes, nominal length (H) 2 250 mm or 2 440 mm and nominal width, (B) 3 660 mm or 3 210 mm.

NOTE — Maximum glass size available from manufacturer are one consideration, the processing equipment limitation, capabilities of contract fabricator to install unit, availability of specialized transport and handling equipment to deliver unit should be checked in addition.

4.7.5 *Split Sizes*

Glass is delivered in equal or unequal split sizes from the jumbo or stock size.

4.7.6 *Squareness*

For given the nominal dimensions for length (H) and width (B), the pane shall not be larger than a prescribed rectangle resulting from the nominal dimensions increased by the permissible plus tolerance or smaller than the prescribed rectangle reduced by the permissible minus tolerance.

The sides of the prescribed rectangles (*see* Fig. 4) shall be parallel to one another and these rectangles shall have a common centre. For stock/standard sizes the tolerances on nominal dimensions length (H) and width (B), are ± 5 mm.

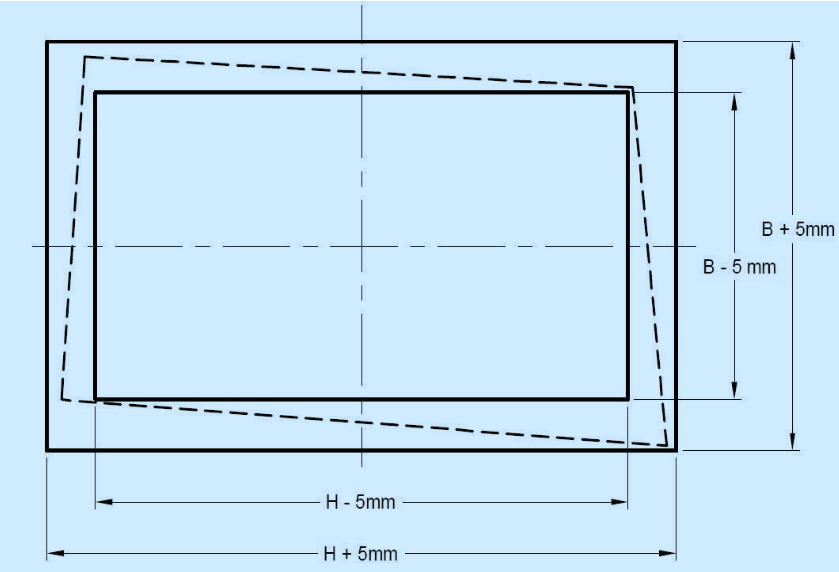


FIG. 4 DETERMINATION OF LENGTH, WIDTH AND SQUARENESS FOR STOCK/SQUARENESS DIRECTION OF DRAW

4.7.7 *As-Cut Finished Size*

The nominal dimension for width and length being given, the finished pane or as-cut finished size shall not be greater than the prescribed rectangle from the nominal dimension increased by the tolerance '*t*' or smaller than the prescribed rectangle reduced by the tolerance '*t*'. The sides of the prescribed rectangles are parallel to one another and these shall have a common centre in accordance with Fig. 5. The limits of the squareness are also mentioned. Tolerances shall be as given in respective accepted standards. An indicative list of such accepted standards is provided in Table 4.

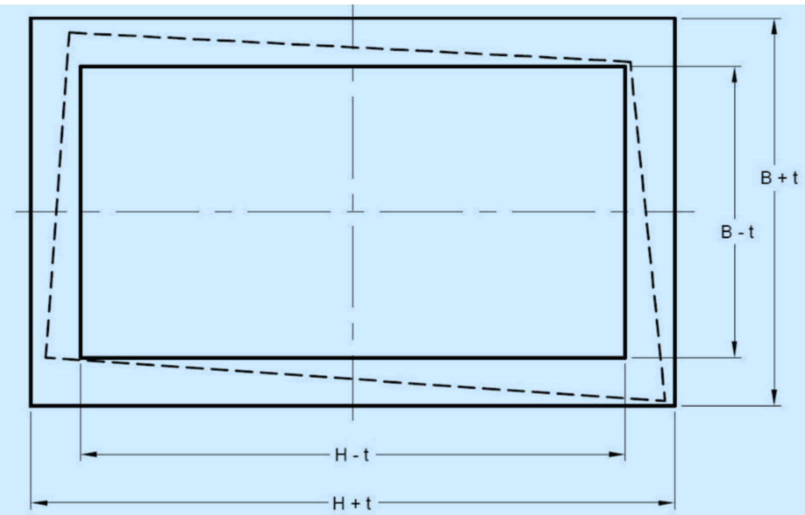


FIG. 5 TOLERANCE (t) FOR WIDTH (B) AND LENGTH (H)

Table 4 Indicative List of Accepted Standards for Different Types of Glass

(*Clause* 4.7.7)

Sl No. (1)	Type of Glass (2)	Accepted Standard (3)
i)	Flat transparent sheet glass	[C-8(5)]
ii)	Transparent float glass	[C-8(6)]
iii)	Rolled glass — Patterned, Extra Clear patterned, Wired and Wired patterned glass	[C-8(10)]
iv)	Heat strengthened glass	[C-8(8)]
v)	Insulating glazing unit	[C-8(9)]
vi)	Safety glass for architectural, building and general uses	[C-8(7)]
vii)	Tinted float glass	[C-8(4)]

5 ENERGY AND LIGHT

5.1 General

Energy and light performance of glazing system is defined in terms of U-value, solar heat gain coefficient, visible light transmission, internal and external reflection. The overall performance is determined by the efficiency of glass, frame, shading systems and the air tightness of the system. The performance requirement for glazing system shall be suitably selected. Minimum performance requirement is mentioned in the Annex B.

Specific methods of calculating light and energy factors for glass in buildings are covered here and their characteristic data can serve as a basis for light, heating and ventilation calculations of rooms and can permit comparison between different types of glazing. It is applicable to all flat glass material.

5.2 Thermal Energy Transmission

5.2.1 *General*

Glazed areas in buildings should be designed considering overall energy balance, the effects on thermal comfort of occupants and the cooling and heating energy requirements. Solar energy gain is due to transmission of solar radiant energy through the glass into the building. Solar energy is all at relatively short wavelengths and is controlled by using the glass to absorb or reflect the energy. Energy loss is due to the transfer of energy by conduction, convection and long wavelength radiation. The solar energy gain and loss can be regulated by several factors, for example, incorporating air cavities, including low emissivity glass and use of shading systems. Solar energy gain through glazing systems can be advantageous in cold climates for improving thermal comfort and reducing the heating energy requirements.

5.2.2 *Thermal Comfort*

Energy transmission through glazing can significantly influence occupant comfort by raising or lowering room air temperatures. For example, hot sunny weather can lead to excessive energy gains and energy losses can occur through the glazing during cold weather or at night. Thermal comfort can also be influenced by direct solar radiation through the glazing and/or by radiation exchange between the glazing and the occupants. Appropriate choice of glazing and opaque wall systems is essential to avoid radiant asymmetry related thermal discomfort.

5.2.3 *Solar Energy Gain*

The solar energy transmitted through the glass from the outside environment is the part of solar radiation which is transmitted directly through the glass and the part which is re-emitted from the glass after being absorbed. In warm and hot climates, this heat energy which is transmitted through the glass has to be limited in-order to achieve thermal comfort for the occupants and also to reduce the energy demands of the building. Factors that can influence the amount of solar gain through the glazing include:

a) orientation;

b) glazed area;

c) shading devices, both internal and external; and

d) properties of the glazing.

5.2.4 *Total Solar Energy Transmittance*

Total solar energy transmittance is the proportion of solar radiation at normal incidence transferred through the glazing. It is composed of the direct transmittance (short wave component) and the part of the solar absorptance dissipated inwards by long wave radiation and convection (long wave component). The total solar energy transmission properties of solar control glazing can be described by their shading coefficients and solar heat gain coefficient (SHGC)/solar factor (SF). The shading coefficient is derived by comparing the properties of the solar control glazing with a clear float glass having a total solar energy transmittance of 0.87 (that is clear glass between 3 mm and 4 mm thick).

Solar heat gain coefficient (SHGC)/solar factor (SF) is the measure of amount of heat transfer from outside to inside by direct transmission (short wave radiation) and internal remitted radiation (long wave radiation). The SHGC (*see* Fig. 6) or SF depends on the tint of the substrate and the type of coating that is done on the base glass. The amount of solar energy gained through glass is between 0 and 1. Multiplying the SHGC or SF by 100 gives the percentage of solar energy allowed into the building.

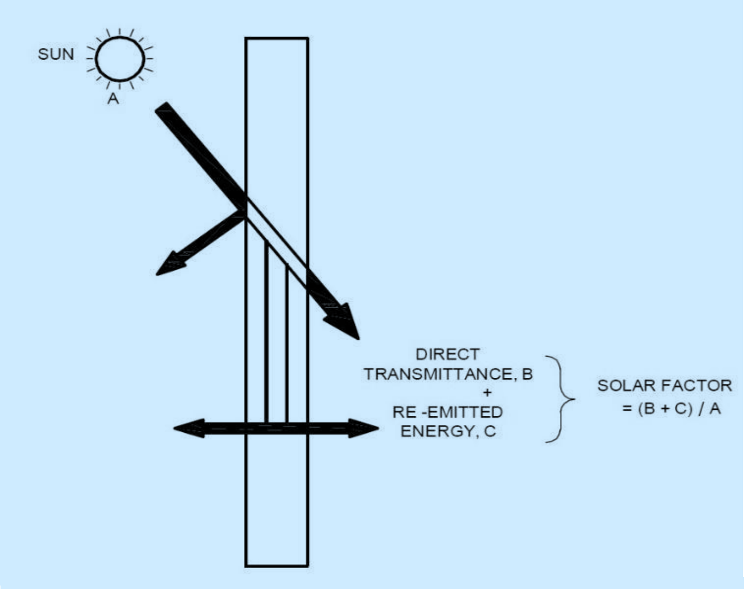


FIG. 6 SOLAR HEAT GAIN COEFFICIENT

The total solar energy transmittance g is the sum of the solar direct transmittance τ_e and the secondary heat transfer factor q_i towards the inside, the latter resulting from heat transfer by convection and long-wave IR-radiation of that part of the incident solar radiation which has been absorbed by the glazing and is expressed as:

$$g = \tau_e + q_i$$

5.2.5 *Division of Incident Solar Radiation Flux*

The incident solar radiant flux per unit area φ_e is divided into the following three parts (*see* Fig. 7):

a) transmitted part, $\tau_e\varphi_e$;

b) reflected part, $\rho_e\varphi_e$; and

c) absorbed part, $\alpha_e\varphi_e$.

where

τ_e = solar direct transmittance;

ρ_e = solar direct reflectance; and

α_e = solar direct absorptances.

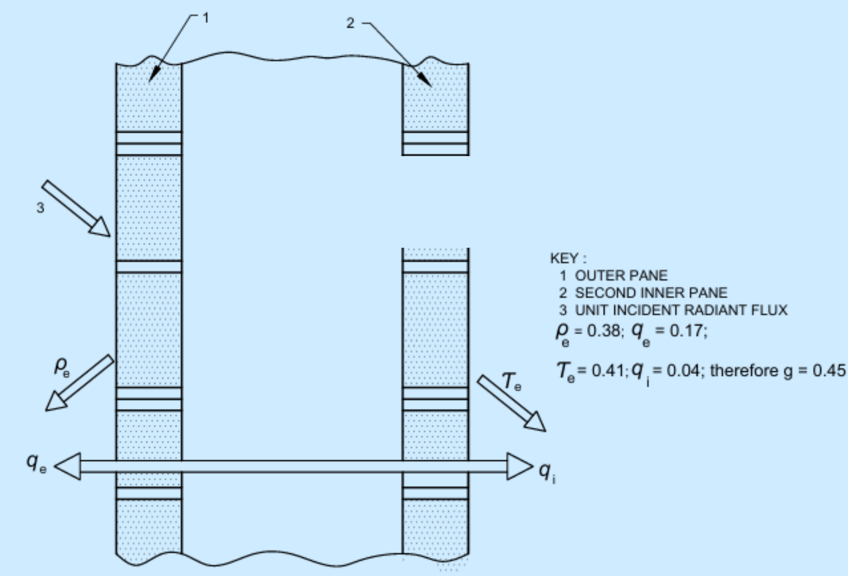

1
2
3
KEY :
1 OUTER PANE
2 SECOND INNER PANE
3 UNIT INCIDENT RADIANT FLUX
ρ_e = 0.38; q_e = 0.17;
τ_e = 0.41; q_i = 0.04; therefore g = 0.45
ρ_e
τ_e
q_e
q_i

FIG. 7 COMPONENTS OF INCIDENT SOLAR RADIANT FLUX

The relationship between the three characteristics is:

$$\tau_e + \rho_e + \alpha_e = 1$$

The absorbed part $\alpha_e\varphi_e$ is subsequently divided into two parts $q_i\varphi_e$ and $q_e\varphi_e$, which are energy transferred to the inside and outside, respectively:

$$\alpha_e = q_i + q_e$$

where

q_i = secondary heat transfer factor of the glazing towards the inside; and

q_e = secondary heat transfer factor of the glazing towards the outside.

5.2.6 *Solar Direct Transmittance*

The solar direct transmittance τ_e of glazing shall be calculated using the following formula:

$$\tau_e = \frac{\sum_{\lambda=300\text{ nm}}^{2\,500\text{ nm}} \tau(\lambda) S_\lambda \,\Delta\lambda}{\sum_{\lambda=300\text{ nm}}^{2\,500\text{ nm}} S_\lambda \,\Delta\lambda}$$

where

S_λ = relative spectral distribution of the solar radiation;

$\tau(\lambda)$ = spectral transmittance of the glazing; and

$\Delta\lambda$ = integration procedure are the same as in 5.4.5.4 except that the data points shall be chosen at the wavelengths given in Table 5.

5.2.7 *Solar Direct Reflectance*

The solar direct reflectance ρ_e of the glazing shall be calculated using the following formula:

$$\rho_e = \frac{\sum_{\lambda=300\text{ nm}}^{2\,500\text{ nm}} \rho_o\ (\lambda) S_\lambda\ \Delta\lambda}{\sum_{\lambda=300\text{ nm}}^{2\,500\text{ nm}}\ S_\lambda\ \Delta\lambda}$$

where

S_λ = relative spectral distribution of the solar radiation (*see* **5.2.6**);

$\rho_o(\lambda)$ = spectral external reflectance of the glazing; and

$\Delta\lambda$ = integration procedure are the same as in light transmittance (*see* **5.4.5.4**) except that the data points shall be chosen at the wavelengths given in Table 5.

In the case of multiple glazing, the spectral external reflectance ρ_o (λ) is calculated in accordance with **5.5.1**.

Table 5 Normalized Relative Spectral Distribution of Global Solar Radiation

(*Clauses* 5.2.6, 5.2.7, 5.2.9.3 *and* 5.2.9.4)

Sl No. (1)	λ nm (2)	$S_\lambda\Delta\lambda$ (3)
i)	300	0
ii)	305	0.000 057
iii)	310	0.000 236
iv)	315	0.000 554
v)	320	0.000 916
vi)	325	0.001 309
vii)	330	0.001 914
viii)	335	0.002 018
ix)	340	0.002 189
x)	345	0.000 260
xi)	350	0.002 445
xii)	355	0.002 555
xiii)	360	0.002 683
xiv)	365	0.003 020
xv)	370	0.003 359
xvi)	375	0.003 509
xvii)	380	0.003 600
xviii)	385	0.003 529
xix)	390	0.003 551
xx)	395	0.004 294
xxi)	400	0.007 812
xxii)	410	0.011 638
xxiii)	420	0.011 877
xxiv)	430	0.011 347
xxv)	440	0.013 245
xxvi)	450	0.015 343
xxvii)	460	0.016 166
xxviii)	470	0.016 178
xxix)	480	0.016 402
xxx)	490	0.015 794

Table 5 (*Concluded*)

Sl No. (1)	λ nm (2)	$S_\lambda \Delta\lambda$ (3)
xxxi)	500	0.015 801
xxxii)	510	0.015 973
xxxiii)	520	0.015 357
xxxiv)	530	0.015 857
xxxv)	540	0.015 827
xxxvi)	550	0.015 844
xxxvii)	560	0.015 590
xxxviii)	570	0.015 255
xxxix)	580	0.014 745
xl)	590	0.014 330
xli)	600	0.014 663
xlii)	610	0.015 030
xliii)	620	0.014 859
xliv)	630	0.014 622
xlv)	640	0.014 526
xlvi)	650	0.014 445
xlvii)	660	0.014 313
xlviii)	670	0.014 023
xlix)	680	0.012 838
l)	690	0.011 788
li)	700	0.012 453
lii)	710	0.012 798
liii)	720	0.010 589
liv)	730	0.011 233
lv)	740	0.012 175
lvi)	750	0.012 181
lvii)	760	0.009 515
lviii)	770	0.010 479
lix)	780	0.011 381
lx)	790	0.011 262
lxi)	800	0.026 718
lxii)	850	0.048 240
lxiii)	900	0.040 297
lxiv)	950	0.021 384
lxv)	1 000	0.036 097

Table 5 (*Concluded*)

Sl No. (1)	**λ** nm (2)	**$S_\lambda \Delta\lambda$** (3)
lxvi)	1 050	0.034 110
lxvii)	1 100	0.018 861
lxviii)	1 150	0.013 228
lxix)	1 200	0.022 551
lxx)	1 250	0.023 376
lxxi)	1 300	0.017 756
lxxii)	1 350	0.003 743
lxxiii)	1 400	0.000 741
lxxiv)	1 450	0.003 792
lxxv)	1 500	0.009 693
lxxvi)	1 550	0.013 693
lxxvii)	1 600	0.012 203
lxxviii)	1 650	0.010 615
lxxix)	1 700	0.007 255
lxxx)	1 750	0.007 183
lxxxi)	1 800	0.002 157
lxxxii)	1 850	0.000 395
lxxxiii)	1 900	0.000 082
lxxxiv)	1 950	0.001 087
lxxxv)	2 000	0.003 024
lxxxvi)	2 050	0.003 988
lxxxvii)	2 100	0.004 229
lxxxviii)	2 150	0.004 142
lxxxix)	2 200	0.003 690
xc)	2 250	0.003 592
xci)	2 300	0.003 436
xcii)	2 350	0.003 163
xciii)	2 400	0.002 233
xciv)	2 450	0.001 202
xcv)	2 500	0.000 475

NOTE — The values in this table are calculated according to the trapezoidal rule.

5.2.8 *Solar Direct Absorptance*

The solar direct absorptance α_e shall be calculated from the following formula:

$$\tau_e + \rho_e + \alpha_e = 1$$

5.2.9 *Secondary Heat Transfer Factor Towards the Inside*

5.2.9.1 *Boundary conditions*

For the calculation of the secondary heat transfer factor towards the inside, q_i, the heat transfer coefficients of the glazing towards the outside, h_e, and towards the inside, h_i, are needed. These values mainly depend on the position of the glazing, wind velocity, inside and outside temperatures and, furthermore, on the temperature of the two external glazing surfaces.

As the purpose of this Section is to provide basic information on the performance of glazing, the following conventional conditions have been stated for simplicity:

a) Position of the glazing: vertical;

b) Outside surface: wind velocity approximately 4 m/s; corrected emissivity 0.837;

c) Inside surface: natural convection; emissivity optional; and

d) Air spaces are unventilated.

Under these conventional, average conditions, standard values for h_e and h_i are obtained:

$$h_e = 23 \text{ W/(m}^2\text{K)}$$

$$h_i = \left(3.6 + \frac{4.4\,\varepsilon_i}{0.837}\right) W/(m^2.K)$$

where

ε_i = corrected emissivity of the inside surface [for soda lime glass, $\varepsilon_i = 0.837$ and $h_i = 8$ W/(m^{2}K)].

If other boundary conditions are used to meet special requirements they shall be stated in the test report. Values for ε_i lower than 0.837 (due to surface coatings with higher reflectance in the far infrared) should only to be taken into account if condensation on the coated surface can be excluded.

5.2.9.2 *Single glazing*

The secondary heat transfer factor towards the inside, q_i, of single glazing shall be calculated using the following formula:

$$q_i = \alpha_e \frac{h_i}{h_e + h_i}$$

where

α_e = solar direct absorptance obtained from the in accordance with 5.2.5, and

h_e, h_i = heat transfer coefficients towards the outside and inside, respectively, in accordance with 5.2.9.1.

5.2.9.3 *Double glazing*

The secondary heat transfer factor towards the inside, q_i, of double glazing shall be calculated using the following formula:

$$q_i = \frac{\left(\frac{\alpha_{e1} + \alpha_{e2}}{h_e} + \frac{\alpha_{e2}}{\Lambda}\right)}{\left(\frac{1}{h_i} + \frac{1}{h_e} + \frac{1}{\Lambda}\right)}$$

where

α_{e1} = solar direct absorptance of the outer (first) pane within the double glazing;

α_{e2} = solar direct absorptance of the second pane within the double glazing;

Λ = thermal conductance between the outer surface and the innermost surface of the double glazing (*see* Fig. 8), in watts per square metre per Kelvin (W/m^2.K); and

h_e, h_i = heat transfer coefficients towards the outside and the inside, respectively in accordance with **5.2.9.1**.

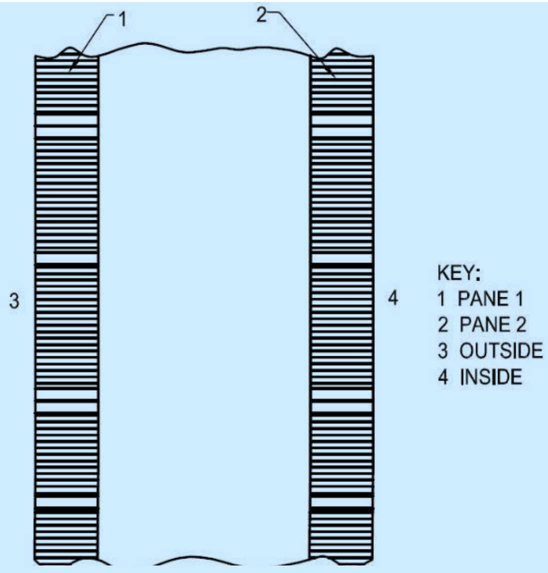


FIG. 8 ILLUSTRATION OF THE MEANING OF THERMAL CONDUCTANCE, Λ

Characteristics αe1 and αe2 are calculated as follows:

$$\alpha_{\mathrm{e1}} = \frac{\sum_{\lambda=300\ \mathrm{nm}}^{2\ 500\ \mathrm{nm}} \left\{ \alpha_1(\lambda) + \frac{\alpha_1'(\lambda)\tau_1(\lambda)\rho_2(\lambda)}{1-\rho_1'(\lambda)\,\rho_2(\lambda)} \right\} S_\lambda \Delta\lambda}{\sum_{\lambda=300\ \mathrm{nm}}^{2\ 500\ \mathrm{nm}} S_\lambda \Delta\lambda}$$

$$\alpha_{\mathrm{e2}} = \frac{\sum_{\lambda=300\ \mathrm{nm}}^{2\ 500\ \mathrm{nm}} \left\{ \frac{\alpha_2(\lambda)\tau_1(\lambda)}{1-\rho_1'(\lambda)\,\rho_2(\lambda)} \right\} S_\lambda \Delta\lambda}{\sum_{\lambda=300\ \mathrm{nm}}^{2\ 500\ \mathrm{nm}} S_\lambda \Delta\lambda}$$

where

$\tau_1(\lambda), \tau_2(\lambda), \rho_1(\lambda), \rho_1'(\lambda), \rho_2(\lambda)$ are as defined in light transmittance (*see* **5.4.5.4**)

$\alpha_1(\lambda)$ = spectral direct absorptance of the outer pane, measured in the direction of the incident radiation, given by the relationship:

$$\alpha_1(\lambda) = 1 - \tau_1(\lambda) - \rho_1(\lambda)$$

$\alpha_1'(\lambda)$ = spectral direct absorptance of the outer pane, measured in the opposite direction to the incident radiation, given by the relationship:

$$\alpha_1'(\lambda) = 1 - \tau_1(\lambda) - \rho'_1(\lambda)$$

$\alpha_2(\lambda)$ = spectral direct absorptance of the second pane, measured in the direction of the incident radiation, given by the relationship:

$$\alpha_2(\lambda) = 1 - \tau_2(\lambda) - \rho_2(\lambda)$$

$\Delta\lambda$ and the integration procedure are the same as in **5.4.5.4** except that the data points shall be chosen at the wavelengths given in Table 5.

The thermal conductance Λ shall be determined for a temperature difference of $\Delta T = 15$ °C across the sample and a mean temperature of the sample of 10 °C, or by measuring methods using the standard guarded hot plate method, or the standard heat flow metre method.

If another temperature difference ΔT across the sample and/or another mean temperature of the sample is used for the determination of the thermal conductance Λ to meet special requirements, this shall be stated in the test report.

5.2.9.4 *Multiple glazing with n > 2 components*

The secondary heat transfer factor towards the inside, q_i, of a multiple glazing with more than two components shall be calculated using the following formula:

$$q_i = \frac{\dfrac{\alpha_{e1} + \alpha_{e2} + \alpha_{e3} + \cdots + \alpha_{en}}{h_e} + \dfrac{\alpha_{e2} + \alpha_{e3} + \cdots + \alpha_{en}}{\Lambda_{12}} + \dfrac{\alpha_{e3} + \cdots + \alpha_{en}}{\Lambda_{23}} + \cdots + \dfrac{\alpha_{en}}{h_e}}{\dfrac{1}{h_i} + \dfrac{1}{h_e} + \dfrac{1}{\Lambda_{12}} + \dfrac{1}{\Lambda_{23}} + \cdots + \dfrac{1}{\Lambda_{(n-1)n}}}$$

where

α_{e1} = solar direct absorptance of the outer (first) pane within the *n*-fold glazing;

α_{e2} = solar direct absorptance of the second pane within the *n*-fold glazing;

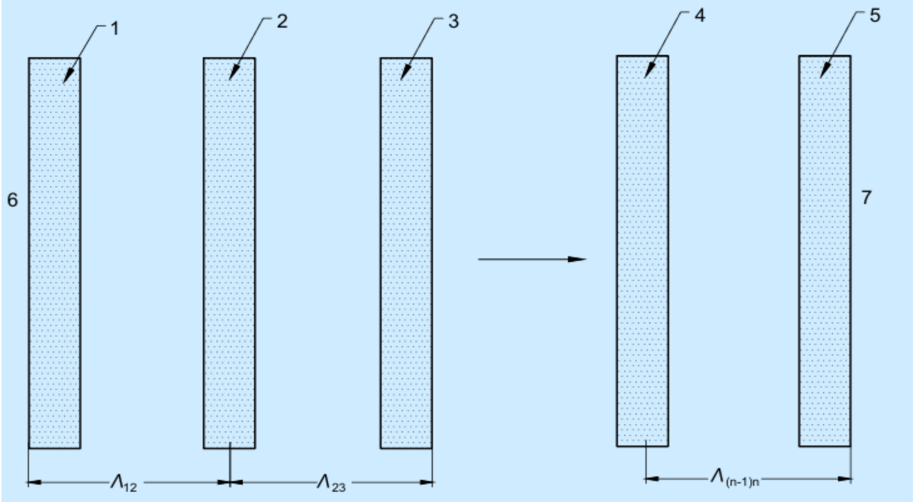
α_{en} = solar direct absorptance of the n^{th} (inner) pane of the *n*-fold glazing;

h_e, h_i = heat transfer coefficients towards the outside and towards the inside, respectively in accordance with **5.2.9.1**;

Λ_{12} = thermal conductance between the outer surface of the outer (first) pane and the centre of the second pane (*see* Fig. 9);

$\Lambda_{(n-1)n}$ = thermal conductance between the centre of the $(n-1)^{th}$ pane and the outer surface of the n^{th}(inner) pane (*see* Fig. 9); and

Λ_{23} = thermal conductance between the centre of the second pane and the centre of the third pane (*see* Fig. 9);



KEY:
1 PANE 1
2 PANE 2
3 PANE 3
4 PANE (n - 1)
5 PANE n
6 OUTSIDE
7 INSIDE

NOTE — For triple glazing, pane 3 corresponds to pane n.

FIG. 9 ILLUSTRATION OF THE MEANING OF THE THERMAL CONDUCTANCES Λ_{12}, Λ_{23}……..$\Lambda_{(n-1)\,n}$

The thermal conductances Λ_{12}, Λ_{23}........$\Lambda_{(n-1)n}$ shall be determined by iteration technique. The calculation of the direct solar absorptances α_{e1}, α_{e2},...α_{en} shall be performed using the methods given in 5.2.9.3.

As an example for the calculation of the direct solar absorptances the following procedure is given which consist of the following (n-1) steps for a glazing consisting of n components:

a) First step — calculate the spectral characteristics of a unit consisting of (n-1) components 2,3,.......n according to what has been prescribed in 5.4.5.4 and 6.1. Then combine this unit with the first (outer) pane as a double glazing;

b) Second step — calculate the spectral characteristics of a unit consisting of the (n-2) components 3,....,n and furthermore, those of a double glazing consisting of pane 1 and pane 2. These units are then combined as a double glazing. The sum $\alpha_{e1} + \alpha_{e2}$ is then obtained. This procedure is continued up to the last (n-1)th step; and

c) (n-1)th step — combine the (n-1) panes 1,2,... (n-1) and determine the spectral characteristics of this unit. This unit is then combined with the nth (inner) pane as a double glazing. From the second equation in 5.2.9.3, the sum α_{e1}, α_{e2} ...$\alpha_{e(n-1)}$ is obtained, that is with the known values α_{e1}, α_{e2},... $\alpha_{e(n-2)}$ from the previous steps $\alpha_{e(n-1)}$ is determined. α_{en} is obtained according to the expression of α_{e2} in 5.2.9.3.

In the case of triple glazing for the solar absorptances α_{e1}, α_{e2} and α_{e3} as a function of the spectral characteristics of the individual components of the unit, the following formulae are obtained:

$$\alpha_{e1} = \frac{\sum_{\lambda=300\text{ nm}}^{2\,500\text{ nm}} \left\{ \alpha_1(\lambda) + \frac{\tau_1(\lambda)\alpha'_1(\lambda)\rho_2(\lambda)\,[1-\rho'_2(\lambda)\,\rho_3(\lambda)] + \tau_1(\lambda)\tau_2^2(\lambda)\alpha'_1(\lambda)\,\rho_3(\lambda)}{[1-\rho'_1(\lambda)\,\rho_2(\lambda)].[1-\rho'_2(\lambda)\,\rho_3(\lambda)] - \tau_2^2(\lambda)\rho'_1(\lambda)\,\rho_3(\lambda)} \right\} S_\lambda \Delta\lambda}{\sum_{\lambda=300\text{ nm}}^{2\,500\text{ nm}} S_\lambda \Delta\lambda}$$

$$\alpha_{e2} = \frac{\sum_{\lambda=300\text{ nm}}^{2\,500\text{ nm}} \left\{ \frac{\tau_1(\lambda)\alpha_2(\lambda)\,[1-\rho'_2(\lambda)\,\rho_3(\lambda)] + \tau_1(\lambda)\tau_2(\lambda)\alpha'_2(\lambda)\,\rho_3(\lambda)}{[1-\rho'_1(\lambda)\,\rho_2(\lambda)].[1-\rho'_2(\lambda)\,\rho_3(\lambda)] - \tau_2^2(\lambda)\rho'_1(\lambda)\,\rho_3(\lambda)} \right\} S_\lambda \Delta\lambda}{\sum_{\lambda=300\text{ nm}}^{2\,500\text{ nm}} S_\lambda \Delta\lambda}$$

$$\alpha_{e3} = \frac{\sum_{\lambda=300\text{ nm}}^{2\,500\text{ nm}} \left\{ \frac{\tau_1(\lambda)\tau_2(\lambda)\alpha_3(\lambda)}{[1-\rho'_1(\lambda)\,\rho_2(\lambda)].[1-\rho'_2(\lambda)\,\rho_3(\lambda)] - \tau_2^2(\lambda)\rho'_1(\lambda)\,\rho_3(\lambda)} \right\} S_\lambda \Delta\lambda}{\sum_{\lambda=300\text{ nm}}^{2\,500\text{ nm}} S_\lambda \Delta\lambda}$$

where

$\tau_1(\lambda)$, $\tau_2(\lambda)$, $\tau_3(\lambda)$, $\rho_1(\lambda)$, $\rho'_1(\lambda)$, $\rho_2(\lambda)$, $\rho'_2(\lambda)$, $\rho_3(\lambda)$ are as defined in light transmittance;

$\alpha_1(\lambda)$, $\alpha'_1(\lambda)$ and $\alpha_2(\lambda)$ are as defined in 5.2.9.3 for double glazing;

$\alpha'_2(\lambda)$ = spectral direct absorptance of the second pane, measured in the opposite direction to the incident radiation, given by the relationship:

$$\alpha'_2(\lambda) = 1 - \tau_2(\lambda) - \rho'_2(\lambda)$$

$\alpha_3(\lambda)$ = spectral direct absorptance of the third pane, measured in the direction of the incident radiation, given by the relationship:

$$\alpha_3(\lambda) = 1 - \tau_3(\lambda) - \rho_3(\lambda)$$

$\Delta\lambda$ and the integration procedure are the same as in 5.4.5.4 except that the data points shall be chosen at the wavelengths given in Table 5.

For a glazing with more than three components, the formulae for the solar absorptances α_{e1}, α_{e2}, ..., α_{en} as a function of the individual components.

5.2.9.5 *Mean radiant temperature* (*MRT*)

Besides solar energy transmittance, heat gain and losses occur by radiation exchange between the glazing which influences thermal comfort of the occupants. Mean radiant temperature (MRT), which is defined as the uniform temperature of an imaginary enclosure in which radiant heat transfer from the human body is equal to the radiant heat transfer in the actual non-uniform enclosure, is used as a metric in thermal comfort assessment. MRT can be calculated by various methods, among which measuring with globe thermometer is the most common and is given by:

$$MRT = \sqrt[4]{{T_g}^4 + \frac{h_{cg}}{\varepsilon_g \sigma}(T_g - T_a)^4}$$

where

T_a = air temperature, in Kelvin;

T_g = black globe temperature, in Kelvin;

ε_g = emissivity of black globe;

σ = Stefane-Boltzmann constant; and

h_{cg} = convective heat transfer coefficient of the black globe.

5.2.10 *Thermal Transmittance due to Temperature Difference*

The other part to be looked at is the transfer of heat from outside to inside environment through the glass, due to the temperature difference. This is known as U-value, which is the rate of heat flow through one square metre of glazing when there is a temperature difference of 1 °C. The lower the U-value, the lesser is the heat transfer.

5.2.11 *Total Solar Energy Transmission*

The total solar energy transmitted into the room per unit area of glazing φ_{ei} is given by the relationship:

$$\varphi_{ei} = \varphi_e g$$

where

φ_e = incident solar radiation flux per unit area;

g = total solar energy transmittance of the glazing; and

The values of φ_e can be obtained from appropriate tables in meteorological literature.

NOTE — The SHGC/SF requirement for the glazing should be selected based on the prescriptive requirements are mentioned in Annex B.

5.2.11.1 *Additional heat transfer*

If the room temperature T_i differs from the outside temperature T_o, an additional heat transfer occurs in addition to φ_{ei}. This additional heat flow q_z can be calculated as follows:

$$q_z = U\,(T_o - T_i)$$

where U is the U-value (thermal transmittance) of glazing.

5.2.12 *Frames*

These can contribute to a significant amount of energy gain and energy loss through the glazing system. For improved efficiency, some frames are designed with internal thermal breaks that reduce energy flow through the frame (*see* Fig. 10). The sealing between the openings and the window frames and between the opening sashes of windows and fixed portions are important areas to be addressed as major heat loss happens from this area due to poor design, selection and application of sealant material. Adequate provision shall also be made to ensure that the frames are not susceptible to water ingress in case of driving rain.

NOTE — As the evaluation of structural property differs from a monolithic profile, for evaluation of the structural property of thermally broken profile, the method described in Annex G of accepted standard [C-8(12)] shall be followed.

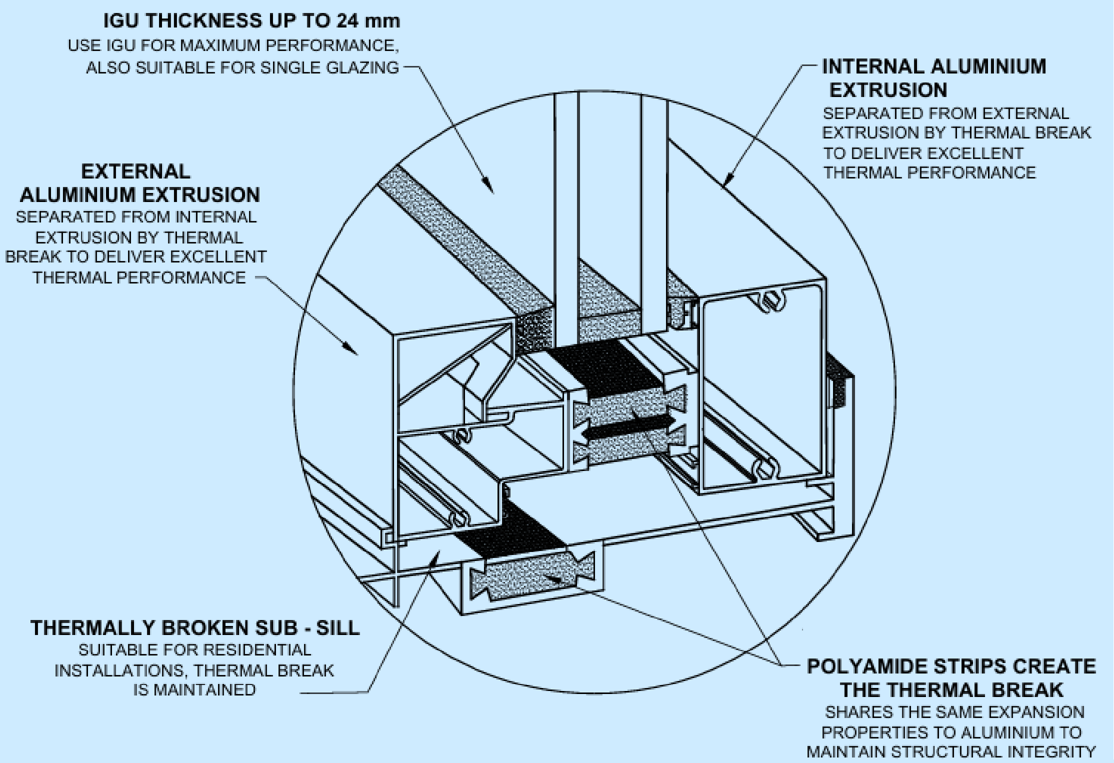

IGU THICKNESS UP TO 24 mm
USE IGU FOR MAXIMUM PERFORMANCE, ALSO SUITABLE FOR SINGLE GLAZING
INTERNAL ALUMINIUM EXTRUSION
SEPARATED FROM EXTERNAL EXTRUSION BY THERMAL BREAK TO DELIVER EXCELLENT THERMAL PERFORMANCE
EXTERNAL ALUMINIUM EXTRUSION
SEPARATED FROM INTERNAL EXTRUSION BY THERMAL BREAK TO DELIVER EXCELLENT THERMAL PERFORMANCE
THERMALLY BROKEN SUB - SILL
SUITABLE FOR RESIDENTIAL INSTALLATIONS, THERMAL BREAK IS MAINTAINED
POLYAMIDE STRIPS CREATE THE THERMAL BREAK
SHARES THE SAME EXPANSION PROPERTIES TO ALUMINIUM TO MAINTAIN STRUCTURAL INTEGRITY

FIG. 10 THERMALLY BROKEN ALUMINIUM FRAME ASSEMBLY FOR IMPROVED THERMAL PERFORMANCE IN GLAZING SYSTEMS

5.2.13 *Shading Systems*

These regulate the solar radiation incident on the glazing thereby reducing the effective solar heat gain coefficient of the glazing system. Besides reduction in direct solar gains inside the building, shading systems reduce the radiant heat gain from the glazing surface. Shading system design requires due consideration for the geographic location of the building, orientation of the facade, location of the system, and solar geometry. External shading systems are effective in solar control compared to internal shading systems (*see* Fig. 11). Shading systems may impact the daylight availability and the views available for occupants. Kinetic systems, either automated or manually operated, can be used to vary shading system positions dynamically based on solar position, daylight requirements and occupant preferences.

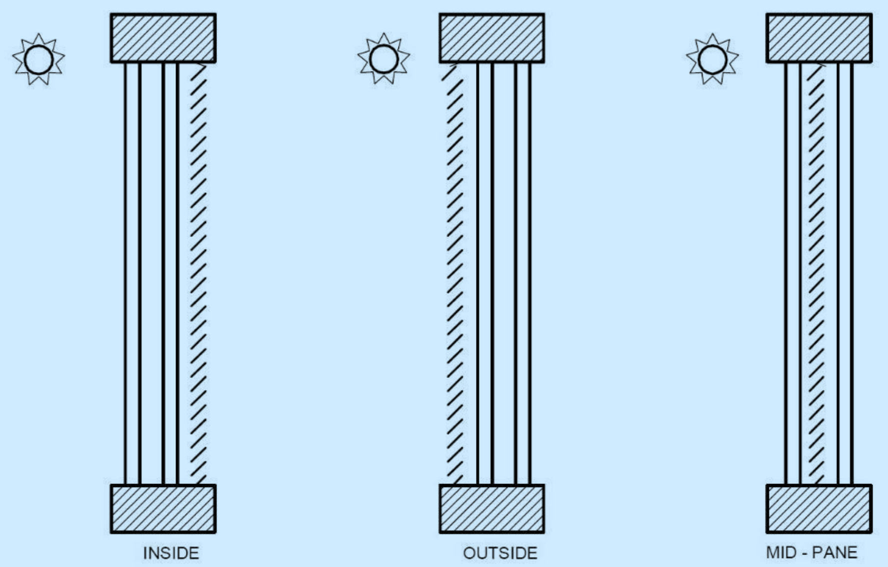
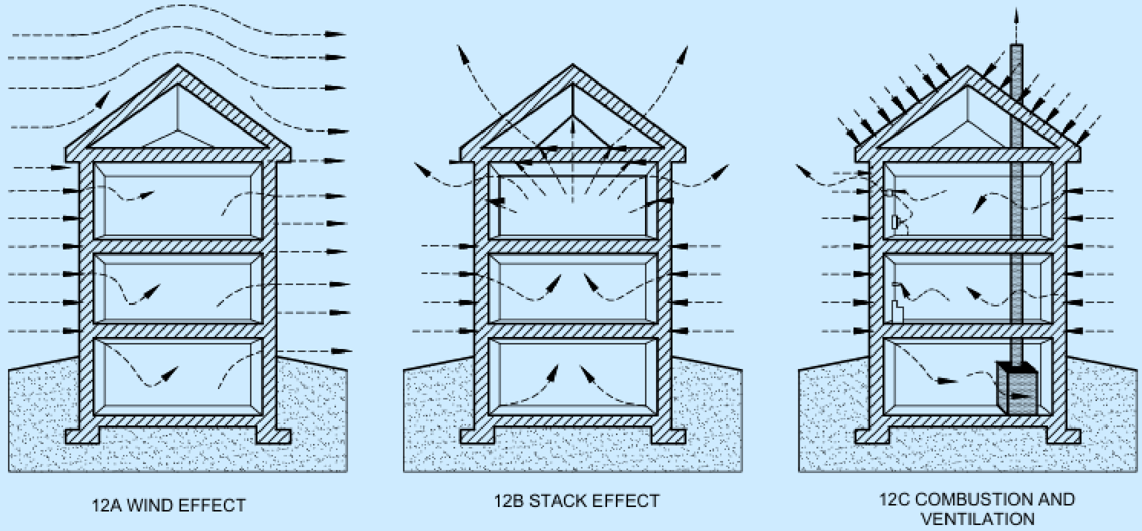


FIG. 11 PLACEMENT OF SHADING DEVICES FOR OPTIMAL SUN CONTROL IN GLAZING SYSTEMS

5.2.14 *Air Infiltration*

Inadequate control of airflow through the building envelope is often a primary factor contributing to premature building envelope failures. Air infiltration may be caused by wind pressure, stack pressure or fan pressure (*see* Fig. 12). Wind creates a positive pressure on the windward face and negative pressure on the leeward face, causing infiltration and exfiltration. Besides the positive or negative pressure created by the heating, ventilation and air conditioning system may lead to exfiltration or infiltration, respectively.

The stack effect is when warm air moves upward in a building because it is lighter than cold air and escapes out of the upper levels of the building, through penetrations and cracks in the building envelope or other openings. The rising warm air reduces the pressure in the base of the building, forcing cold air to infiltrate through open doors, windows, or other openings. The stack effect basically causes air infiltration on the lower portion of a building and exfiltration on the upper part. Mechanical equipment such as fans and blowers cause the movement of air within buildings and through enclosures, which can generate pressure differences. If more air is exhausted from a building than is supplied, a net negative pressure is generated, which can induce unwanted airflow through the building envelope.


12A WIND EFFECT

12B STACK EFFECT

12C COMBUSTION AND VENTILATION

FIG. 12 MECHANISMS OF AIR INFILTRATION: WIND EFFECT, STACK EFFECT, AND COMBUSTION AND VENTILATION IN BUILDING ENCLOSURES

5.2.14.1 *Considerations for controlling air infiltration*

a) Ensuring the continuity of each component serving its role in resisting infiltration, such as a window assembly or a curtain, and ensuring they are interconnected to prevent air leakage at the joints between materials, components, assemblies, and systems; and

b) Effective structural support shall be ensured so that all components can resist the positive or negative structural loads imposed on them by wind, stack effect, and HVAC fan pressures without rupture, displacement or undue deflection, thereby resisting air infiltration through them. Design considerations shall ensure that these loads are safely transferred to the structure and provision of adequate resistance to these pressures by use of fasteners, tapes, adhesives, etc.

Inadequate sealing of the glazing system may lead to energy gains and losses, thereby affecting thermal comfort and increasing the cooling and heating energy demand. If moisture-laden air infiltrates through the glazing system, the moisture may, under certain environmental conditions condense, especially in cold climates.

5.3 Methods for Improving Thermal Insulation

Glass readily conducts energy and so is a poor insulator. To improve resistance to energy transfer, insulating glass units, coupled glazing or high performance coatings can be used. Increasing the thickness of the glass makes little difference to the U-value of the glazing.

5.3.1 *Use of Low Emissivity Coatings*

Low emissivity (low-E) coatings have surface emissivity of less than 0.2. The use of such a solar control low-E coating on glass improves the thermal insulation. They are most efficient when used on the cavity surfaces of insulating glass units.

5.3.2 *Solar Control Glass*

Solar control glass can be manufactured in several forms. The function of solar control glass is to reduce the total solar energy transmittance, which usually leads to a decrease in the transmission of the visible part of the solar spectrum. However, some tints and coatings are able to attenuate preferentially non-visible solar radiation, leaving the transmission of the greater proportion of the visible radiation largely unchanged.

The application of ceramic frit-fired into the surface of the glass can also be used to modify the energy and light transmission of the glass. The effect can be varied across a pane depending on the screen print pattern. Manufacturers should be consulted for specific details.

Solar control glass can be used in single glazed or double glazed unit depending upon the site requirements. The relationship between light transmission and total solar energy transmission is expressed as the light/energy ratio.

There is no optimum light/energy ratio. The selection of an appropriate product depends on the requirements of the building. Solar gain may be relatively high for making use of passive solar gains, or low to reduce air conditioning loads. Light transmission will depend on the extent to which daylight is used to obviate artificial lighting.

Some solar control glasses can be toughened or heat strengthened and gives a means of raising the design stress and enhances safety of thermal fracture. The following are the common varieties.

NOTE — Some manufacturers use this as a descriptive code, quoting a light transmission figure followed by a total solar energy transmission figure.

a) *Body tinted glass* (*for increased absorption*) — Solar control properties and colour vary with the thickness of the glass. When used in insulating glass units, body tinted glass should be positioned as the outer pane because the energy due to the absorbed radiation is more easily dissipated to the outside.

b) *Reflective coated glass* — It uses the principle of increasing the direct reflection to maximize solar energy attenuation. In comparison with clear glass, its absorption of solar energy is also increased. An informative annex on test requirements is given at Annex C.

The advantages of such glass types are:

1) Greater performance range than body tinted glass;
2) Higher performances (greater solar energy attenuation);
3) Light/energy ratios nearer to the theoretical limit; and
4) A range of colour appearances in transmission and reflection.

The coatings may be placed on to body-tinted glass to extend the range of performances.

NOTES

1 Compared with a float glass surface, these reflective coatings (owing to their composition) exhibit lower levels of emissivity which improves their *U*-value.
2 Performance data in comparison to clear glass can be had from manufacturers.

c) *Laminated glass* — It is commonly manufactured with clear glass and clear interlayers, but solar control properties can be incorporated into laminated glass by including either solar control glass or tinted interlayers or both.

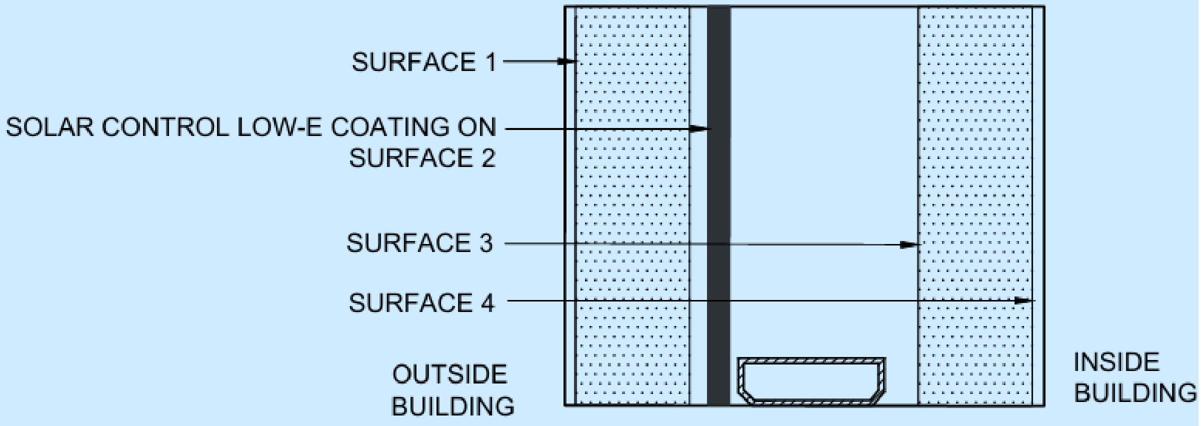
Laminated glass with clear interlayers and solar control glass exhibit similar properties to the solar control glass from which it is made.
Laminated glass with a tinted interlayer acts in a similar manner to body tinted glass, by absorbing the solar radiation, but with a different range of colours and performances.

NOTE — Performance data in comparison to clear glass can be had from manufacturers. Performances of a typical range of laminated glass products with clear glass and tinted interlayers can be had from manufacturers.

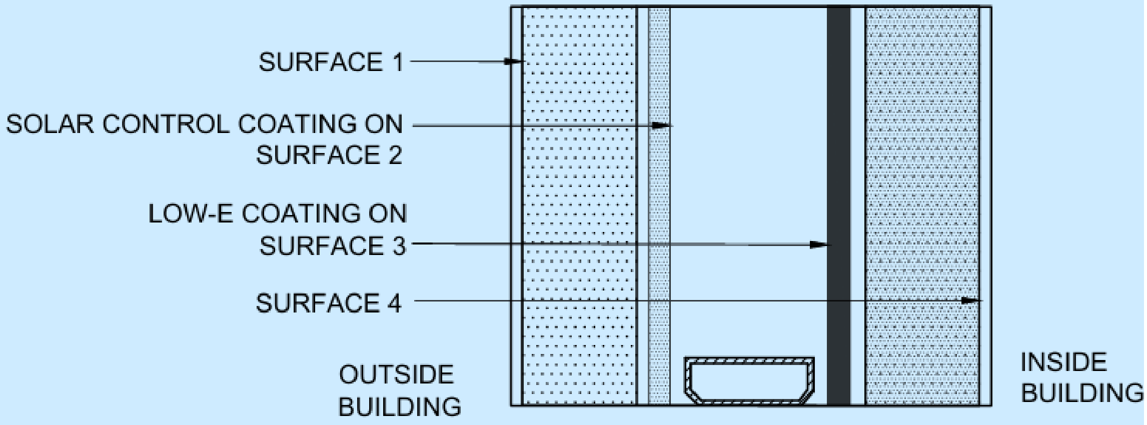
d) *Insulating glass units* — These are used primarily for improved thermal transmittance (*U*-value) (*see* **5.2.10**), but can also improve the total solar energy transmittance. This improvement is a result of the incorporation of a second pane of glass together with the hermetically sealed air space. The second glass pane can be of any glass type. Outer pane can be solar control low emissivity glass (surface 2) and inner pane can be clear glass (*see* Fig. 13A). The other option is outer pane can be solar control glass (surface 2) and inner pane with low emissivity coating glass (surface 3) (*see* Fig. 13B).

NOTES

1 Soft coat low emissivity glass can be used as the hermetically sealed airspace protects the coating.
2 Performances of a typical range of insulating glass units with clear float inner pane or with hard/soft coat low emissivity glass inner pane can be had from manufacturers.


SURFACE 1
SOLAR CONTROL LOW-E COATING ON SURFACE 2
SURFACE 3
SURFACE 4
OUTSIDE BUILDING
INSIDE BUILDING

13A OPTION 1


SURFACE 1
SOLAR CONTROL COATING ON SURFACE 2
LOW-E COATING ON SURFACE 3
SURFACE 4
OUTSIDE BUILDING
INSIDE BUILDING

13B OPTION 2

FIG. 13 CONFIGURATIONS OF INSULATING GLASS UNITS

5.3.3 *Reducing Thermal Transmittance of Glazing System*

5.3.3.1 *Increasing the width of the air space*

Enhanced thermal insulation can be achieved by increasing the width of the airspace. However, there is a convection of the gas in the cavity.

5.3.3.2 *Using gases of lower thermal conductivity*

Replacing the air in the cavity with, for example, argon/krypton, can improve the thermal insulation.

5.3.3.3 *Inhibiting convection within the air space*

Filling the cavity with cellulose material reduces convection and makes the cavity a more efficient insulator. However, this usually results in loss of vision, since the materials are, at best, translucent.

5.3.3.4 *Evacuation of the air space*

In theory, a vacuum shall eliminate energy transfer by conduction and convection. However, a vacuum puts high demands on the glass from the external air pressure.

NOTE — Evacuation of the air space is currently considered to be technically impractical.

5.3.3.5 *Evaluation of type of spacer used in double glazed unit*

Thermal performance of the glazing system for conduction can be improved by changing the material of the spacer.

5.3.3.6 *Typical U-values of glass products*

Table 6, Table 7 and Table 8 give typical *U*-values.

Table 6 Thermal Transmittance (*U*-Value) of Glass Products: Single Glazing

(*Clause* 5.3.3.6)

Sl No. (1)	Glass Thickness mm (2)	*U*-Value W/m^{2}K (3)
i)	4	5.8
ii)	6	5.7
iii)	10	5.6
iv)	12	5.5

Table 7 Thermal Transmittance (*U*-Value) of Glass Products: Insulating Glass Units

(*Clause* 5.3.3.6)

Sl No.	Clear glass Thickness and type mm	Cavity Width mm	*U*-Value W/m^{2}K	
			Air	Argon
(1)	(2)	(3)	(4)	(5)
i)	4+4	6	3.3	3.1
		12	2.9	2.7
		16	2.7	2.6
		20	2.8	2.6
ii)	4+4 Low E (ϵ_d = 0.15)	6	2.7	2.3
		12	1.9	1.6
		16	1.7	1.5
		20	1.7	1.5
iii)	4 + 4 Low E (ϵ_d = 0.04)	6	2.5	2.0
		12	1.6	1.3
		16	1.4	1.2
		20	1.4	1.2
iv)	4 + 4 + 4	6	2.4	2.1
		12	1.9	1.8
		16	1.8	1.7
		20	1.8	1.7
v)	4 Low E (ϵ_d = 0.15) + 4 + 4 Low E (ϵ_d = 0.15)	6	1.7	1.4
		12	1.7	1.0
		16	1.0	0.8
		20	0.9	0.8
vi)	4 Low E (ϵ_d = 0.04) + 4 + 4 Low E (ϵ_d = 0.04)	6	1.6	1.2
		12	1.0	0.7
		16	0.8	0.6
		20	0.7	0.6

Table 7 (*Concluded*)

Table 7 Thermal Transmittance (*U*-Value) of Glass Products: Insulating Glass Units

(*Clause* 5.3.3.6)

Sl No.	**Clear glass Thickness and type** mm	**Cavity Width** mm	***U*-Value** W/m^{2}K	
			Air	Argon
(1)	(2)	(3)	(4)	(5)

NOTES

1 *U*-values for argon gas-filled cavity based on 90 percent argon/10 percent air.
2 ϵ_d is the declared (normal) emissivity.

Table 8 Thermal Transmittance (*U*-Value) of Glass Products: Coupled Glazing

(*Clause* 5.3.3.6)

Sl No.	**Clear Glass Thickness and Type** mm	**Separation** mm	***U*-Value** W/m^{2}K
(1)	(2)	(3)	(4)
i)	4 + 4	25	2.8
		75	2.8
ii)	4 + 4 Low E	25	1.7
		75	1.9

NOTE — ϵ_d is the declared (normal) emissivity.

The *U*-value requirement for the glazing system should be selected in accordance with the Table 9 and Annex B.

Table 9 Thermal Performance of Different Glass Shading Devices

(*Clause* 5.3.3.6)

Sl No. (1)	Name of the Shading Device (2)	Transmittance, *U*-Value (3)	Shade Factor (4)
i)	Plain glass sheet (3.0 mm thick)	5.23	1.00
ii)	Plain glass + Wire mesh outside	5.00	0.65
iii)	Painted glass:		
	a) White paint	5.22	0.35
	b) Yellow paint	5.22	0.37
	c) Green paint	5.22	0.40
iv)	Heat absorbing glass	4.65	0.45
v)	Plain glass sheet + Venetian blind inside:	3.14	
	a) Light colour		0.35
	b) Dark colour		0.40
vi)	Plain glass sheet which is,	5.23	
	a) 100 percent shaded		0.14
	b) 75 percent shaded		0.34
	c) 60 percent shaded		0.56

NOTE — Indicative values, actual value of the system to be measured using either approved simulation software or testing at laboratory.

5.3.4 *Thermal Safety of Glass*

Thermal safety of glass should be assessed considering the amount of radiation incident on the surface and the thermal capabilities of the glass. For example, the solar radiation intensity on the glass surface should be determined along with the air temperature range applicable to the location of the building. These measurements, together with the energy transfer coefficients and the glass absorption allow determination of the appropriate basic temperature difference between the central area of the glass and its edge. The difference is related to the thermal stress and then modified for the type of glazing system, taking account of extraneous effects resulting from curtains, blinds, back-up walls, proximity to heaters, etc to derive a stress in actual service conditions.

NOTES

1 High air temperatures, low rates of air movement, and the insulation provided by curtains, blinds, back-up walls and multiple glazing tend to reduce the loss of energy and uphold the centre temperature. Low temperatures at the edges are maintained by conduction from the glass through the frame to a cold building structure with a large thermal capacity.

2 Advice may be sought from the manufacturer of glass as to the methods for assessing the thermal safety of the glass.

The resultant service stress should then be compared with the design stress for the glass. If on comparison, the service stress is less than or equal to the design stress, the glass and glazing system may be accepted as thermally safe provided, that the edges of the glass are of adequate quality.

NOTE — Where the application of a solar control film is being considered to existing glazing, advice should be sought from the manufacturer on the effect of any additional thermal stress likely to be induced in the glass.

The normal mode of thermal breakage of glass is by the action of tensile stress located in and parallel to an edge, and so the breaking stress of the glass is mainly dependent on the extent and position of flaws in the edges. The condition of the glass edge is therefore extremely important.

Solar control glasses should not be nipped to size and any panes with shelled or vented edges should not be accepted for glazing in orientations subject to direct sunlight. Although a wheel-cut edge is the most satisfactory, laminated glasses with worked edges may be used.

Where clean-cut edges are not permitted, arises should be created by a wet process, working parallel to the edge and not across the thickness, and the design implications of such an action should be examined.

Where solar control glasses are to be used in sliding doors and windows there is always the possibility that, when opened during sunny periods, the overlapping will function as double glazing with little ventilation in the air space, and it is this condition that should be assumed in assessing the thermal safety of glass.

Thermal safety assessment is based on the behaviour of glass in good condition and properly glazed. Even if the glass is shown to be thermally safe, this depends on close adherence to the recommend glazing procedures. All necessary precautions should be taken to see that only glass with edges of an acceptable condition is used. The glass should be stored and handled so that no contact with hard bodies can damage the edges and each pane or insulating glass unit should be carefully examined immediately before glazing.

5.3.5 *UV-Transmittance*

The UV-transmittance of glazing is the fraction of the incident solar radiation transmitted by the glazing in the 300 nm to 380 nm range (UV-B range from 300 nm to 315 nm and UV-A range from 315 nm to 380 nm). The UV-transmittance τ_{UV} is calculated as follows:

$$\tau_{\mathrm{UV}} = \frac{\sum_{\lambda=300\ \mathrm{nm}}^{380\ \mathrm{nm}} \tau(\lambda) S_\lambda\, \Delta\lambda}{\sum_{\lambda=300\ \mathrm{nm}}^{380\ \mathrm{nm}} S_\lambda\, \Delta\lambda}$$

where

S_λ = relative spectral distribution of UV radiation;

$\tau(\lambda)$ = spectral transmittance of the glazing; and

$\Delta\lambda$ and the integration procedure are the same as **5.4.5.4** except that the data points shall be chosen at the wavelength given in Table 10.

This average extends over the defined UV-portion of the solar spectrum. It may not be correlated with solar radiation damage of materials and skin.

Table 10 Normalized Relative Spectral Distribution of Global Solar Radiation

(*Clause* 5.3.5)

Sl No. (1)	λ nm (2)	$S_\lambda \Delta\lambda$ (3)
i)	300	0
ii)	305	0.001 859
iii)	310	0.007 665
iv)	315	0.017 961
v)	320	0.029 732
vi)	325	0.042 466
vii)	330	0.062 108
viii)	335	0.065 462
ix)	340	0.071 020
x)	345	0.073 326
xi)	350	0.079 330

Table 10 (*Concluded*)

Table 10 Normalized Relative Spectral Distribution of Global Solar Radiation

(*Clause* 5.3.5)

Sl No. (1)	λ nm (2)	$S_\lambda \Delta\lambda$ (3)
xii)	355	0.082 894
xviii)	360	0.087 039
xix)	365	0.097 963
xx)	370	0.108 987
xxi)	375	0.113 837
xxii)	380	0.058 351

NOTE — The values in this table are calculated according to the trapezoidal rule.

5.4 Daylight Transmission

Good glazing system design can, by reducing reliance on artificial lighting, can be one of the largest single means of saving energy and should be carefully considered.

Account should be taken of shape of the room, window orientation, occupancy patterns and task, together with the relationship of windows to surrounding buildings and other obstruction. As with task lighting, possible solar overheating might result and similar precautions should be taken.

5.4.1 *Light Transmission Properties of Window*

Light transmission is defined as the fraction of visible light at normal incidence transmitted through the glazing. For properties of plastic glazing sheet materials, manufacturers may be consulted.

Dirt on glazing reduces the light transmission, often by an appreciable extent before becoming noticeable. To ensure day lighting levels are adequate, an allowance for the reduced light transmission should be made in day lighting calculation by introducing a ‘dirt factor’ between 0.7 and 1.0. Regular cleaning of glass and plastic glazing sheet materials is therefore important.

5.4.2 *Glare*

5.4.2.1 *General*

Glare results from excessive contrast of illumination, or from an excess of illumination in the field of view. Reaction to it is subjective. When correctly designed, natural lighting should not result in glare problem.

NOTE — Contrasts in excess of 10 : 1 in illumination in different parts of the field of view might give rise to glare in some form.

5.4.2.2 *Disability glare*

Disability glare is glare which impairs the visibility of objects without necessarily causing discomfort.

During a sunny day, even a light transmission of the glazing resulting in 10 000 lux or lower, is likely to cause disability glare.

Glare can be reduced by some form of mechanical shading, for example a canopy, an overhanging floor, a balcony or a louvre system. Alternatively, internal screening can be provided by louvres or blinds.

NOTE — Any fixed shading system reduces the amount of natural light entering the building throughout the year, irrespective of whether there is a glare problem at any particular time.

It may also be possible to re-orientate the glazing to avoid entry of direct solar radiation. Alternatively, the interior layout can be suitably designed to eliminate glare.

5.4.2.3 *Discomfort glare*

Glazing products with light transmission lower than 50 percent can ameliorate discomfort glare. These products decrease the sky luminance components but permanently reduce the admission of daylight. Alternatively, shading devices, internal or external, movable or fixed, may be used.

Other methods of reducing the problems of glare should be considered, including,

a) installation of windows in more than one wall to raise the general background illumination and, in so doing, to reduce the contrast between a window and its surrounding surfaces;

b) use of light coloured matt finishes for the window frames and the surrounding surfaces;

c) splayed reveals, to assist in reducing the contrast between the window and its surroundings;

d) use of slender glazing bars and transoms of high reflectance; and

e) lowering window sills to allow increased illumination to enter, which increases the adaptation level and reduces the likelihood of discomfort glare.

5.4.3 *Diffusion and Obscuration*

The nature of some glazing products (for example, patterned or acid etched glass) can cause the direct incident solar beam to be scattered diffusely. Hence the window might assume an uncomfortable high brightness and become a discomfort glare source in its own right. Diffusing glazing used within the normal field of view should be used with caution.

5.4.4 *Fading*

Most materials can fade when subjected to either daylight (particularly direct sunlight) or artificial light. Fading is a complex phenomenon involving many chemical reactions, initiated or accelerated by light of different wavelengths. Generally, the better quality dyes and pigments fade relatively slowly and react only to the shorter wavelengths (ultraviolet and the blue end of the visible spectrum). Other materials can fade quickly and might do so under light of much longer wavelengths. It is the combination of wavelength, available light and transmission which determines glass selection to minimise fading, not simply the UV transmission.

5.4.5 *Determination of Characteristic Parameters*

5.4.5.1 *General*

The characteristic parameters are determined for quasi-parallel, almost normal radiation incidence.

5.4.5.2 *Test setup*

The samples shall be irradiated by a beam whose axis is at an angle not exceeding 10° from the normal to the surface. The angle between the axis and any ray of the illuminating beam shall not exceed 5°.

The characteristic parameters are as follows:

a) spectral transmittance $\tau(\lambda)$, the spectral external reflectance $\rho_o(\lambda)$ and the spectral internal reflectance $\rho_i(\lambda)$ in the wavelength range of 300 nm to 2 500 nm;

b) light transmittance τ_V, the external light reflectance $\rho_{v,0}$ and the internal light reflectance $\rho_{v,i}$ for illuminant D65;

c) solar direct transmittance τ_e and the solar direct reflectance ρ_e;

d) total solar energy transmittance (solar heat gain co efficient SHGC) g; and

e) UV-transmittance τ_{UV};

When calculating the characteristic parameters of multiple glazing, the spectral data of each glass component is to be used instead of integrating data of the complete unit.

5.4.5.3 *Performance requirements of optical measurements*

Optical measurements in transmission and reflection require special care to achieve accuracy in transmittance and reflectance of about ± 0.01.

The wavelength calibration and the photometric linearity of commercial spectrophotometers shall be checked periodically using reference materials obtained from metrological laboratories.

The wavelength calibration shall be performed by measuring glass plates which feature relatively sharp absorption bands at specified wavelengths; the photometric linearity shall be checked using grey filters with a certified transmittance.

For reflectance measurements, reference materials having reflection behaviour (that is, reflectance level and ratio of diffuse and direct reflectance).

Thick samples (that is laminated glass or insulating units) can modify the optical path of the instrument's beam as compared to the path in air and therefore the sample beam hits an area of the detector having a different responsivity.

A similar source of inaccuracy occurs in case of samples with significant wedge angles which deflect the transmitted (and reflected) beams. It is recommended to check the reproducibility by repeating the measurement after rotating the sample.

Additionally, in the case of reflectance measurements, glass sheets cause a lateral shear of the beam reflected by the second surface, causing reflectance losses (whose extent is particularly evident in the case of thick and/or wedged samples). This source of inaccuracy shall be taken into account particularly in the case of reflectance measurements through the uncoated side. In order to quantify and correct systematic errors, it is recommended to use calibrated reflectance standards with a thickness similar to the unknown sample.

In the case of diffusing samples (or samples with a non-negligible diffusing component or wedged samples), transmittance and reflectance measurements shall be performed using integrating spheres whose openings are sufficiently large to collect the entire diffusely transmitted or reflected beam. The sphere diameter shall be adequate and the internal surface adequately coated with a highly diffusing reflectance material, so that the internal area can provide the necessary multiple reflections. Reference materials with characteristics similar to the unknown sample as specified above shall be used. If the transmittance or reflectance curve recorded by the spectrometer exhibits a high level of noise for some wavelengths, the values to be considered for those wavelengths should be obtained after a smoothing of the noise.

5.4.5.4 *Light transmittance*

Light transmittance is the measure of the amount of light passing through the glazing. The visible light lies between the wavelength 380 nm and 780 nm. The light transmission of the glazing depends on the substrate type and coating layer done on the base glass.

The light transmittance, τ_v of glazing shall be calculated using the following formula:

$$\tau_{\mathrm{v}} = \frac{\sum_{\lambda=380\ \mathrm{nm}}^{780\ \mathrm{nm}} \tau(\lambda) D_\lambda\, V(\lambda)\, \Delta\lambda}{\sum_{\lambda=380\ \mathrm{nm}}^{780\ \mathrm{nm}} D_\lambda\, V(\lambda) \Delta\lambda}$$

where

D_λ = relative spectral distribution of illuminant D65;

$\tau(\lambda)$ = the spectral transmittance of glazing;

$V(\lambda)$ = spectral luminous efficiency for photopic vision defining the standard observer for photometry; and

$\Delta\lambda$ = wavelength interval.

Table 11 indicates the values for $D_\lambda V(\lambda)\Delta\lambda$ for wavelength intervals of 10 nm. The table has been drawn up in such a way that $\Sigma D_\lambda V(\lambda)\Delta\lambda = 1$.

In the case of multiple glazing, the spectral transmittance $\tau(\lambda)$ shall be obtained by calculation from the spectral characteristics of the individual components. Alternatively, measurements on non-diffusing multiple units may be performed using an integrating sphere. This may be achieved after reducing the interspaces under conditions that allow the collection of the whole transmitted beam.

The calculation of the spectral transmittance $\tau(\lambda)$ shall be performed using methods such as algebraic manipulation. Any algorithm that can be shown to yield consistently the correct solution is acceptable.

For the calculation of $\tau(\lambda)$ as well as for the calculation of spectral reflectance the following symbols for the spectral transmittance and spectral reflectance of the individual components are used:

$\tau_1(\lambda)$ = spectral transmittance of the outer (first) pane;

$\tau_2(\lambda)$ = spectral transmittance of the second pane;

$\tau_n(\lambda)$ = the spectral transmittance of the n^{th} (inner) pane (for example, for triple glazing $n= 3$);

$\rho_1(\lambda)$ = spectral reflectance of the outer (first) pane measured in the direction of incident radiation;

$\rho'_1(\lambda)$ = spectral reflectance of the outer (first) pane measured in the opposite direction of incident radiation;

$\rho_2(\lambda)$ = spectral reflectance of the second pane measured in the direction of incident radiation;

$\rho'_2(\lambda)$ = spectral reflectance of the second pane measured in the opposite direction of incident radiation;

$\rho_n(\lambda)$ = spectral reflectance of the n^{th} (inner) pane measured in the direction of incident radiation;

$\rho'_n(\lambda)$ = spectral reflectance of the n^{th} (inner) pane measured in the opposite direction of incident radiation.

For the spectral transmittance $\tau(\lambda)$ as a function of the spectral characteristics of the individual components of the unit, the following formulae are obtained:

a) For double glazing; and

b) For triple glazing.

For multiple glazing with more than three components, relationships similar to above expressions are found to calculate $\tau(\lambda)$ of such glazing from the spectral characteristics of the individual components.

As an example for calculating $\tau(\lambda)$ according to the procedures of this Section, a glazing composed of five components may be treated as follows:

1) First consider the first three components as triple glazing and calculate the spectral characteristics of this combination;

2) Next, run the same procedure for the next two components as double glazing; and

3) Then calculate $\tau(\lambda)$ for the five component glazing, considering it as double glazing consisting of the preceding triple and double glazing.

The light transmission requirement for the glazing should be selected in accordance with relevant Indian Standards.

Table 11 Normalized Relative Spectral Distribution $D_\lambda V(\lambda)\Delta\lambda$

(*Clause* 5.4.5.4)

Sl No. (1)	λ nm (2)	$D_\lambda V(\lambda)\Delta\lambda \times 10^2$ (3)
i)	380	0
ii)	390	0.000 5
iii)	400	0.003 0
iv)	410	0.0103
v)	420	0.035 2
vi)	430	0.094 8
vii)	440	0.227 4
viii)	450	0.419 2
ix)	460	0.666 3
x)	470	0.985 0
xi)	480	1.518 9
xii)	490	2.133 6
xiii)	500	3.349 1
xiv)	510	5.139 3
xv)	520	7.052 3
xvi)	530	8.799 0
xvii)	540	9.442 7
xviii)	550	9.807 7
xix)	560	9.430 6
xx)	570	8.689 1
xxi)	580	7.899 4
xxii)	590	6.330 6
xxiii)	600	5.354 2
xxiv)	610	4.249 1
xxv)	620	3.150 2
xxvi)	630	2.081 2
xxvii)	640	1.381 0
xxviii)	650	0.807 0
xxix)	660	0.461 2
xxx)	670	0.248 5
xxxi)	680	0.125 5
xxxii)	690	0.053 6
xxxiii)	700	0.027 6
xxxiv)	710	0.014 6

Table 11 (*Concluded*)

Sl No. (1)	λ nm (2)	$D_\lambda V(\lambda)\Delta\lambda \times 10^2$ (3)
xxxv)	720	0.005 7
xxxvi)	730	0.003 5
xxxvii)	740	0.002 1
xxxviii)	750	0.000 8
xxxix)	760	0.000 1
xxxx)	770	0.000 0
xxxxi)	780	0.000 0

NOTE — Normalized relative spectral distribution D_λ of illuminant D65 multiplied by the spectral luminous efficiency $V(\lambda)$ and by the wavelength interval $\Delta\lambda$. The values in this table are calculated according to the trapezoidal rule.

5.5 Light Reflectance

5.5.1 *External Light Reflectance of Glazing*

External light reflectance corresponds to the amount of sunlight reflected by the external glass surface. The amount of light reflection depends on the type of base glass (substrate tint) and the position of coating on the glass surface.

The external light reflectance of glazing $\rho_{v,o}$ shall be calculated using the following formula:

$$\rho_{v,o} = \frac{\sum_{\lambda=380\text{ nm}}^{780\text{ nm}} \rho_o(\lambda) D_\lambda V(\lambda)\,\Delta\lambda}{\sum_{\lambda=380\text{ nm}}^{780\text{ nm}} D_\lambda V(\lambda)\Delta\lambda}$$

where

$\rho_o(\lambda)$ = spectral external reflectance of glazing, and D_λ, $V(\lambda)$, $\Delta\lambda$ and the integration procedure are defined in 5.4.5.4.

For multiple glazing, the calculation of the spectral external reflectance $\rho_o(\lambda)$ shall be performed using the same methods as given in 5.4.5.4 for the calculation of the spectral transmittance $\tau(\lambda)$.

For the spectral external reflectance $\rho_o(\lambda)$ as a function of the spectral characteristics of the individual components of the unit, the following formulae are applied:

a) For double glazing:

$$\rho_o(\lambda) = \rho_1(\lambda) + \frac{\tau_1^2(\lambda)\,\rho_2(\lambda)}{1 - \rho_1'(\lambda)\,\rho_2(\lambda)}$$

b) For triple glazing:

$$\rho_o(\lambda) = \rho_1(\lambda) + \frac{\tau_1^2(\lambda)\,\rho_2(\lambda)[1 - \rho_2'(\lambda)\,\rho_3(\lambda)] + \tau_1^2(\lambda)\,\tau_2^2(\lambda)\,\rho_3(\lambda)}{[1 - \rho_1'(\lambda)\,\rho_2(\lambda)].[1 - \rho_2'(\lambda)\,\rho_3(\lambda)] - \tau_2^2(\lambda)\rho_1'(\lambda)\,\rho_3(\lambda)}$$

For multiple glazing with more than three components, relationships similar to above equations are found to calculate $\rho_o(\lambda)$ of such glazing from the spectral characteristics of the individual components.

As an example for calculating $\rho_o(\lambda)$, a glazing composed of five components may be treated in the same way as described in 5.4.5.4.

5.5.2 *Internal Light Reflectance of Glazing*

Internal light reflectance corresponds to the amount of light reflected by the inner glass surface. The amount of light reflection depends on the type of base glass (substrate tint) and the position of coating on the glass surface.

The internal light reflectance of glazing $\rho_{\text{v,i}}$ shall be calculated using the following formula:

$$\rho_{\text{v,i}} = \frac{\sum_{\lambda=380\text{ nm}}^{780\text{ nm}} \rho_{\text{i}}(\lambda) D_\lambda\, V(\lambda)\, \Delta\lambda}{\sum_{\lambda=380\text{ nm}}^{780\text{ nm}} D_\lambda\, V(\lambda) \Delta\lambda}$$

where

$\rho_{\text{i}}(\lambda)$ = spectral internal reflectance of glazing; and

$D\lambda$, $V(\lambda)$, $\Delta\lambda$ and the integration procedure are as defined in light transmittance in 5.4.5.4.

For multiple glazing, the calculation of the spectral internal reflectance $\rho_{\text{i}}(\lambda)$ shall be performed using the same methods as given in **5.4.5.4** for the calculation of the spectral transmittance $\tau(\lambda)$.

For the spectral internal reflectance $\rho_{\text{i}}(\lambda)$ as a function of the spectral characteristics of the individual components of the unit, the following formulae are applied.

b) *For double glazing:*

$$\rho_i(\lambda) = \rho_2'(\lambda) + \frac{\tau_2^2(\lambda)\, \rho_1'(\lambda)}{1 - \rho_1'(\lambda)\, \rho_2(\lambda)}$$

c) *For triple glazing:*

$$\rho_i(\lambda) = \rho_3'(\lambda) + \frac{\tau_3^2(\lambda)\, \rho_2'(\lambda)[1 - \rho_2(\lambda)\rho_1'(\lambda)] + \tau_3^2(\lambda)\, \tau_2^2(\lambda)\rho_1'(\lambda)}{[1 - \rho_3(\lambda)\, \rho_2'(\lambda)].[1 - \rho_2(\lambda)\rho_1'(\lambda)] - \tau_2^2(\lambda)\, \rho_3(\lambda)\rho_1'(\lambda)}$$

For multiple glazing with more than three components, relationships similar to above expressions are found to calculate $\rho_{\text{i}}(\lambda)$ of such glazing from the spectral characteristics of the individual components.

5.6 Energy Design Considerations

5.6.1 *General*

Glass and glazing system design shall enhance daylighting into the building, improve the views to outdoor environments for the occupants, minimize the energy gains in hot climates, energy losses in cold climates and facilitate air movement in naturally ventilated spaces.

Fenestration, glazing and shading systems shall be designed by considering the climate characteristics, solar geometry, design sky conditions, orientation of the facade and building use. Effective design of the glazing system can minimize energy gains during summer and energy losses during winter. Height of the vision panel and the lintel height can be effectively adjusted to optimize the daylight penetration into the building.

5.6.2 *Design factors*

The following factors/components of a glazing system shall be considered during design for achieving energy efficiency:

a) Light transmittance and glare,

b) Thermal transmittance (solar heat gain co-efficient and U-value),

c) Fenestration size and placement,

d) Thermal properties of the frames,

e) Shading devices, and

f) Air infiltration.

5.6.3 *Analysis for Glazing System Selection*

5.6.3.1 *Building orientation and solar geometry analysis*

Optimal building orientation is a critical aspect for climate responsive design. Knowledge of the solar geometry at a site is essential for designing building facades to regulate energy and daylight transmission as well as reduce glare and overheating inside the building. Choice of glass and the shading system can considerably vary based on orientation of the facade and the solar geometry. A well oriented building maximises daylighting through its facades, thereby reducing the need for artificial lighting. Such building regulates the energy gains and losses through the facade, thereby minimizing thermal discomfort and cooling and heating energy demand.

5.6.3.2 *Solar insolation and shading analysis*

Design of glazing system is driven by the insolation levels on the facade, the desirable energy gains/losses and daylight requirements for a given building. Solar insolation varies with geographic location, orientation of the facade, time of the day and season. Direct solar incident radiation is the energy transmitted from the sun, which lies between the wavelength range of 250 nm and 2 500 nm. Solar radiation typically consists of 3 percent ultraviolet light, 42 percent visible light, and 55 percent infrared light. Infrared radiation is the major heat carrying radiation, followed by visible light. Analysing solar radiation helps to assess its impact on the building's elevations, allowing for a better understanding of how this influences the building's performance. Solar insolation and shading analysis are employed for determining optimum SHGC and U-value of glass, U-value of the frame and the design of shading system necessary for minimizing the energy gains and losses through the facade.

5.6.3.3 *Daylight analysis*

Daylight analysis is used to assess the penetration of natural light on the building floor plan or at the working plane level. A good lighting strategy involves optimizing the glazed area, increasing the daylight autonomy and thereby reducing the dependency on artificial lighting. Using a glass with optimal light transmission can go a long way in curtailing the dependence on artificial lighting. Additionally, the presence of natural light alleviates the claustrophobic feeling often associated with buildings that have limited glazing and outdoor views. Daylight calculations are conducted for overcast conditions to represent the worst-case scenario for outdoor lighting levels. Detailed methods for daylight analysis are provided in good practice [C-8(13)].

Any glass with enhanced energy performance will inevitably reduce the amount of daylight transmitted, even though it remains transparent for outward vision. The higher the demand for energy performance, the greater the compromise on daylight. Therefore, the selection of glass should begin by assessing the daylight requirements and deciding the optimum visible light transmittance (VLT). This approach helps narrow down the options, allowing for the selection of glass that provides the best performance for the specified VLT while also considering cost and aesthetics.

Floor plate geometry plays an important role as the daylight distribution will depend on the depth of the plate from the glazed area. Planforms incorporating courtyard and atrium have a great advantage of harnessing maximum daylight.

5.6.4 *Integrated Design Approach*

Glass and glazing system design shall duly consider the trade-offs in enhancing daylight availability, maximizing or minimizing the heat gains/losses, reduction in glare and improving views for the occupants. Table 12 provides the relation between glazing system parameters and different performance attributes.

Table 12 Relation Between Glazing System Parameters and Different Performance Attributes

(*Clause* 5.6.4)

Sl No.	Performance Attributes	Glazing System Parameters				
		VLT	U-Value	SHGC	Shading system	Fenestration size
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	Daylight	∝	–	ID	$\frac{1}{\propto}$	∝
ii)	View	∝	–	ID	$\frac{1}{\propto}$	∝
iii)	Heat transfer	–	∝	∝	$\frac{1}{\propto}$	∝
iv)	Ventilation	–	–	–	$\frac{1}{\propto}$	∝

∝: directly proportional; $\frac{1}{\propto}$: Inversely proportional; ID: Indirect relationship

NOTE — The effects may vary depending on the geographic location, orientation of the facade and on-site and off-site features. The factors also have inter-dependencies.

5.7 Window Design Guideline for Non-Conditioned/Mixed Mode Buildings

In non-conditioned spaces, windows typically use single-glazed units, as they are often opened to allow ventilation. In such buildings, shading devices play a critical role in the thermal performance of windows. Considerations for selecting type of window and the necessary design considerations for energy efficiency and natural ventilation may be made in accordance with the relevant guidelines/best practices (Handbook on 'Sustainability in Buildings').

NOTE — Air infiltration Class B in accordance with accepted standard [C-8(14)] is adequate for non-conditioned buildings.

6 STRUCTURAL PARAMETERS AND FIRE SAFETY

6.1 Determination of Appropriate Glass Thickness

6.1.1 *General*

This Section gives provisions to determine the minimum glass thickness to be used to resist the ultimate limit state design wind pressures. However, the location of the glass within the building require additional considerations, such as safety with respect to human which may impose either a minimum glass thickness above the basic calculation of this part or a provision for a specific glass type or both.

In addition to the provisions herein, the design requirements such as wind loads determined in accordance with good practice [C-8(15)] and the serviceability deflection requirement limit given in this Section shall have to be complied.

The provisions under **6** are applicable provided the following parameters are satisfied:

a) Ultimate limit state wind pressure shall not be greater than 10 kPa;

b) For laminated glass, the two sheets may be of equal or unequal thickness and the interlayer material is either polyvinyl butyral or an equivalent type of interlayer with a modulus of elasticity of about 24 MPa and a Poisson's ratio of 0.50 at 20 °C;

c) Design flexural tensile strength of glass depends upon the design strength obtained after applying a factor of safety of 2.5. The minimum design strength of normal glass for thickness up to 6 mm is 16.7 N/mm^2 and for thickness above 6 mm is 15.2 N/mm^2.

6.1.2 *Design Considerations*

The following design considerations shall be taken into account in determination of appropriate thickness of glass:

a) Maximum area of glass panel is restricted to 15 m^2;

b) Maximum span of glass panel is restricted to 4 m;

c) Aspect ratio of the glass panel should be greater than 1.5. If it is less than 1.5, next higher available thickness should be selected in order to reduce the stress level;

d) Factor of safety applied is 2.5 considering the variability in strength of glass;

e) Applicable to normal, reflective, laminated, tempered and insulating glass;

f) Applicable to rectangular panels properly secured;

g) Design minimum thickness of laminated glass will be the maximum value of thickness in accordance with Table 2 of accepted standard [C-8(6)]; and

h) The parameters listed in (a) to (g) are valid for calculating glass thickness using the empirical relationship in **6.1.3**. For glass sizes larger than those mentioned, any recognized method of analysis may be used for design, in consultation with the manufacturer and the expert in the field.

6.1.3 *Empirical Relationship*

Empirical relation between the wind pressure, area of the glass panel and the required glass thickness can be used:

$$P_{\text{net}}.A = 200T^{k} \text{ (for } T \leq 6 \text{ mm)}$$

$$P_{\text{net}}.A = 200T^{k} + 1\,900 \text{ (for } T > 6 \text{ mm)}$$

where

P_{net} = Net design wind pressure as per **6.1.4**, in N/m^2;

A = Area of glass panel, in m^2;

T = Standard nominal thickness (SNT) of glass from Table 13, in mm; and

k = Constant from the Table 13.

Table 13 Value of k for the Corresponding Standard Nominal Thickness of Float Glass

(*Clause* 6.1.3)

***T*, mm**	3	4	5	6	8	10	12	15	19	25
k	1.683	1.732	1.753	1.765	1.57	1.578	1.583	1.579	1.569	1.569

6.1.3.1 *Glass supported on two opposite sides*

a) Normal and laminated glass panels supported on two opposite sides can be designed using following empirical relations:

1) For $T \leq 6$ mm :

$$b = \frac{4.39\,T}{\sqrt{\left(\frac{P_{net}}{P_f}\right)}}$$

2) For $T > 6$ mm :

$$b = \frac{4.22\,T}{\sqrt{\left(\frac{P_{net}}{P_f}\right)}}$$

b) Tempered/toughened panel supported on two opposite sides can be designed using following empirical relations:

   1) For $T \leq 6$ mm :

$$b = \frac{3.268\,8\,T}{\sqrt{\left(\frac{P_{net}}{P_f}\right)}}$$

   2) For $T > 6$ mm :

$$b = \frac{2.906\,9\,T}{\sqrt{\left(\frac{P_{net}}{P_f}\right)}}$$

where

b = span, in m; and

P_f = strength factors as in Table 14.

For insulated glass, thickness of only one glass pane shall be considered. If the glass panes are of different thickness, the minimum of the two thicknesses shall be considered.

For laminated glass, the thickness of PVB has not been considered. The value to be used is:

T = Standard nominal thickness —Thickness of PVB.

6.1.3.2 For non-linear analysis, specialist literature may be consulted for various shapes, sizes, and types of support conditions of glass.

6.1.4 *Determination of Design Wind Pressure*

Net design wind pressure (P_{net}) is an important parameter governing the thickness of glass to be used in the window panels. It depends on factors as given below:

a) Location of the building (wind zone),

b) Construction patterns around buildings (terrain category),

c) Topography of site,

d) Building plan and height, etc.

Net design wind pressure (P_{net}), may be defined using the following equation:

$$P_{net} = p_z . C_p$$

where

C_p= net pressure coefficient as per good practice [C-8(15)]; and

p_z = design wind pressure as per good practice [C-8(15)], in N/m^2.
$= 0.6\ V_z^2$

$V_z = V_b.k_1.k_2.k_3.k_4$

where

V_b = basic wind speed based on location {as per Fig. 1 of good practice [C-8(15)]};

k_1 = risk co-efficient factor;

k_2 = terrain factor;

k_3 = topography factor;

k_4 = importance factor for the cyclonic region; and

V_z = design wind speed, in m/s.

6.1.4.1 *Laminated/tempered/insulating glass*

To determine the thickness of laminated/ tempered/ insulating glass, the design wind pressure P_{net} is modified by dividing it with the strength or pressure factor P_f, dependent on the type of glass. The values of the P_f are given in Table 14.

Using the modified values of P_{net}, the thickness of other glass types can be obtained in accordance with **6.1.3**.

Table 14 Strength Factor, P_f

[*Clauses* 6.1.3.1(b), 6.1.4.1, 6.3.5 *and* E-1.1.1]

Sl No. (1)	**Glass Type** (2)	**P_f** (3)
i)	Normal (Annealed)	1.00
ii)	Laminated	0.80
iii)	Tempered	2.50
iv)	Insulated	1.50
v)	Heat strengthened	1.60
vi)	Wired	0.50

6.1.5 *Aspect Ratio* (AR_{max})

The design of the thickness using empirical relation in accordance with **6.1.3** shall be valid up to a limiting aspect ratio AR_{max}. The value of AR_{max} for different thickness (T) of glass is given in Table 15.

Table 15 Thickness and Corresponding AR_{max} Values (*Clause* 6.1.5 *and* E-1.1.1)

T, in mm	3	4	5	6	8	10	12	15	19	25
AR**max**	7.3	6.8	6.5	6.3	5.9	4.9	4.3	3.8	3.3	2.9

6.1.6 *Seismic Design*

6.1.6.1 *Seismic load* (*EQ*)

The design for seismic forces shall be performed in steps to establish upper and lower bound force and movement response parameters. In addition, the response of the structure sensitive to certain parameters such as the damping and the stiffness of the support points may be evaluated.

The principal design criteria for the seismic design are,

- a) Structure will remain elastic during the design seismic event.
- b) ‘Hangers’ will stiffen the cantilever ‘tree’ structure.
- c) ‘Hangers’ will not go slack.

6.1.6.2 *Architectural elements and utilities*

Depending on response sensitivity, architectural elements and utilities can be classified as deformation sensitive, acceleration sensitive, or both deformation and acceleration sensitive. Table 16 classifies non-structural elements according to their response sensitivity.

Table 16 Response Sensitivity of Architectural Component

(*Clause* 6.1.6.2)

Sl No.	Component	Sensitivity	
		Acceleration Sensitive	Deformation Sensitive
(1)	(2)	(3)	(4)
i)	Exterior skin:		
	a) Adhered veneer	S	P
	b) Anchored veneer	S	P
	c) Glass blocks	S	P
	d) Prefabricated panel	S	P
	e) Glazing system	S	P
ii)	Partitions:		
	a) Heavy	S	P
	b) Light	S	P
iii)	Interior veneers:		
	a) Stone, including marble	S	P
	b) Ceramic tile	S	P
iv)	Parapets and appendages	P	—
v)	Canopies and marquees	P	—
vi)	Stairs	P	S

NOTES

1 P = Primary response
2 S = Secondary response

6.1.6.3 *Design seismic force*

Design seismic force on the architectural elements and utilities shall be calculated as per Part C ‘Structural Design, Section 1 Loads and Load Effects’ of this NBCS.

6.1.6.4 *Seismic relative displacement*

a) For two connection points on the same structure *A*, one at a height h_x, and other at a height h_y, seismic relative displacement shall be determined as:

$$D_p = \delta_{xA} - \delta_{yA}$$

D_p is not required to be taken as greater than $R(h_x - h_y)\frac{\Delta_{aA}}{h_{sx}}$

where

δ_{xA} = deflection at building level x of structure A due to design seismic load determined by elastic analysis, and multiplied by response reduction factor R of the building as per Table 9 of good practice [C-8(16)];

δ_{yA} = deflection at building level y of structure A due to design seismic load determined by elastic analysis, and multiplied by response reduction factor R of the building as per Table 9 of good practice [C-8(16)];

h_x = height of level x to which upper connection point is attached;

h_y = height of level y to which lower connection point is attached;

Δ_{aA} = allowable storey drift for structure A calculated as per **7.11.1.1** of good practice [C-8(16)]; and

h_{sx} = storey height below level x.

b) For two connection points on separate structures A and B, or separate structural systems, one at height, h_x and the other at a height, h_y , D_p shall be determined as:

$$D_p = |\delta_{xA}| + |\delta_{yA}|$$

D_p is not required to be taken as greater than

$$R\left(h_x \frac{\Delta_{aA}}{h_{sx}} + h_y \frac{\Delta_{aB}}{h_{sx}}\right)$$

where

δ_{yB} = deflection at building level y of structure *B* due to design seismic load determined by elastic analysis, and multiplied by response reduction factor, R, of the building as per Table 9 of good practice [C-8(16)]; and

Δ_{aB} = allowable storey drift for structure *B* calculated as per **7.11.1.1** of good practice [C-8(16)].

6.1.7 *Imposed Loads*

The uniform distributed load and point load is to be considered based on application and is to be selected in accordance with good practice [C-8(17)]. Appropriate uniform distributed load (UDL) and concentrated load are selected in accordance to good practice [C-8(17)] based on nature of building (for example, residential, institutional, industrial building, etc) and nature of activity under each building type.

6.1.8 *Load Contribution*

6.1.8.1 *Wind load*

The wind load is the effect of wind pressure which is dependent on the location, building height, topography and ground roughness factor. The wind speed is taken from good practice [C-8(15)] for the geographic location.

6.1.8.2 *Dead load*

In case of inclined sloped glazing, the dead weight of the glazing should be considered. In case of component of sloped glazing, the following corresponding component of the total glazing may be used:

a) Point load shall be applied as a uniformly distributed load over a circular area of 0.01 m^2;

b) For a glazed panel supported on all edges, the point loading shall be applied at the centre;

c) For free glazing edges, the point load shall be applied adjacent to the centre of the free edge; and

d) Ultimate limit state design wind pressure shall not be greater than 1.2 kPa. For greater design wind pressures, the glass shall be separately designed to withstand wind loading in accordance with **6.1.4**.

6.1.9 *Reference Chart Relating Wind Load, Maximum Allowable Area for a Thickness of Glass with Respect to Terrain Category*

Table 17 to Table 25 provides relation between design wind pressure and maximum allowable area for a thickness of glass with respect to specific terrain category. User may select the type of glass depending on the support conditions.

Specialist literature may be consulted for use of non-linear analysis.

NOTE — Specialist literature shall mean any national/international publication, codes or peer reviewed research papers on the topic.

The deflection at the centre of glass pane can be calculated using the formula in accordance to Annex D.

Typical model calculation to calculate thickness and determine wind load and deflection at the centre of the glazing is given at Annex E.

Table 17 Maximum Areas for Annealed Glass Fixed on All Four Sides, m^2

(*Clauses* 6.1.9 *and* 6.3.6.1)

Sl No.	**Design Wind Pressure** N/m^2	**Nominal Thickness of Glass, *T*** mm								
		3	4	5	6	8	10	12	15	19
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
i)	500	2.13	3.86	6.03	8.63	13.06	15.00	15.00	15.00	15.00
ii)	550	1.93	3.51	5.48	7.85	11.88	15.00	15.00	15.00	15.00
iii)	600	1.77	3.21	5.02	7.19	10.89	14.61	15.00	15.00	15.00
iv)	650	1.64	2.97	4.64	6.64	10.05	13.48	15.00	15.00	15.00
v)	700	1.52	2.75	4.31	6.17	9.33	12.52	15.00	15.00	15.00
vi)	750	1.42	2.57	4.02	5.76	8.71	11.69	14.75	15.00	15.00
vii)	800	1.33	2.41	3.77	5.40	8.16	10.96	13.83	15.00	15.00
viii)	850	1.25	2.27	3.55	5.08	7.68	10.31	13.01	15.00	15.00
ix)	900	1.18	2.14	3.35	4.80	7.26	9.74	12.29	15.00	15.00
x)	950	1.12	2.03	3.17	4.54	6.88	9.23	11.64	15.00	15.00
xi)	1 000	1.06	1.93	3.01	4.32	6.53	8.76	11.06	15.00	15.00
xii)	1 050	1.01	1.84	2.87	4.11	6.22	8.35	10.53	14.38	15.00
xiii)	1 100	0.97	1.75	2.74	3.92	5.94	7.97	10.06	13.73	15.00
xiv)	1 150	0.93	1.68	2.62	3.75	5.68	7.62	9.62	13.13	15.00

Table 17 (*Continued*)

Sl No.	**Design Wind Pressure** N/m^2	**Nominal Thickness of Glass, *T*** mm								
		3	4	5	6	8	10	12	15	19
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
xv)	1 200	0.89	1.61	2.51	3.60	5.44	7.30	9.22	12.58	15.00
xvi)	1 250	0.85	1.54	2.41	3.45	5.23	7.01	8.85	12.08	15.00
xvii)	1 300	0.82	1.48	2.32	3.32	5.02	6.74	8.51	11.61	15.00
xviii)	1 350	0.79	1.43	2.23	3.20	4.84	6.49	8.19	11.18	14.98
xix)	1 400	0.76	1.38	2.15	3.08	4.67	6.26	7.90	10.78	14.44
xx)	1 450	0.73	1.33	2.08	2.98	4.50	6.04	7.63	10.41	13.95
xxi)	1 500	0.71	1.29	2.01	2.88	4.35	5.84	7.37	10.07	13.48
xxii)	1 550	0.69	1.24	1.94	2.78	4.21	5.65	7.14	9.74	13.05
xxiii)	1 600	0.67	1.21	1.88	2.70	4.08	5.48	6.91	9.44	12.64
xxiv)	1 650	0.64	1.17	1.83	2.62	3.96	5.31	6.70	9.15	12.25
xxv)	1 700	0.63	1.13	1.77	2.54	3.84	5.16	6.51	8.88	11.89
xxvi)	1 750	0.61	1.10	1.72	2.47	3.73	5.01	6.32	8.63	11.55
xxvii)	1 800	0.59	1.07	1.67	2.40	3.63	4.87	6.14	8.39	11.23
xxviii)	1 850	0.58	1.04	1.63	2.33	3.53	4.74	5.98	8.16	10.93
xxix)	1 900	0.56	1.01	1.59	2.27	3.44	4.61	5.82	7.95	10.64
xxx)	1 950	0.55	0.99	1.55	2.21	3.35	4.49	5.67	7.74	10.37
xxxi)	2 000	0.53	0.96	1.51	2.16	3.27	4.38	5.53	7.55	10.11
xxxii)	2 050	0.52	0.94	1.47	2.11	3.19	4.28	5.40	7.36	9.86
xxxiii)	2 100	0.51	0.92	1.44	2.06	3.11	4.17	5.27	7.19	9.63
xxxiv)	2 150	0.49	0.90	1.40	2.01	3.04	4.08	5.14	7.02	9.40
xxxv)	2 200	0.48	0.88	1.37	1.96	2.97	3.98	5.03	6.86	9.19
xxxvi)	2 250	0.47	0.86	1.34	1.92	2.90	3.90	4.92	6.71	8.99
xxxvii)	2 300	0.46	0.84	1.31	1.88	2.84	3.81	4.81	6.56	8.79
xxxviii)	2 350	0.45	0.82	1.28	1.84	2.78	3.73	4.71	6.42	8.60
xxxix)	2 400	0.44	0.80	1.26	1.80	2.72	3.65	4.61	6.29	8.43
xl)	2 450	0.43	0.79	1.23	1.76	2.67	3.58	4.51	6.16	8.25
xli)	2 500	0.43	0.77	1.21	1.73	2.61	3.51	4.42	6.04	8.09
xlii)	2 550	0.42	0.76	1.18	1.69	2.56	3.44	4.34	5.92	7.93
xliii)	2 600	0.41	0.74	1.16	1.66	2.51	3.37	4.25	5.81	7.78
xliv)	2 650	0.40	0.73	1.14	1.63	2.46	3.31	4.17	5.70	7.63
xlv)	2 700	0.39	0.71	1.12	1.60	2.42	3.25	4.10	5.59	7.49
xlvi)	2 750	0.39	0.70	1.10	1.57	2.38	3.19	4.02	5.49	7.35
xlvii)	2 800	0.38	0.69	1.08	1.54	2.33	3.13	3.95	5.39	7.22

Table 17 (*Continued*)

Sl No.	Design Wind Pressure N/m^2	Nominal Thickness of Glass, *T* mm								
		3	4	5	6	8	10	12	15	19
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
xlviii)	2 850	0.37	0.68	1.06	1.51	2.29	3.08	3.88	5.30	7.09
xlix)	2 900	0.37	0.66	1.04	1.49	2.25	3.02	3.81	5.21	6.97
l)	2 950	0.36	0.65	1.02	1.46	2.21	2.97	3.75	5.12	6.85
li)	3 000	0.35	0.64	1.00	1.44	2.18	2.92	3.69	5.03	6.74
lii)	3 050	0.35	0.63	0.99	1.42	2.14	2.87	3.63	4.95	6.63
liii)	3 100	0.34	0.62	0.97	1.39	2.11	2.83	3.57	4.87	6.52
liv)	3 150	0.34	0.61	0.96	1.37	2.07	2.78	3.51	4.79	6.42
lv)	3 200	0.33	0.60	0.94	1.35	2.04	2.74	3.46	4.72	6.32
lvi)	3 250	0.33	0.59	0.93	1.33	2.01	2.70	3.40	4.65	6.22
lvii)	3 300	0.32	0.58	0.91	1.31	1.98	2.66	3.35	4.58	6.13
lviii)	3 350	0.32	0.58	0.90	1.29	1.95	2.62	3.30	4.51	6.04
lix)	3 400	0.31	0.57	0.89	1.27	1.92	2.58	3.25	4.44	5.95
lx)	3 450	0.31	0.56	0.87	1.25	1.89	2.54	3.21	4.38	5.86
lxi)	3 500	0.30	0.55	0.86	1.23	1.87	2.50	3.16	4.31	5.78
lxii)	3 550	0.30	0.54	0.85	1.22	1.84	2.47	3.12	4.25	5.70
lxiii)	3 600	0.30	0.54	0.84	1.20	1.81	2.43	3.07	4.19	5.62
lxiv)	3 650	0.29	0.53	0.83	1.18	1.79	2.40	3.03	4.14	5.54
lxv)	3 700	0.29	0.52	0.81	1.17	1.77	2.37	2.99	4.08	5.47
lxvi)	3 750	0.28	0.51	0.80	1.15	1.74	2.34	2.95	4.03	5.39
lxvii)	3 800	0.28	0.51	0.79	1.14	1.72	2.31	2.91	3.97	5.32
lxviii)	3 850	0.28	0.50	0.78	1.12	1.70	2.28	2.87	3.92	5.25
lxix)	3 900	0.27	0.49	0.77	1.11	1.67	2.25	2.84	3.87	5.18
lxx)	3 950	0.27	0.49	0.76	1.09	1.65	2.22	2.80	3.82	5.12
lxxi)	4 000	0.27	0.48	0.75	1.08	1.63	2.19	2.77	3.77	5.06
lxxii)	4 050	0.26	0.48	0.74	1.07	1.61	2.16	2.73	3.73	4.99
lxxiii)	4 100	0.26	0.47	0.74	1.05	1.59	2.14	2.70	3.68	4.93
lxxiv)	4 150	0.26	0.46	0.73	1.04	1.57	2.11	2.67	3.64	4.87
lxxv)	4 200	0.25	0.46	0.72	1.03	1.56	2.09	2.63	3.59	4.81
lxxvi)	4 250	0.25	0.45	0.71	1.02	1.54	2.06	2.60	3.55	4.76
lxxvii)	4 300	0.25	0.45	0.70	1.00	1.52	2.04	2.57	3.51	4.70
lxxviii)	4 350	0.24	0.44	0.69	0.99	1.50	2.01	2.54	3.47	4.65
lxxix)	4 400	0.24	0.44	0.69	0.98	1.48	1.99	2.51	3.43	4.60
lxxx)	4 450	0.24	0.43	0.68	0.97	1.47	1.97	2.49	3.39	4.54

Table 17 (*Concluded*)

Sl No.	Design Wind Pressure N/m^2	Nominal Thickness of Glass, *T* mm								
		3	4	5	6	8	10	12	15	19
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
lxxxi)	4 500	0.24	0.43	0.67	0.96	1.45	1.95	2.46	3.36	4.49
lxxxii)	4 550	0.23	0.42	0.66	0.95	1.44	1.93	2.43	3.32	4.44
lxxxiii)	4 600	0.23	0.42	0.66	0.94	1.42	1.91	2.40	3.28	4.40
lxxxiv)	4 650	0.23	0.41	0.65	0.93	1.40	1.88	2.38	3.25	4.35
lxxxv)	4 700	0.23	0.41	0.64	0.92	1.39	1.86	2.35	3.21	4.30
lxxxvi)	4 750	0.22	0.41	0.63	0.91	1.38	1.85	2.33	3.18	4.26
lxxxvii)	4 800	0.22	0.40	0.63	0.90	1.36	1.83	2.30	3.15	4.21
lxxxviii)	4 850	0.22	0.40	0.62	0.89	1.35	1.81	2.28	3.11	4.17
lxxxix)	4 900	0.22	0.39	0.62	0.88	1.33	1.79	2.26	3.08	4.13
xc)	4 950	0.21	0.39	0.61	0.87	1.32	1.77	2.23	3.05	4.08
xci)	5 000	0.21	0.39	0.60	0.86	1.31	1.75	2.21	3.02	4.04
xcii)	Maximum aspect ratio	7.3	6.8	6.5	6.3	5.9	4.9	4.3	3.8	3.3

Table 18 Maximum Areas for Laminated Glass Fixed on All Four Sides, m^2

(*Clauses* 6.1.9, 6.3.5 *and* 6.3.6.1)

Sl No.	Design Wind Pressure N/m^2	Nominal Thickness of Laminated Glass, *T* mm					
		5.38	6.38	8.38	10.38	12.38	16.38
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	500	4.47	6.28	10.45	14.02	15.00	15.00
ii)	550	4.06	5.71	9.50	12.75	15.00	15.00
iii)	600	3.72	5.23	8.71	11.69	15.00	15.00
iv)	650	3.44	4.83	8.04	10.79	13.93	15.00
v)	700	3.19	4.48	7.46	10.02	12.94	15.00
vi)	750	2.98	4.19	6.97	9.35	12.08	15.00
vii)	800	2.79	3.92	6.53	8.76	11.32	15.00
viii)	850	2.63	3.69	6.15	8.25	10.66	15.00
ix)	900	2.48	3.49	5.81	7.79	10.06	14.21

Table 18 (*Continued*)

Sl No.	Design Wind Pressure N/m^2	Nominal Thickness of Laminated Glass, *T* mm					
		5.38	6.38	8.38	10.38	12.38	16.38
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
x)	950	2.35	3.30	5.50	7.38	9.53	13.46
xi)	1 000	2.23	3.14	5.23	7.01	9.06	12.79
xii)	1 050	2.13	2.99	4.98	6.68	8.63	12.18
xiii)	1 100	2.03	2.85	4.75	6.37	8.23	11.63
xiv)	1 150	1.94	2.73	4.54	6.10	7.88	11.12
xv)	1 200	1.86	2.62	4.35	5.84	7.55	10.66
xvi)	1 250	1.79	2.51	4.18	5.61	7.25	10.23
xvii)	1 300	1.72	2.41	4.02	5.39	6.97	9.84
xviii)	1 350	1.66	2.33	3.87	5.19	6.71	9.47
xix)	1 400	1.60	2.24	3.73	5.01	6.47	9.14
xx)	1 450	1.54	2.16	3.60	4.84	6.25	8.82
xxi)	1 500	1.49	2.09	3.48	4.67	6.04	8.53
xxii)	1 550	1.44	2.03	3.37	4.52	5.84	8.25
xxiii)	1 600	1.40	1.96	3.27	4.38	5.66	7.99
xxiv)	1 650	1.35	1.90	3.17	4.25	5.49	7.75
xxv)	1 700	1.31	1.85	3.07	4.12	5.33	7.52
xxvi)	1 750	1.28	1.79	2.99	4.01	5.18	7.31
xxvii)	1 800	1.24	1.74	2.90	3.90	5.03	7.11
xxviii)	1 850	1.21	1.70	2.82	3.79	4.90	6.91
xxix)	1 900	1.18	1.65	2.75	3.69	4.77	6.73
xxx)	1 950	1.15	1.61	2.68	3.60	4.64	6.56
xxxi)	2 000	1.12	1.57	2.61	3.51	4.53	6.40
xxxii)	2 050	1.09	1.53	2.55	3.42	4.42	6.24
xxxiii)	2 100	1.06	1.49	2.49	3.34	4.31	6.09
xxxiv)	2 150	1.04	1.46	2.43	3.26	4.21	5.95
xxxv)	2 200	1.02	1.43	2.38	3.19	4.12	5.81
xxxvi)	2 250	0.99	1.40	2.32	3.12	4.03	5.68
xxxvii)	2 300	0.97	1.36	2.27	3.05	3.94	5.56

Table 18 (*Continued*)

Sl No.	**Design Wind Pressure** N/m^2	**Nominal Thickness of Laminated Glass, *T*** mm					
		5.38	6.38	8.38	10.38	12.38	16.38
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
xxxviii)	2 350	0.95	1.34	2.22	2.98	3.85	5.44
xxxix)	2 400	0.93	1.31	2.18	2.92	3.77	5.33
xl)	2 450	0.91	1.28	2.13	2.86	3.70	5.22
xli)	2 500	0.89	1.26	2.09	2.80	3.62	5.12
xlii)	2550	0.88	1.23	2.05	2.75	3.55	5.02
xliii)	2 600	0.86	1.21	2.01	2.70	3.48	4.92
xliv)	2 650	0.84	1.18	1.97	2.65	3.42	4.83
xlv)	2 700	0.83	1.16	1.94	2.60	3.35	4.74
xlvi)	2 750	0.81	1.14	1.90	2.55	3.29	4.65
xlvii)	2 800	0.80	1.12	1.87	2.50	3.23	4.57
xlviii)	2 850	0.78	1.10	1.83	2.46	3.18	4.49
xlix)	2 900	0.77	1.08	1.80	2.42	3.12	4.41
l)	2 950	0.76	1.06	1.77	2.38	3.07	4.34
li)	3 000	0.74	1.05	1.74	2.34	3.02	4.26
lii)	3 050	0.73	1.03	1.71	2.30	2.97	4.19
liii)	3 100	0.72	1.01	1.69	2.26	2.92	4.13
liv)	3 150	0.71	1.00	1.66	2.23	2.88	4.06
lv)	3 200	0.70	0.98	1.63	2.19	2.83	4.00
lvi)	3 250	0.69	0.97	1.61	2.16	2.79	3.94
lvii)	3 300	0.68	0.95	1.58	2.12	2.74	3.88
lviii)	3 350	0.67	0.94	1.56	2.09	2.70	3.82
lix)	3 400	0.66	0.92	1.54	2.06	2.66	3.76
lx)	3 450	0.65	0.91	1.51	2.03	2.63	3.71
lxi)	3 500	0.64	0.90	1.49	2.00	2.59	3.65
lxii)	3 550	0.63	0.88	1.47	1.98	2.55	3.60
lxiii)	3 600	0.62	0.87	1.45	1.95	2.52	3.55
lxiv)	3 650	0.61	0.86	1.43	1.92	2.48	3.50
lxv)	3 700	0.60	0.85	1.41	1.90	2.45	3.46

Table 18 (*Concluded*)

Sl No.	Design Wind Pressure N/m^2	Nominal Thickness of Laminated Glass, *T* mm					
		5.38	6.38	8.38	10.38	12.38	16.38
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
lxvi)	3 750	0.60	0.84	1.39	1.87	2.42	3.41
lxvii)	3 800	0.59	0.83	1.38	1.85	2.38	3.37
lxviii)	3 850	0.58	0.82	1.36	1.82	2.35	3.32
lxix)	3 900	0.57	0.80	1.34	1.80	2.32	3.28
lxx)	3 950	0.57	0.79	1.32	1.78	2.29	3.24
lxxi)	4 000	0.56	0.78	1.31	1.75	2.26	3.20
lxxii)	4 050	0.55	0.78	1.29	1.73	2.24	3.16
lxxiii)	4 100	0.55	0.77	1.27	1.71	2.21	3.12
lxxiv)	4 150	0.54	0.76	1.26	1.69	2.18	3.08
lxxv)	4 200	0.53	0.75	1.24	1.67	2.16	3.05
lxxvi)	4 250	0.53	0.74	1.23	1.65	2.13	3.01
lxxvii)	4 300	0.52	0.73	1.22	1.63	2.11	2.97
lxxviii)	4 350	0.51	0.72	1.20	1.61	2.08	2.94
lxxix)	4 400	0.51	0.71	1.19	1.59	2.06	2.91
lxxx)	4 450	0.50	0.71	1.17	1.58	2.04	2.87
lxxxi)	4 500	0.50	0.70	1.16	1.56	2.01	2.84
lxxxii)	4 550	0.49	0.69	1.15	1.54	1.99	2.81
lxxxiii)	4 600	0.49	0.68	1.14	1.52	1.97	2.78
lxxxiv)	4 650	0.48	0.68	1.12	1.51	1.95	2.75
lxxxv)	4 700	0.48	0.67	1.11	1.49	1.93	2.72
lxxxvi)	4 750	0.47	0.66	1.10	1.48	1.91	2.69
lxxxvii)	4 800	0.47	0.65	1.09	1.46	1.89	2.66
lxxxviii)	4 850	0.46	0.65	1.08	1.45	1.87	2.64
lxxxix)	4 900	0.46	0.64	1.07	1.43	1.85	2.61
xc)	4 950	0.45	0.63	1.06	1.42	1.83	2.58
xci)	5 000	0.45	0.63	1.05	1.40	1.81	2.56
xcii)	Maximum aspect ratio	6.5	6.2	5.7	4.8	4.3	3.6

Table 19 Maximum Areas for Tempered Glass Fixed on All Four Sides, m^2

(*Clauses* 6.1.9 *and* 6.3.6.1)

Sl No.	**Design Wind Pressure** N/m^2	**Nominal Thickness of Tempered Glass, *T*** mm								
		3	4	5	6	8	10	12	15	19
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
i)	500	5.32	9.64	15.00	15.00	15.00	15.00	15.00	15.00	15.00
ii)	550	4.84	8.76	13.70	15.00	15.00	15.00	15.00	15.00	15.00
iii)	600	4.43	8.03	12.56	15.00	15.00	15.00	15.00	15.00	15.00
iv)	650	4.09	7.42	11.59	15.00	15.00	15.00	15.00	15.00	15.00
v)	700	3.80	6.89	10.77	15.00	15.00	15.00	15.00	15.00	15.00
vi)	750	3.55	6.43	10.05	14.39	15.00	15.00	15.00	15.00	15.00
vii)	800	3.33	6.03	9.42	13.49	15.00	15.00	15.00	15.00	15.00
viii)	850	3.13	5.67	8.87	12.70	15.00	15.00	15.00	15.00	15.00
ix)	900	2.96	5.36	8.37	11.99	15.00	15.00	15.00	15.00	15.00
x)	950	2.80	5.07	7.93	11.36	15.00	15.00	15.00	15.00	15.00
xi)	1 000	2.66	4.82	7.54	10.79	15.00	15.00	15.00	15.00	15.00
xii)	1 050	2.53	4.59	7.18	10.28	15.00	15.00	15.00	15.00	15.00
xiii)	1 100	2.42	4.38	6.85	9.81	14.84	15.00	15.00	15.00	15.00
xiv)	1 150	2.31	4.19	6.55	9.38	14.20	15.00	15.00	15.00	15.00
xv)	1 200	2.22	4.02	6.28	8.99	13.61	15.00	15.00	15.00	15.00
xvi)	1 250	2.13	3.86	6.03	8.63	13.06	15.00	15.00	15.00	15.00
xvii)	1 300	2.05	3.71	5.80	8.30	12.56	15.00	15.00	15.00	15.00
xviii)	1 350	1.97	3.57	5.58	7.99	12.10	15.00	15.00	15.00	15.00
xix)	1 400	1.90	3.44	5.38	7.71	11.66	15.00	15.00	15.00	15.00
xx)	1 450	1.83	3.32	5.20	7.44	11.26	15.00	15.00	15.00	15.00
xxi)	1 500	1.77	3.21	5.02	7.19	10.89	14.61	15.00	15.00	15.00
xxii)	1 550	1.72	3.11	4.86	6.96	10.53	14.14	15.00	15.00	15.00
xxiii)	1 600	1.66	3.01	4.71	6.74	10.21	13.69	15.00	15.00	15.00
xxiv)	1 650	1.61	2.92	4.57	6.54	9.90	13.28	15.00	15.00	15.00
xxv)	1 700	1.56	2.84	4.43	6.35	9.61	12.89	15.00	15.00	15.00
xxvi)	1 750	1.52	2.75	4.31	6.17	9.33	12.52	15.00	15.00	15.00
xxvii)	1 800	1.48	2.68	4.19	6.00	9.07	12.17	15.00	15.00	15.00
xxviii)	1 850	1.44	2.61	4.07	5.83	8.83	11.84	14.95	15.00	15.00

Table 19 (*Continued*)

Sl No.	Design Wind Pressure N/m^2	Nominal Thickness of Tempered Glass, *T* mm								
		3	4	5	6	8	10	12	15	19
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
xxix)	1 900	1.40	2.54	3.97	5.68	8.59	11.53	14.55	15.00	15.00
xxx)	1 950	1.36	2.47	3.86	5.53	8.37	11.24	14.18	15.00	15.00
xxxi)	2 000	1.33	2.41	3.77	5.40	8.16	10.96	13.83	15.00	15.00
xxxii)	2 050	1.30	2.35	3.68	5.26	7.97	10.69	13.49	15.00	15.00
xxxiii)	2 100	1.27	2.30	3.59	5.14	7.78	10.43	13.17	15.00	15.00
xxxiv)	2 150	1.24	2.24	3.51	5.02	7.59	10.19	12.86	15.00	15.00
xxxv)	2 200	1.21	2.19	3.43	4.91	7.42	9.96	12.57	15.00	15.00
xxxvi)	2 250	1.18	2.14	3.35	4.80	7.26	9.74	12.29	15.00	15.00
xxxvii)	2 300	1.16	2.10	3.28	4.69	7.10	9.53	12.02	15.00	15.00
xxxviii)	2 350	1.13	2.05	3.21	4.59	6.95	9.32	11.77	15.00	15.00
xxxix)	2 400	1.11	2.01	3.14	4.50	6.80	9.13	11.52	15.00	15.00
xl)	2 450	1.09	1.97	3.08	4.40	6.66	8.94	11.29	15.00	15.00
xli)	2 500	1.06	1.93	3.01	4.32	6.53	8.76	11.06	15.00	15.00
xlii)	2 550	1.04	1.89	2.96	4.23	6.40	8.59	10.84	14.80	15.00
xliii)	2 600	1.02	1.85	2.90	4.15	6.28	8.43	10.64	14.52	15.00
xliv)	2 650	1.00	1.82	2.84	4.07	6.16	8.27	10.43	14.24	15.00
xlv)	2 700	0.99	1.79	2.79	4.00	6.05	8.12	10.24	13.98	15.00
xlvi)	2 750	0.97	1.75	2.74	3.92	5.94	7.97	10.06	13.73	15.00
xlvii)	2 800	0.95	1.72	2.69	3.85	5.83	7.83	9.88	13.48	15.00
xlviii)	2 850	0.93	1.69	2.64	3.79	5.73	7.69	9.70	13.24	15.00
xlix)	2 900	0.92	1.66	2.60	3.72	5.63	7.56	9.54	13.02	15.00
l)	2 950	0.90	1.63	2.55	3.66	5.54	7.43	9.37	12.79	15.00
li)	3 000	0.89	1.61	2.51	3.60	5.44	7.30	9.22	12.58	15.00
lii)	3 050	0.87	1.58	2.47	3.54	5.35	7.18	9.07	12.38	15.00
liii)	3 100	0.86	1.56	2.43	3.48	5.27	7.07	8.92	12.18	15.00
liv)	3 150	0.84	1.53	2.39	3.43	5.18	6.96	8.78	11.98	15.00
lv)	3 200	0.83	1.51	2.36	3.37	5.10	6.85	8.64	11.79	15.00
lvi)	3 250	0.82	1.48	2.32	3.32	5.02	6.74	8.51	11.61	15.00
lvii)	3 300	0.81	1.46	2.28	3.27	4.95	6.64	8.38	11.44	15.00
lviii)	3 350	0.79	1.44	2.25	3.22	4.87	6.54	8.25	11.27	15.00

Table 19 (*Continued*)

Sl No.	Design Wind Pressure N/m^2	Nominal Thickness of Tempered Glass, *T* mm								
		3	4	5	6	8	10	12	15	19
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
lix)	3 400	0.78	1.42	2.22	3.17	4.80	6.44	8.13	11.10	14.87
lx)	3 450	0.77	1.40	2.18	3.13	4.73	6.35	8.02	10.94	14.65
lxi)	3 500	0.76	1.38	2.15	3.08	4.67	6.26	7.90	10.78	14.44
lxii)	3 550	0.75	1.36	2.12	3.04	4.60	6.17	7.79	10.63	14.24
lxiii)	3 600	0.74	1.34	2.09	3.00	4.54	6.09	7.68	10.48	14.04
lxiv)	3 650	0.73	1.32	2.06	2.96	4.47	6.00	7.58	10.34	13.85
lxv)	3 700	0.72	1.30	2.04	2.92	4.41	5.92	7.47	10.20	13.66
lxvi)	3 750	0.71	1.29	2.01	2.88	4.35	5.84	7.37	10.07	13.48
lxvii)	3 800	0.70	1.27	1.98	2.84	4.30	5.77	7.28	9.93	13.30
lxviii)	3 850	0.69	1.25	1.96	2.80	4.24	5.69	7.18	9.80	13.13
lxix)	3 900	0.68	1.24	1.93	2.77	4.19	5.62	7.09	9.68	12.96
lxx)	3 950	0.67	1.22	1.91	2.73	4.13	5.55	7.00	9.56	12.80
lxxi)	4 000	0.67	1.21	1.88	2.70	4.08	5.48	6.91	9.44	12.64
lxxii)	4 050	0.66	1.19	1.86	2.66	4.03	5.41	6.83	9.32	12.48
lxxiii)	4 100	0.65	1.18	1.84	2.63	3.98	5.34	6.74	9.21	12.33
lxxiv)	4 150	0.64	1.16	1.82	2.60	3.93	5.28	6.66	9.09	12.18
lxxv)	4 200	0.63	1.15	1.79	2.57	3.89	5.22	6.58	8.99	12.04
lxxvi)	4 250	0.63	1.13	1.77	2.54	3.84	5.16	6.51	8.88	11.89
lxxvii)	4 300	0.62	1.12	1.75	2.51	3.80	5.10	6.43	8.78	11.76
lxxviii)	4 350	0.61	1.11	1.73	2.48	3.75	5.04	6.36	8.68	11.62
lxxix)	4 400	0.60	1.10	1.71	2.45	3.71	4.98	6.28	8.58	11.49
lxxx)	4 450	0.60	1.08	1.69	2.43	3.67	4.92	6.21	8.48	11.36
lxxxi)	4 500	0.59	1.07	1.67	2.40	3.63	4.87	6.14	8.39	11.23
lxxxii)	4 550	0.58	1.06	1.66	2.37	3.59	4.82	6.08	8.30	11.11
lxxxiii)	4 600	0.58	1.05	1.64	2.35	3.55	4.76	6.01	8.21	10.99
lxxxiv)	4 650	0.57	1.04	1.62	2.32	3.51	4.71	5.95	8.12	10.87
lxxxv)	4 700	0.57	1.03	1.60	2.30	3.47	4.66	5.88	8.03	10.76
lxxxvi)	4 750	0.56	1.01	1.59	2.27	3.44	4.61	5.82	7.95	10.64
lxxxvii)	4 800	0.55	1.00	1.57	2.25	3.40	4.56	5.76	7.86	10.53
lxxxviii)	4 850	0.55	0.99	1.55	2.23	3.37	4.52	5.70	7.78	10.42

Table 19 (*Concluded*)

Sl No.	Design Wind Pressure N/m^2	Nominal Thickness of Tempered Glass, *T* mm								
		3	4	5	6	8	10	12	15	19
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
lxxxix)	4 900	0.54	0.98	1.54	2.20	3.33	4.47	5.64	7.70	10.32
xc)	4 950	0.54	0.97	1.52	2.18	3.30	4.43	5.59	7.63	10.21
xci)	5 000	0.53	0.96	1.51	2.16	3.27	4.38	5.53	7.55	10.11
xcii)	Maximum aspect ratio	7.3	6.8	6.5	6.3	5.9	4.9	4.3	3.8	3.3

Table 20 Maximum Areas for Insulating Glass Fixed on All Four Sides, m^2

(*Clauses* 6.1.9 *and* 6.3.6.1)

Sl No.	Design Wind Pressure N/m^2	Nominal Thickness of Glass, *T* mm						
		3 + 3	4 + 4	5 + 5	6 + 6	8 + 8	10 + 10	12 + 12
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
i)	500	3.19	5.78	9.04	12.95	15.00	15.00	15.00
ii)	550	2.90	5.26	8.22	11.77	15.00	15.00	15.00
iii)	600	2.66	4.82	7.54	10.79	15.00	15.00	15.00
iv)	650	2.46	4.45	6.96	9.96	15.00	15.00	15.00
v)	700	2.28	4.13	6.46	9.25	14.00	15.00	15.00
vi)	750	2.13	3.86	6.03	8.63	13.06	15.00	15.00
vii)	800	2.00	3.62	5.65	8.09	12.25	15.00	15.00
viii)	850	1.88	3.40	5.32	7.62	11.53	15.00	15.00
ix)	900	1.77	3.21	5.02	7.19	10.89	14.61	15.00
x)	950	1.68	3.04	4.76	6.82	10.31	13.84	15.00
xi)	1 000	1.60	2.89	4.52	6.48	9.80	13.15	15.00
xii)	1 050	1.52	2.75	4.31	6.17	9.33	12.52	15.00
xiii)	1 100	1.45	2.63	4.11	5.89	8.91	11.95	15.00
xiv)	1 150	1.39	2.52	3.93	5.63	8.52	11.43	14.43
xv)	1 200	1.33	2.41	3.77	5.40	8.16	10.96	13.83
xvi)	1 250	1.28	2.31	3.62	5.18	7.84	10.52	13.27
xvii)	1 300	1.23	2.22	3.48	4.98	7.54	10.11	12.76
xviii)	1 350	1.18	2.14	3.35	4.80	7.26	9.74	12.29

Table 20 (*Continued*)

Sl No.	**Design Wind Pressure** N/m^2	**Nominal Thickness of Glass, *T*** mm						
		3 + 3	4 + 4	5 + 5	6 + 6	8 + 8	10 + 10	12 + 12
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
xix)	1 400	1.14	2.07	3.23	4.63	7.00	9.39	11.85
xx)	1 450	1.10	1.99	3.12	4.47	6.76	9.07	11.44
xxi)	1 500	1.06	1.93	3.01	4.32	6.53	8.76	11.06
xxii)	1 550	1.03	1.87	2.92	4.18	6.32	8.48	10.70
xxiii)	1 600	1.00	1.81	2.83	4.05	6.12	8.22	10.37
xxiv)	1 650	0.97	1.75	2.74	3.92	5.94	7.97	10.06
xxv)	1 700	0.94	1.70	2.66	3.81	5.76	7.73	9.76
xxvi)	1 750	0.91	1.65	2.58	3.70	5.60	7.51	9.48
xxvii)	1 800	0.89	1.61	2.51	3.60	5.44	7.30	9.22
xxviii)	1 850	0.86	1.56	2.44	3.50	5.30	7.11	8.97
xxix)	1 900	0.84	1.52	2.38	3.41	5.16	6.92	8.73
xxx)	1 950	0.82	1.48	2.32	3.32	5.02	6.74	8.51
xxxi)	2 000	0.80	1.45	2.26	3.24	4.90	6.57	8.30
xxxii)	2 050	0.78	1.41	2.21	3.16	4.78	6.41	8.09
xxxiii)	2 100	0.76	1.38	2.15	3.08	4.67	6.26	7.90
xxxiv)	2 150	0.74	1.35	2.10	3.01	4.56	6.11	7.72
xxxv)	2 200	0.73	1.31	2.06	2.94	4.45	5.98	7.54
xxxvi)	2 250	0.71	1.29	2.01	2.88	4.35	5.84	7.37
xxxvii)	2 300	0.69	1.26	1.97	2.82	4.26	5.72	7.21
xxxviii)	2 350	0.68	1.23	1.92	2.76	4.17	5.59	7.06
xxxix)	2 400	0.67	1.21	1.88	2.70	4.08	5.48	6.91
xl)	2 450	0.65	1.18	1.85	2.64	4.00	5.37	6.77
xli)	2 500	0.64	1.16	1.81	2.59	3.92	5.26	6.64
xlii)	2 550	0.63	1.13	1.77	2.54	3.84	5.16	6.51
xliii)	2 600	0.61	1.11	1.74	2.49	3.77	5.06	6.38
xliv)	2 650	0.60	1.09	1.71	2.44	3.70	4.96	6.26
xlv)	2 700	0.59	1.07	1.67	2.40	3.63	4.87	6.14
xlvi)	2 750	0.58	1.05	1.64	2.35	3.56	4.78	6.03
xlvii)	2 800	0.57	1.03	1.61	2.31	3.50	4.70	5.93
xlviii)	2 850	0.56	1.01	1.59	2.27	3.44	4.61	5.82

Table 20 (*Continued*)

Sl No.	Design Wind Pressure N/m^2	Nominal Thickness of Glass, *T* mm						
		3 + 3	4 + 4	5 + 5	6 + 6	8 + 8	10 + 10	12 + 12
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
xlix)	2 900	0.55	1.00	1.56	2.23	3.38	4.53	5.72
l)	2 950	0.54	0.98	1.53	2.19	3.32	4.46	5.62
li)	3 000	0.53	0.96	1.51	2.16	3.27	4.38	5.53
lii)	3 050	0.52	0.95	1.48	2.12	3.21	4.31	5.44
liii)	3 100	0.51	0.93	1.46	2.09	3.16	4.24	5.35
liv)	3 150	0.51	0.92	1.44	2.06	3.11	4.17	5.27
lv)	3 200	0.50	0.90	1.41	2.02	3.06	4.11	5.18
lvi)	3 250	0.49	0.89	1.39	1.99	3.01	4.05	5.11
lvii)	3 300	0.48	0.88	1.37	1.96	2.97	3.98	5.03
lviii)	3 350	0.48	0.86	1.35	1.93	2.92	3.92	4.95
lix)	3 400	0.47	0.85	1.33	1.90	2.88	3.87	4.88
lx)	3 450	0.46	0.84	1.31	1.88	2.84	3.81	4.81
lxi)	3 500	0.46	0.83	1.29	1.85	2.80	3.76	4.74
lxii)	3 550	0.45	0.81	1.27	1.82	2.76	3.70	4.67
lxiii)	3 600	0.44	0.80	1.26	1.80	2.72	3.65	4.61
lxiv)	3 650	0.44	0.79	1.24	1.77	2.68	3.60	4.55
lxv)	3 700	0.43	0.78	1.22	1.75	2.65	3.55	4.48
lxvi)	3 750	0.43	0.77	1.21	1.73	2.61	3.51	4.42
lxvii)	3 800	0.42	0.76	1.19	1.70	2.58	3.46	4.37
lxviii)	3 850	0.41	0.75	1.17	1.68	2.54	3.41	4.31
lxix)	3 900	0.41	0.74	1.16	1.66	2.51	3.37	4.25
lxx)	3 950	0.40	0.73	1.14	1.64	2.48	3.33	4.20
lxxi)	4 000	0.40	0.72	1.13	1.62	2.45	3.29	4.15
lxxii)	4 050	0.39	0.71	1.12	1.60	2.42	3.25	4.10
lxxiii)	4 100	0.39	0.71	1.10	1.58	2.39	3.21	4.05
lxxiv)	4 150	0.38	0.70	1.09	1.56	2.36	3.17	4.00
lxxv)	4 200	0.38	0.69	1.08	1.54	2.33	3.13	3.95
lxxvi)	4 250	0.38	0.68	1.06	1.52	2.31	3.09	3.90
lxxvii)	4 300	0.37	0.67	1.05	1.51	2.28	3.06	3.86
lxxviii)	4 350	0.37	0.66	1.04	1.49	2.25	3.02	3.81

Table 20 (*Concluded*)

Sl No. (1)	**Design Wind Pressure** N/m² (2)	**Nominal Thickness of Glass, *T*** mm 3 + 3 (3)	4 + 4 (4)	5 + 5 (5)	6 + 6 (6)	8 + 8 (7)	10 + 10 (8)	12 + 12 (9)
lxxix)	4 400	0.36	0.66	1.03	1.47	2.23	2.99	3.77
lxxx)	4 450	0.36	0.65	1.02	1.46	2.20	2.95	3.73
lxxxi)	4 500	0.35	0.64	1.00	1.44	2.18	2.92	3.69
lxxxii)	4 550	0.35	0.64	0.99	1.42	2.15	2.89	3.65
lxxxiii)	4 600	0.35	0.63	0.98	1.41	2.13	2.86	3.61
lxxxiv)	4 650	0.34	0.62	0.97	1.39	2.11	2.83	3.57
lxxxv)	4 700	0.34	0.62	0.96	1.38	2.08	2.80	3.53
lxxxvi)	4 750	0.34	0.61	0.95	1.36	2.06	2.77	3.49
lxxxvii)	4 800	0.33	0.60	0.94	1.35	2.04	2.74	3.46
lxxxviii)	4 850	0.33	0.60	0.93	1.34	2.02	2.71	3.42
lxxxix)	4 900	0.33	0.59	0.92	1.32	2.00	2.68	3.39
xc)	4 950	0.32	0.58	0.91	1.31	1.98	2.66	3.35
xci)	5 000	0.32	0.58	0.90	1.30	1.96	2.63	3.32
xcii)	Maximum aspect ratio	7.3	6.8	6.5	6.3	5.9	4.9	4.3

Table 21 Maximum Area for Heat Strengthened Glass Fixed on Four Sides, m²

(*Clauses* 6.1.9, 6.3.5 *and* 6.3.6.1)

Sl No. (1)	**Design Wind Pressure** N/m² (2)	**Nominal Thickness of Heat Strengthened Glass, *T*** mm 3 (3)	4 (4)	5 (5)	6 (6)	8 (7)	10 (8)	12 (9)	15 (10)	19 (11)
i)	500	3.41	6.17	9.65	13.81	15.00	15.00	15.00	15.00	15.00
ii)	550	3.10	5.61	8.77	12.56	15.00	15.00	15.00	15.00	15.00
iii)	600	2.84	5.14	8.04	11.51	15.00	15.00	15.00	15.00	15.00
iv)	650	2.62	4.75	7.42	10.63	15.00	15.00	15.00	15.00	15.00
v)	700	2.43	4.41	6.89	9.87	14.93	15.00	15.00	15.00	15.00
vi)	750	2.27	4.11	6.43	9.21	13.93	15.00	15.00	15.00	15.00
vii)	800	2.13	3.86	6.03	8.63	13.06	15.00	15.00	15.00	15.00

Table 21 (*Continued*)

Sl No.	**Design Wind Pressure** N/m^2	**Nominal Thickness of Heat Strengthened Glass, *T*** mm								
		3	4	5	6	8	10	12	15	19
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
viii)	850	2.00	3.63	5.67	8.13	12.29	15.00	15.00	15.00	15.00
ix)	900	1.89	3.43	5.36	7.67	11.61	15.00	15.00	15.00	15.00
x)	950	1.79	3.25	5.08	7.27	11.00	14.76	15.00	15.00	15.00
xi)	1 000	1.70	3.09	4.82	6.91	10.45	14.02	15.00	15.00	15.00
xii)	1 050	1.62	2.94	4.59	6.58	9.95	13.36	15.00	15.00	15.00
xiii)	1 100	1.55	2.80	4.38	6.28	9.50	12.75	15.00	15.00	15.00
xiv)	1 150	1.48	2.68	4.19	6.01	9.09	12.19	15.00	15.00	15.00
xv)	1 200	1.42	2.57	4.02	5.76	8.71	11.69	14.75	15.00	15.00
xvi)	1 250	1.36	2.47	3.86	5.53	8.36	11.22	14.16	15.00	15.00
xvii)	1 300	1.31	2.37	3.71	5.31	8.04	10.79	13.61	15.00	15.00
xviii)	1 350	1.26	2.29	3.57	5.12	7.74	10.39	13.11	15.00	15.00
xix)	1 400	1.22	2.20	3.45	4.93	7.46	10.02	12.64	15.00	15.00
xx)	1 450	1.17	2.13	3.33	4.76	7.21	9.67	12.21	15.00	15.00
xxi)	1 500	1.14	2.06	3.22	4.60	6.97	9.35	11.80	15.00	15.00
xxii)	1 550	1.10	1.99	3.11	4.46	6.74	9.05	11.42	15.00	15.00
xxiii)	1 600	1.06	1.93	3.01	4.32	6.53	8.76	11.06	15.00	15.00
xxiv)	1 650	1.03	1.87	2.92	4.19	6.33	8.50	10.73	14.64	15.00
xxv)	1 700	1.00	1.81	2.84	4.06	6.15	8.25	10.41	14.21	15.00
xxvi)	1 750	0.97	1.76	2.76	3.95	5.97	8.01	10.11	13.80	15.00
xxvii)	1 800	0.95	1.71	2.68	3.84	5.81	7.79	9.83	13.42	15.00
xxviii)	1 850	0.92	1.67	2.61	3.73	5.65	7.58	9.57	13.06	15.00
xxix)	1 900	0.90	1.62	2.54	3.64	5.50	7.38	9.31	12.71	15.00
xxx)	1 950	0.87	1.58	2.47	3.54	5.36	7.19	9.08	12.39	15.00
xxxi)	2 000	0.85	1.54	2.41	3.45	5.23	7.01	8.85	12.08	15.00
xxxii)	2 050	0.83	1.50	2.35	3.37	5.10	6.84	8.63	11.78	15.00
xxxiii)	2 100	0.81	1.47	2.30	3.29	4.98	6.68	8.43	11.50	15.00
xxxiv)	2 150	0.79	1.43	2.24	3.21	4.86	6.52	8.23	11.24	15.00
xxxv)	2 200	0.77	1.40	2.19	3.14	4.75	6.37	8.04	10.98	14.71
xxxvi)	2 250	0.76	1.37	2.14	3.07	4.64	6.23	7.87	10.74	14.38
xxxvii)	2 300	0.74	1.34	2.10	3.00	4.54	6.10	7.69	10.50	14.07

Table 21 (*Continued*)

Sl No.	**Design Wind Pressure** N/m^2	**Nominal Thickness of Heat Strengthened Glass, *T*** mm								
		3	4	5	6	8	10	12	15	19
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
xxxviii)	2 350	0.72	1.31	2.05	2.94	4.45	5.97	7.53	10.28	13.77
xxxix)	2 400	0.71	1.29	2.01	2.88	4.35	5.84	7.37	10.07	13.48
xl)	2 450	0.69	1.26	1.97	2.82	4.27	5.72	7.22	9.86	13.21
xli)	2 500	0.68	1.23	1.93	2.76	4.18	5.61	7.08	9.66	12.94
xlii)	2 550	0.67	1.21	1.89	2.71	4.10	5.50	6.94	9.47	12.69
xliii)	2 600	0.65	1.19	1.86	2.66	4.02	5.39	6.81	9.29	12.44
xliv)	2 650	0.64	1.16	1.82	2.61	3.94	5.29	6.68	9.12	12.21
xlv)	2 700	0.63	1.14	1.79	2.56	3.87	5.19	6.55	8.95	11.98
xlvi)	2 750	0.62	1.12	1.75	2.51	3.80	5.10	6.44	8.78	11.76
xlvii)	2 800	0.61	1.10	1.72	2.47	3.73	5.01	6.32	8.63	11.55
xlviii)	2 850	0.60	1.08	1.69	2.42	3.67	4.92	6.21	8.48	11.35
xlix)	2 900	0.59	1.06	1.66	2.38	3.60	4.84	6.10	8.33	11.16
l)	2 950	0.58	1.05	1.63	2.34	3.54	4.75	6.00	8.19	10.97
li)	3 000	0.57	1.03	1.61	2.30	3.48	4.67	5.90	8.05	10.78
lii)	3 050	0.56	1.01	1.58	2.26	3.43	4.60	5.80	7.92	10.61
liii)	3 100	0.55	1.00	1.56	2.23	3.37	4.52	5.71	7.79	10.44
liv)	3 150	0.54	0.98	1.53	2.19	3.32	4.45	5.62	7.67	10.27
lv)	3 200	0.53	0.96	1.51	2.16	3.27	4.38	5.53	7.55	10.11
lvi)	3 250	0.52	0.95	1.48	2.13	3.22	4.31	5.45	7.43	9.95
lvii)	3 300	0.52	0.93	1.46	2.09	3.17	4.25	5.36	7.32	9.80
lviii)	3 350	0.51	0.92	1.44	2.06	3.12	4.19	5.28	7.21	9.66
lix)	3 400	0.50	0.91	1.42	2.03	3.07	4.12	5.21	7.10	9.52
lx)	3 450	0.49	0.89	1.40	2.00	3.03	4.06	5.13	7.00	9.38
lxi)	3 500	0.49	0.88	1.38	1.97	2.99	4.01	5.06	6.90	9.24
lxii)	3 550	0.48	0.87	1.36	1.95	2.94	3.95	4.99	6.80	9.11
lxiii)	3 600	0.47	0.86	1.34	1.92	2.90	3.90	4.92	6.71	8.99
lxiv)	3 650	0.47	0.85	1.32	1.89	2.86	3.84	4.85	6.62	8.86
lxv)	3 700	0.46	0.83	1.30	1.87	2.82	3.79	4.78	6.53	8.74
lxvi)	3 750	0.45	0.82	1.29	1.84	2.79	3.74	4.72	6.44	8.63
lxvii)	3 800	0.45	0.81	1.27	1.82	2.75	3.69	4.66	6.36	8.51

Table 21 (*Concluded*)

Sl No.	**Design Wind Pressure** N/m^2	**Nominal Thickness of Heat Strengthened Glass, *T*** mm								
		3	4	5	6	8	10	12	15	19
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
lxviii)	3 850	0.44	0.80	1.25	1.79	2.71	3.64	4.60	6.27	8.40
lxix)	3 900	0.44	0.79	1.24	1.77	2.68	3.60	4.54	6.19	8.30
lxx)	3 950	0.43	0.78	1.22	1.75	2.65	3.55	4.48	6.12	8.19
lxxi)	4 000	0.43	0.77	1.21	1.73	2.61	3.51	4.42	6.04	8.09
lxxii)	4 050	0.42	0.76	1.19	1.71	2.58	3.46	4.37	5.96	7.99
lxxiii)	4 100	0.42	0.75	1.18	1.68	2.55	3.42	4.32	5.89	7.89
lxxiv)	4 150	0.41	0.74	1.16	1.66	2.52	3.38	4.26	5.82	7.80
lxxv)	4 200	0.41	0.73	1.15	1.64	2.49	3.34	4.21	5.75	7.70
lxxvi)	4 250	0.40	0.73	1.13	1.63	2.46	3.30	4.16	5.68	7.61
lxxvii)	4 300	0.40	0.72	1.12	1.61	2.43	3.26	4.12	5.62	7.52
lxxviii)	4 350	0.39	0.71	1.11	1.59	2.40	3.22	4.07	5.55	7.44
lxxix)	4 400	0.39	0.70	1.10	1.57	2.38	3.19	4.02	5.49	7.35
lxxx)	4 450	0.38	0.69	1.08	1.55	2.35	3.15	3.98	5.43	7.27
lxxxi)	4 500	0.38	0.69	1.07	1.53	2.32	3.12	3.93	5.37	7.19
lxxxii)	4 550	0.37	0.68	1.06	1.52	2.30	3.08	3.89	5.31	7.11
lxxxiii)	4 600	0.37	0.67	1.05	1.50	2.27	3.05	3.85	5.25	7.03
lxxxiv)	4 650	0.37	0.66	1.04	1.49	2.25	3.02	3.81	5.19	6.96
lxxxv)	4 700	0.36	0.66	1.03	1.47	2.22	2.98	3.77	5.14	6.88
lxxxvi)	4 750	0.36	0.65	1.02	1.45	2.20	2.95	3.73	5.09	6.81
lxxxvii)	4 800	0.35	0.64	1.00	1.44	2.18	2.92	3.69	5.03	6.74
lxxxviii)	4 850	0.35	0.64	0.99	1.42	2.15	2.89	3.65	4.98	6.67
lxxxix)	4 900	0.35	0.63	0.98	1.41	2.13	2.86	3.61	4.93	6.60
xc)	4 950	0.34	0.62	0.97	1.40	2.11	2.83	3.58	4.88	6.54
xci)	5 000	0.34	0.62	0.96	1.38	2.09	2.80	3.54	4.83	6.47
xcii)	Maximum aspect ratio	7.3	6.8	6.5	6.3	5.9	4.9	4.3	3.8	3.3

Table 22 Maximum Span for Annealed Glass Fixed on Two Opposite Sides, m

(*Clauses* 6.1.9 *and* 6.3.6.1)

Sl No.	**Design Wind Pressure** N/m^2	**Nominal Thickness of Annealed Glass, *T*** mm								
		3	4	5	6	8	10	12	15	19
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
i)	500	0.53	0.73	0.92	1.12	1.40	1.77	2.11	2.68	3.36
ii)	550	0.51	0.69	0.88	1.07	1.33	1.69	2.02	2.56	3.20
iii)	600	0.48	0.66	0.84	1.02	1.27	1.62	1.93	2.45	3.07
iv)	650	0.46	0.64	0.81	0.98	1.22	1.56	1.85	2.35	2.95
v)	700	0.45	0.61	0.78	0.95	1.18	1.50	1.79	2.26	2.84
vi)	750	0.43	0.59	0.75	0.91	1.14	1.45	1.73	2.19	2.74
vii)	800	0.42	0.57	0.73	0.88	1.10	1.40	1.67	2.12	2.66
viii)	850	0.41	0.56	0.71	0.86	1.07	1.36	1.62	2.06	2.58
ix)	900	0.40	0.54	0.69	0.83	1.04	1.32	1.58	2.00	2.50
x)	950	0.38	0.53	0.67	0.81	1.01	1.29	1.53	1.94	2.44
xi)	1 000	0.37	0.51	0.65	0.79	0.99	1.25	1.49	1.89	2.38
xii)	1 050	0.37	0.50	0.64	0.77	0.96	1.22	1.46	1.85	2.32
xiii)	1 100	0.36	0.49	0.62	0.75	0.94	1.20	1.43	1.81	2.26
xiv)	1 150	0.35	0.48	0.61	0.74	0.92	1.17	1.39	1.77	2.22
xv)	1 200	0.34	0.47	0.60	0.72	0.90	1.15	1.36	1.73	2.17
xvi)	1 250	0.34	0.46	0.58	0.71	0.88	1.12	1.34	1.69	2.12
xvii)	1 300	0.33	0.45	0.57	0.69	0.87	1.10	1.31	1.66	2.08
xviii)	1 350	0.32	0.44	0.56	0.68	0.85	1.08	1.29	1.63	2.04
xix)	1 400	0.32	0.43	0.55	0.67	0.83	1.06	1.26	1.60	2.01
xx)	1 450	0.31	0.43	0.54	0.66	0.82	1.04	1.24	1.57	1.97
xxi)	1 500	0.31	0.42	0.53	0.65	0.81	1.02	1.22	1.55	1.94
xxii)	1 550	0.30	0.41	0.52	0.64	0.79	1.01	1.20	1.52	1.91
xxiii)	1 600	0.30	0.41	0.52	0.63	0.78	0.99	1.18	1.50	1.88
xxiv)	1 650	0.29	0.40	0.51	0.62	0.77	0.98	1.16	1.48	1.85
xxv)	1 700	0.29	0.39	0.50	0.61	0.76	0.96	1.15	1.45	1.82
xxvi)	1 750	0.28	0.39	0.49	0.60	0.75	0.95	1.13	1.43	1.80
xxvii)	1 800	0.28	0.38	0.49	0.59	0.74	0.93	1.11	1.41	1.77
xxviii)	1 850	0.28	0.38	0.48	0.58	0.73	0.92	1.10	1.39	1.75
xxix)	1 900	0.27	0.37	0.47	0.57	0.72	0.91	1.08	1.37	1.72
xxx)	1 950	0.27	0.37	0.47	0.57	0.71	0.90	1.07	1.36	1.70

Table 22 (*Continued*)

Sl No.	Design Wind Pressure N/m^2	Nominal Thickness of Annealed Glass, *T* mm								
		3	4	5	6	8	10	12	15	19
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
xxxi)	2 000	0.27	0.36	0.46	0.56	0.70	0.89	1.06	1.34	1.68
xxxii)	2 050	0.26	0.36	0.46	0.55	0.69	0.88	1.04	1.32	1.66
xxxiii)	2 100	0.26	0.35	0.45	0.55	0.68	0.87	1.03	1.31	1.64
xxxiv)	2 150	0.26	0.35	0.44	0.54	0.67	0.86	1.02	1.29	1.62
xxxv)	2 200	0.25	0.35	0.44	0.53	0.67	0.85	1.01	1.28	1.60
xxxvi)	2 250	0.25	0.34	0.43	0.53	0.66	0.84	1.00	1.26	1.58
xxxvii)	2 300	0.25	0.34	0.43	0.52	0.65	0.83	0.99	1.25	1.57
xxxviii)	2 350	0.24	0.34	0.43	0.52	0.64	0.82	0.97	1.24	1.55
xxxix)	2 400	0.24	0.33	0.42	0.51	0.64	0.81	0.96	1.22	1.53
xl)	2 450	0.24	0.33	0.42	0.51	0.63	0.80	0.95	1.21	1.52
xli)	2 500	0.24	0.32	0.41	0.50	0.62	0.79	0.95	1.20	1.50
xlii)	2 550	0.23	0.32	0.41	0.50	0.62	0.79	0.94	1.19	1.49
xliii)	2 600	0.23	0.32	0.40	0.49	0.61	0.78	0.93	1.18	1.47
xliv)	2 650	0.23	0.32	0.40	0.49	0.61	0.77	0.92	1.16	1.46
xlv)	2 700	0.23	0.31	0.40	0.48	0.60	0.76	0.91	1.15	1.45
xlvi)	2 750	0.23	0.31	0.39	0.48	0.60	0.76	0.90	1.14	1.43
xlvii)	2 800	0.22	0.31	0.39	0.47	0.59	0.75	0.89	1.13	1.42
xlviii)	2 850	0.22	0.30	0.39	0.47	0.58	0.74	0.89	1.12	1.41
xlix)	2 900	0.22	0.30	0.38	0.46	0.58	0.74	0.88	1.11	1.39
l)	2 950	0.22	0.30	0.38	0.46	0.57	0.73	0.87	1.10	1.38
li)	3 000	0.22	0.30	0.38	0.46	0.57	0.72	0.86	1.09	1.37
lii)	3 050	0.21	0.29	0.37	0.45	0.57	0.72	0.86	1.09	1.36
liii)	3 100	0.21	0.29	0.37	0.45	0.56	0.71	0.85	1.08	1.35
liv)	3 150	0.21	0.29	0.37	0.45	0.56	0.71	0.84	1.07	1.34
lv)	3 200	0.21	0.29	0.36	0.44	0.55	0.70	0.84	1.06	1.33
lvi)	3 250	0.21	0.28	0.36	0.44	0.55	0.70	0.83	1.05	1.32
lvii)	3 300	0.21	0.28	0.36	0.44	0.54	0.69	0.82	1.04	1.31
lviii)	3 350	0.20	0.28	0.36	0.43	0.54	0.69	0.82	1.04	1.30
lix)	3 400	0.20	0.28	0.35	0.43	0.54	0.68	0.81	1.03	1.29
lx)	3 450	0.20	0.28	0.35	0.43	0.53	0.68	0.80	1.02	1.28

Table 22 (*Continued*)

Sl No.	Design Wind Pressure N/m^2	Nominal Thickness of Annealed Glass, *T* mm								
		3	4	5	6	8	10	12	15	19
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
lxi)	3 500	0.20	0.27	0.35	0.42	0.53	0.67	0.80	1.01	1.27
lxii)	3 550	0.20	0.27	0.35	0.42	0.52	0.67	0.79	1.01	1.26
lxiii)	3 600	0.20	0.27	0.34	0.42	0.52	0.66	0.79	1.00	1.25
lxiv)	3 650	0.20	0.27	0.34	0.41	0.52	0.66	0.78	0.99	1.24
lxv)	3 700	0.19	0.27	0.34	0.41	0.51	0.65	0.78	0.99	1.23
lxvi)	3 750	0.19	0.27	0.34	0.41	0.51	0.65	0.77	0.98	1.23
lxvii)	3 800	0.19	0.26	0.33	0.41	0.51	0.64	0.77	0.97	1.22
lxviii)	3 850	0.19	0.26	0.33	0.40	0.50	0.64	0.76	0.97	1.21
lxix)	3 900	0.19	0.26	0.33	0.40	0.50	0.64	0.76	0.96	1.20
lxx)	3 950	0.19	0.26	0.33	0.40	0.50	0.63	0.75	0.95	1.20
lxxi)	4 000	0.19	0.26	0.33	0.40	0.49	0.63	0.75	0.95	1.19
lxxii)	4 050	0.19	0.26	0.32	0.39	0.49	0.62	0.74	0.94	1.18
lxxiii)	4 100	0.19	0.25	0.32	0.39	0.49	0.62	0.74	0.94	1.17
lxxiv)	4 150	0.18	0.25	0.32	0.39	0.48	0.62	0.73	0.93	1.17
lxxv)	4 200	0.18	0.25	0.32	0.39	0.48	0.61	0.73	0.92	1.16
lxxvi)	4 250	0.18	0.25	0.32	0.38	0.48	0.61	0.72	0.92	1.15
lxxvii)	4 300	0.18	0.25	0.31	0.38	0.48	0.60	0.72	0.91	1.15
lxxviii)	4 350	0.18	0.25	0.31	0.38	0.47	0.60	0.72	0.91	1.14
lxxix)	4 400	0.18	0.24	0.31	0.38	0.47	0.60	0.71	0.90	1.13
lxxx)	4 450	0.18	0.24	0.31	0.38	0.47	0.59	0.71	0.90	1.13
lxxxi)	4 500	0.18	0.24	0.31	0.37	0.47	0.59	0.70	0.89	1.12
lxxxii)	4 550	0.18	0.24	0.31	0.37	0.46	0.59	0.70	0.89	1.11
lxxxiii)	4 600	0.17	0.24	0.30	0.37	0.46	0.58	0.70	0.88	1.11
lxxxiv)	4 650	0.17	0.24	0.30	0.37	0.46	0.58	0.69	0.88	1.10
lxxxv)	4 700	0.17	0.24	0.30	0.36	0.46	0.58	0.69	0.87	1.10
lxxxvi)	4 750	0.17	0.24	0.30	0.36	0.45	0.58	0.69	0.87	1.09
lxxxvii)	4 800	0.17	0.23	0.30	0.36	0.45	0.57	0.68	0.86	1.08
lxxxviii)	4 850	0.17	0.23	0.30	0.36	0.45	0.57	0.68	0.86	1.08
lxxxix)	4 900	0.17	0.23	0.29	0.36	0.45	0.57	0.68	0.86	1.07
xc)	4 950	0.17	0.23	0.29	0.36	0.44	0.56	0.67	0.85	1.07

Table 22 (*Concluded*)

Sl No.	Design Wind Pressure N/m^2	Nominal Thickness of Annealed Glass, *T* mm								
		3	4	5	6	8	10	12	15	19
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
xci)	5 000	0.17	0.23	0.29	0.35	0.44	0.56	0.67	0.85	1.06

Table 23 Maximum Span for Laminated Glass Fixed on Two Opposite Sides, m

(*Clauses* 6.1.9, 6.3.5 *and* 6.3.6.1)

Sl No.	Design Wind Pressure N/m^2	Nominal Thickness of Laminated Glass, *T* mm					
		5.38	6.38	8.38	10.38	12.38	16.38
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	500	0.79	0.95	1.25	1.59	1.92	2.50
ii)	550	0.75	0.90	1.19	1.51	1.83	2.38
iii)	600	0.72	0.87	1.14	1.45	1.76	2.28
iv)	650	0.69	0.83	1.10	1.39	1.69	2.19
v)	700	0.67	0.80	1.06	1.34	1.63	2.11
vi)	750	0.65	0.77	1.02	1.30	1.57	2.04
vii)	800	0.62	0.75	0.99	1.25	1.52	1.98
viii)	850	0.61	0.73	0.96	1.22	1.48	1.92
ix)	900	0.59	0.71	0.93	1.18	1.43	1.86
x)	950	0.57	0.69	0.91	1.15	1.40	1.81
xi)	1 000	0.56	0.67	0.88	1.12	1.36	1.77
xii)	1 050	0.55	0.65	0.86	1.09	1.33	1.72
xiii)	1 100	0.53	0.64	0.84	1.07	1.30	1.68
xiv)	1 150	0.52	0.63	0.82	1.05	1.27	1.65
xv)	1 200	0.51	0.61	0.81	1.02	1.24	1.61
xvi)	1 250	0.50	0.60	0.79	1.00	1.22	1.58
xvii)	1 300	0.49	0.59	0.77	0.98	1.19	1.55
xviii)	1 350	0.48	0.58	0.76	0.97	1.17	1.52
xix)	1 400	0.47	0.57	0.75	0.95	1.15	1.49
xx)	1 450	0.46	0.56	0.73	0.93	1.13	1.47
xxi)	1 500	0.46	0.55	0.72	0.92	1.11	1.44

Table 23 (*Continued*)

Sl No.	**Design Wind Pressure** N/m^2	**Nominal Thickness of Laminated Glass, *T*** mm					
		5.38	6.38	8.38	10.38	12.38	16.38
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
xxii)	1 550	0.45	0.54	0.71	0.90	1.09	1.42
xxiii)	1 600	0.44	0.53	0.70	0.89	1.08	1.40
xxiv)	1 650	0.43	0.52	0.69	0.87	1.06	1.38
xxv)	1 700	0.43	0.51	0.68	0.86	1.04	1.35
xxvi)	1 750	0.42	0.51	0.67	0.85	1.03	1.34
xxvii)	1 800	0.42	0.50	0.66	0.84	1.01	1.32
xxviii)	1 850	0.41	0.49	0.65	0.82	1.00	1.30
xxix)	1 900	0.41	0.49	0.64	0.81	0.99	1.28
xxx)	1 950	0.40	0.48	0.63	0.80	0.97	1.27
xxxi)	2 000	0.40	0.47	0.62	0.79	0.96	1.25
xxxii)	2 050	0.39	0.47	0.62	0.78	0.95	1.23
xxxiii)	2 100	0.39	0.46	0.61	0.77	0.94	1.22
xxxiv)	2 150	0.38	0.46	0.60	0.77	0.93	1.20
xxxv)	2 200	0.38	0.45	0.60	0.76	0.92	1.19
xxxvi)	2 250	0.37	0.45	0.59	0.75	0.91	1.18
xxxvii)	2 300	0.37	0.44	0.58	0.74	0.90	1.16
xxxviii)	2 350	0.36	0.44	0.58	0.73	0.89	1.15
xxxix)	2 400	0.36	0.43	0.57	0.72	0.88	1.14
xl)	2 450	0.36	0.43	0.56	0.72	0.87	1.13
xli)	2 500	0.35	0.42	0.56	0.71	0.86	1.12
xlii)	2 550	0.35	0.42	0.55	0.70	0.85	1.11
xliii)	2 600	0.35	0.42	0.55	0.70	0.84	1.10
xliv)	2 650	0.34	0.41	0.54	0.69	0.84	1.09
xlv)	2 700	0.34	0.41	0.54	0.68	0.83	1.08
xlvi)	2 750	0.34	0.40	0.53	0.68	0.82	1.07
xlvii)	2 800	0.33	0.40	0.53	0.67	0.81	1.06
xlviii)	2 850	0.33	0.40	0.52	0.66	0.81	1.05
xlix)	2 900	0.33	0.39	0.52	0.66	0.80	1.04
l)	2 950	0.33	0.39	0.51	0.65	0.79	1.03

Table 23 (*Continued*)

Sl No.	**Design Wind Pressure** N/m^2	**Nominal Thickness of Laminated Glass, *T*** mm					
		5.38	6.38	8.38	10.38	12.38	16.38
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
li)	3 000	0.32	0.39	0.51	0.65	0.79	1.02
lii)	3 050	0.32	0.38	0.51	0.64	0.78	1.01
liii)	3 100	0.32	0.38	0.50	0.64	0.77	1.00
liv)	3 150	0.31	0.38	0.50	0.63	0.77	1.00
lv)	3 200	0.31	0.37	0.49	0.63	0.76	0.99
lvi)	3 250	0.31	0.37	0.49	0.62	0.75	0.98
lvii)	3 300	0.31	0.37	0.49	0.62	0.75	0.97
lviii)	3 350	0.31	0.37	0.48	0.61	0.74	0.97
lix)	3 400	0.30	0.36	0.48	0.61	0.74	0.96
lx)	3 450	0.30	0.36	0.48	0.60	0.73	0.95
lxi)	3 500	0.30	0.36	0.47	0.60	0.73	0.94
lxii)	3 550	0.30	0.36	0.47	0.60	0.72	0.94
lxiii)	3 600	0.29	0.35	0.47	0.59	0.72	0.93
lxiv)	3 650	0.29	0.35	0.46	0.59	0.71	0.92
lxv)	3 700	0.29	0.35	0.46	0.58	0.71	0.92
lxvi)	3 750	0.29	0.35	0.46	0.58	0.70	0.91
lxvii)	3 800	0.29	0.34	0.45	0.58	0.70	0.91
lxviii)	3 850	0.28	0.34	0.45	0.57	0.69	0.90
lxix)	3 900	0.28	0.34	0.45	0.57	0.69	0.89
lxx)	3 950	0.28	0.34	0.44	0.56	0.68	0.89
lxxi)	4 000	0.28	0.34	0.44	0.56	0.68	0.88
lxxii)	4 050	0.28	0.33	0.44	0.56	0.68	0.88
lxxiii)	4 100	0.28	0.33	0.44	0.55	0.67	0.87
lxxiv)	4 150	0.27	0.33	0.43	0.55	0.67	0.87
lxxv)	4 200	0.27	0.33	0.43	0.55	0.66	0.86
lxxvi)	4 250	0.27	0.33	0.43	0.54	0.66	0.86
lxxvii)	4 300	0.27	0.32	0.43	0.54	0.66	0.85
lxxviii)	4 350	0.27	0.32	0.42	0.54	0.65	0.85
lxxix)	4 400	0.27	0.32	0.42	0.53	0.65	0.84

Table 23 (*Concluded*)

Sl No.	**Design Wind Pressure** N/m²	**Nominal Thickness of Laminated Glass, *T*** mm					
		5.38	6.38	8.38	10.38	12.38	16.38
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
lxxx)	4 450	0.26	0.32	0.42	0.53	0.65	0.84
lxxxi)	4 500	0.26	0.32	0.42	0.53	0.64	0.83
lxxxii)	4 550	0.26	0.31	0.41	0.53	0.64	0.83
lxxxiii)	4 600	0.26	0.31	0.41	0.52	0.63	0.82
lxxxiv)	4 650	0.26	0.31	0.41	0.52	0.63	0.82
lxxxv)	4 700	0.26	0.31	0.41	0.52	0.63	0.81
lxxxvi)	4 750	0.26	0.31	0.41	0.51	0.62	0.81
lxxxvii)	4 800	0.26	0.31	0.40	0.51	0.62	0.81
lxxxviii)	4 850	0.25	0.30	0.40	0.51	0.62	0.80
lxxxix)	4 900	0.25	0.30	0.40	0.51	0.61	0.80
xc)	4 950	0.25	0.30	0.40	0.50	0.61	0.79
xci)	5 000	0.25	0.30	0.40	0.50	0.61	0.79

Table 24 Maximum Span for Tempered Glass Fixed on Two Opposite Sides, m

(*Clauses* 6.1.9 *and* 6.3.6.1)

Sl No.	**Design Wind Pressure** N/m²	**Nominal Thickness of Tempered Glass, *T*** mm								
		3	4	5	6	8	10	12	15	19
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
i)	500	0.62	0.86	1.09	1.32	1.52	1.93	2.30	2.92	3.66
ii)	550	0.60	0.82	1.04	1.26	1.45	1.84	2.20	2.78	3.49
iii)	600	0.57	0.78	0.99	1.20	1.39	1.76	2.10	2.66	3.34
iv)	650	0.55	0.75	0.95	1.16	1.33	1.69	2.02	2.56	3.21
v)	700	0.53	0.72	0.92	1.11	1.29	1.63	1.95	2.47	3.09
vi)	750	0.51	0.70	0.89	1.08	1.24	1.58	1.88	2.38	2.99
vii)	800	0.49	0.68	0.86	1.04	1.20	1.53	1.82	2.31	2.89
viii)	850	0.48	0.66	0.83	1.01	1.17	1.48	1.77	2.24	2.81
ix)	900	0.47	0.64	0.81	0.98	1.13	1.44	1.72	2.18	2.73

Table 24 (*Continued*)

Sl No.	Design Wind Pressure N/m^2	Nominal Thickness of Tempered Glass, *T* mm								
		3	4	5	6	8	10	12	15	19
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
x)	950	0.45	0.62	0.79	0.96	1.10	1.40	1.67	2.12	2.65
xi)	1 000	0.44	0.60	0.77	0.93	1.08	1.37	1.63	2.06	2.59
xii)	1 050	0.43	0.59	0.75	0.91	1.05	1.33	1.59	2.01	2.52
xiii)	1 100	0.42	0.58	0.73	0.89	1.03	1.30	1.55	1.97	2.47
xiv)	1 150	0.41	0.56	0.72	0.87	1.00	1.27	1.52	1.92	2.41
xv)	1 200	0.40	0.55	0.70	0.85	0.98	1.25	1.49	1.88	2.36
xvi)	1 250	0.39	0.54	0.69	0.83	0.96	1.22	1.46	1.85	2.31
xvii)	1 300	0.39	0.53	0.67	0.82	0.94	1.20	1.43	1.81	2.27
xviii)	1 350	0.38	0.52	0.66	0.80	0.93	1.18	1.40	1.78	2.23
xix)	1 400	0.37	0.51	0.65	0.79	0.91	1.15	1.38	1.74	2.19
xx)	1 450	0.37	0.50	0.64	0.77	0.89	1.13	1.35	1.71	2.15
xxi)	1 500	0.36	0.49	0.63	0.76	0.88	1.12	1.33	1.69	2.11
xxii)	1 550	0.35	0.49	0.62	0.75	0.86	1.10	1.31	1.66	2.08
xxiii)	1 600	0.35	0.48	0.61	0.74	0.85	1.08	1.29	1.63	2.05
xxiv)	1 650	0.34	0.47	0.60	0.73	0.84	1.06	1.27	1.61	2.01
xxv)	1 700	0.34	0.46	0.59	0.71	0.82	1.05	1.25	1.58	1.98
xxvi)	1 750	0.33	0.46	0.58	0.70	0.81	1.03	1.23	1.56	1.96
xxvii)	1 800	0.33	0.45	0.57	0.69	0.80	1.02	1.21	1.54	1.93
xxviii)	1 850	0.32	0.44	0.56	0.68	0.79	1.00	1.20	1.52	1.90
xxix)	1 900	0.32	0.44	0.56	0.68	0.78	0.99	1.18	1.50	1.88
xxx)	1 950	0.32	0.43	0.55	0.67	0.77	0.98	1.17	1.48	1.85
xxxi)	2 000	0.31	0.43	0.54	0.66	0.76	0.97	1.15	1.46	1.83
xxxii)	2 050	0.31	0.42	0.54	0.65	0.75	0.95	1.14	1.44	1.81
xxxiii)	2 100	0.30	0.42	0.53	0.64	0.74	0.94	1.12	1.42	1.79
xxxiv)	2 150	0.30	0.41	0.52	0.64	0.73	0.93	1.11	1.41	1.76
xxxv)	2 200	0.30	0.41	0.52	0.63	0.73	0.92	1.10	1.39	1.74
xxxvi)	2 250	0.29	0.40	0.51	0.62	0.72	0.91	1.09	1.38	1.72
xxxvii)	2 300	0.29	0.40	0.51	0.61	0.71	0.90	1.07	1.36	1.71
xxxviii)	2 350	0.29	0.39	0.50	0.61	0.70	0.89	1.06	1.35	1.69
xxxix)	2 400	0.28	0.39	0.50	0.60	0.69	0.88	1.05	1.33	1.67

Table 24 (*Continued*)

Sl No.	**Design Wind Pressure** N/m^2	**Nominal Thickness of Tempered Glass, *T*** mm								
		3	4	5	6	8	10	12	15	19
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
xl)	2 450	0.28	0.39	0.49	0.60	0.69	0.87	1.04	1.32	1.65
xli)	2 500	0.28	0.38	0.49	0.59	0.68	0.86	1.03	1.31	1.64
xlii)	2 550	0.28	0.38	0.48	0.58	0.67	0.86	1.02	1.29	1.62
xliii)	2 600	0.27	0.38	0.48	0.58	0.67	0.85	1.01	1.28	1.60
xliv)	2 650	0.27	0.37	0.47	0.57	0.66	0.84	1.00	1.27	1.59
xlv)	2 700	0.27	0.37	0.47	0.57	0.65	0.83	0.99	1.26	1.57
xlvi)	2 750	0.27	0.36	0.46	0.56	0.65	0.82	0.98	1.24	1.56
xlvii)	2 800	0.26	0.36	0.46	0.56	0.64	0.82	0.97	1.23	1.55
xlviii)	2 850	0.26	0.36	0.46	0.55	0.64	0.81	0.96	1.22	1.53
xlix)	2 900	0.26	0.36	0.45	0.55	0.63	0.80	0.96	1.21	1.52
l)	2 950	0.26	0.35	0.45	0.54	0.63	0.80	0.95	1.20	1.51
li)	3 000	0.25	0.35	0.44	0.54	0.62	0.79	0.94	1.19	1.49
lii)	3 050	0.25	0.35	0.44	0.53	0.62	0.78	0.93	1.18	1.48
liii)	3 100	0.25	0.34	0.44	0.53	0.61	0.78	0.92	1.17	1.47
liv)	3 150	0.25	0.34	0.43	0.52	0.61	0.77	0.92	1.16	1.46
lv)	3 200	0.25	0.34	0.43	0.52	0.60	0.76	0.91	1.15	1.45
lvi)	3 250	0.24	0.34	0.43	0.52	0.60	0.76	0.90	1.14	1.44
lvii)	3 300	0.24	0.33	0.42	0.51	0.59	0.75	0.90	1.14	1.42
lviii)	3 350	0.24	0.33	0.42	0.51	0.59	0.75	0.89	1.13	1.41
lix)	3 400	0.24	0.33	0.42	0.51	0.58	0.74	0.88	1.12	1.40
lx)	3 450	0.24	0.33	0.41	0.50	0.58	0.74	0.88	1.11	1.39
lxi)	3 500	0.24	0.32	0.41	0.50	0.57	0.73	0.87	1.10	1.38
lxii)	3 550	0.23	0.32	0.41	0.49	0.57	0.73	0.86	1.10	1.37
lxiii)	3 600	0.23	0.32	0.40	0.49	0.57	0.72	0.86	1.09	1.36
lxiv)	3 650	0.23	0.32	0.40	0.49	0.56	0.72	0.85	1.08	1.35
lxv)	3 700	0.23	0.31	0.40	0.48	0.56	0.71	0.85	1.07	1.34
lxvi)	3 750	0.23	0.31	0.40	0.48	0.56	0.71	0.84	1.07	1.34
lxvii)	3 800	0.23	0.31	0.39	0.48	0.55	0.70	0.84	1.06	1.33
lxviii)	3 850	0.22	0.31	0.39	0.47	0.55	0.70	0.83	1.05	1.32
lxix)	3 900	0.22	0.31	0.39	0.47	0.54	0.69	0.82	1.05	1.31

Table 24 (*Concluded*)

Sl No.	**Design Wind Pressure** N/m^2	**Nominal Thickness of Tempered Glass, *T*** mm								
		3	4	5	6	8	10	12	15	19
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
lxx)	3 950	0.22	0.30	0.39	0.47	0.54	0.69	0.82	1.04	1.30
lxxi)	4 000	0.22	0.30	0.38	0.47	0.54	0.68	0.81	1.03	1.29
lxxii)	4 050	0.22	0.30	0.38	0.46	0.53	0.68	0.81	1.03	1.29
lxxiii)	4 100	0.22	0.30	0.38	0.46	0.53	0.67	0.80	1.02	1.28
lxxiv)	4 150	0.22	0.30	0.38	0.46	0.53	0.67	0.80	1.01	1.27
lxxv)	4 200	0.22	0.30	0.37	0.45	0.52	0.67	0.79	1.01	1.26
lxxvi)	4 250	0.21	0.29	0.37	0.45	0.52	0.66	0.79	1.00	1.25
lxxvii)	4 300	0.21	0.29	0.37	0.45	0.52	0.66	0.79	1.00	1.25
lxxviii)	4 350	0.21	0.29	0.37	0.45	0.52	0.66	0.78	0.99	1.24
lxxix)	4 400	0.21	0.29	0.37	0.44	0.51	0.65	0.78	0.98	1.23
lxxx)	4 450	0.21	0.29	0.36	0.44	0.51	0.65	0.77	0.98	1.23
lxxxi)	4 500	0.21	0.29	0.36	0.44	0.51	0.64	0.77	0.97	1.22
lxxxii)	4 550	0.21	0.28	0.36	0.44	0.50	0.64	0.76	0.97	1.21
lxxxiii)	4 600	0.21	0.28	0.36	0.43	0.50	0.64	0.76	0.96	1.21
lxxxiv)	4 650	0.20	0.28	0.36	0.43	0.50	0.63	0.75	0.96	1.20
lxxxv)	4 700	0.20	0.28	0.35	0.43	0.50	0.63	0.75	0.95	1.19
lxxxvi)	4 750	0.20	0.28	0.35	0.43	0.49	0.63	0.75	0.95	1.19
lxxxvii)	4 800	0.20	0.28	0.35	0.43	0.49	0.62	0.74	0.94	1.18
lxxxviii)	4 850	0.20	0.27	0.35	0.42	0.49	0.62	0.74	0.94	1.17
lxxxix)	4 900	0.20	0.27	0.35	0.42	0.49	0.62	0.74	0.93	1.17
xc)	4 950	0.20	0.27	0.35	0.42	0.48	0.61	0.73	0.93	1.16
xci)	5 000	0.20	0.27	0.34	0.42	0.48	0.61	0.73	0.92	1.16

Table 25 Maximum Span for Heat Strengthened Glass Fixed on Two Opposite Sides, m

(*Clauses* 6.1.9, 6.3.5 *and* 6.3.6.1)

Sl No.	Design Wind Pressure N/m²	Nominal Thickness of Heat Strengthened Glass, *T* mm								
		3	4	5	6	8	10	12	15	19
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
i)	500	0.50	0.68	0.87	1.05	1.22	1.55	1.84	2.34	2.93
ii)	550	0.48	0.65	0.83	1.00	1.16	1.47	1.76	2.23	2.79
iii)	600	0.46	0.62	0.79	0.96	1.11	1.41	1.68	2.13	2.67
iv)	650	0.44	0.60	0.76	0.92	1.07	1.36	1.62	2.05	2.57
v)	700	0.42	0.58	0.73	0.89	1.03	1.31	1.56	1.97	2.47
vi)	750	0.41	0.56	0.71	0.86	0.99	1.26	1.50	1.91	2.39
vii)	800	0.39	0.54	0.69	0.83	0.96	1.22	1.46	1.85	2.31
viii)	850	0.38	0.52	0.67	0.81	0.93	1.19	1.41	1.79	2.24
ix)	900	0.37	0.51	0.65	0.79	0.91	1.15	1.37	1.74	2.18
x)	950	0.36	0.50	0.63	0.76	0.88	1.12	1.34	1.69	2.12
xi)	1 000	0.35	0.48	0.61	0.75	0.86	1.09	1.30	1.65	2.07
xii)	1 050	0.34	0.47	0.60	0.73	0.84	1.07	1.27	1.61	2.02
xiii)	1 100	0.34	0.46	0.59	0.71	0.82	1.04	1.24	1.57	1.97
xiv)	1 150	0.33	0.45	0.57	0.69	0.80	1.02	1.21	1.54	1.93
xv)	1 200	0.32	0.44	0.56	0.68	0.79	1.00	1.19	1.51	1.89
xvi)	1 250	0.32	0.43	0.55	0.67	0.77	0.98	1.16	1.48	1.85
xvii)	1 300	0.31	0.42	0.54	0.65	0.75	0.96	1.14	1.45	1.82
xviii)	1 350	0.30	0.42	0.53	0.64	0.74	0.94	1.12	1.42	1.78
xix)	1 400	0.30	0.41	0.52	0.63	0.73	0.92	1.10	1.40	1.75
xx)	1 450	0.29	0.40	0.51	0.62	0.71	0.91	1.08	1.37	1.72
xxi)	1 500	0.29	0.40	0.50	0.61	0.70	0.89	1.06	1.35	1.69
xxii)	1 550	0.28	0.39	0.49	0.60	0.69	0.88	1.05	1.33	1.66
xxiii)	1 600	0.28	0.38	0.49	0.59	0.68	0.86	1.03	1.31	1.64
xxiv)	1 650	0.27	0.38	0.48	0.58	0.67	0.85	1.01	1.29	1.61
xxv)	1 700	0.27	0.37	0.47	0.57	0.66	0.84	1.00	1.27	1.59
xxvi)	1 750	0.27	0.37	0.46	0.56	0.65	0.83	0.98	1.25	1.56
xxvii)	1 800	0.26	0.36	0.46	0.56	0.64	0.81	0.97	1.23	1.54
xxviii)	1 850	0.26	0.36	0.45	0.55	0.63	0.80	0.96	1.21	1.52
xxix)	1 900	0.26	0.35	0.45	0.54	0.62	0.79	0.94	1.20	1.50
xxx)	1 950	0.25	0.35	0.44	0.53	0.62	0.78	0.93	1.18	1.48

Table 25 (*Continued*)

Sl No.	Design Wind Pressure N/m²	Nominal Thickness of Heat Strengthened Glass, *T* mm								
		3	4	5	6	8	10	12	15	19
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
xxxi)	2 000	0.25	0.34	0.43	0.53	0.61	0.77	0.92	1.17	1.46
xxxii)	2 050	0.25	0.34	0.43	0.52	0.60	0.76	0.91	1.15	1.45
xxxiii)	2 100	0.24	0.33	0.42	0.51	0.59	0.75	0.90	1.14	1.43
xxxiv)	2 150	0.24	0.33	0.42	0.51	0.59	0.75	0.89	1.13	1.41
xxxv)	2 200	0.24	0.33	0.41	0.50	0.58	0.74	0.88	1.11	1.40
xxxvi)	2 250	0.24	0.32	0.41	0.50	0.57	0.73	0.87	1.10	1.38
xxxvii)	2 300	0.23	0.32	0.41	0.49	0.57	0.72	0.86	1.09	1.36
xxxviii)	2 350	0.23	0.32	0.40	0.49	0.56	0.71	0.85	1.08	1.35
xxxix)	2 400	0.23	0.31	0.40	0.48	0.56	0.71	0.84	1.07	1.34
xl)	2 450	0.23	0.31	0.39	0.48	0.55	0.70	0.83	1.05	1.32
xli)	2 500	0.22	0.31	0.39	0.47	0.54	0.69	0.82	1.04	1.31
xlii)	2 550	0.22	0.30	0.38	0.47	0.54	0.68	0.82	1.03	1.30
xliii)	2 600	0.22	0.30	0.38	0.46	0.53	0.68	0.81	1.02	1.28
xliv)	2 650	0.22	0.30	0.38	0.46	0.53	0.67	0.80	1.01	1.27
xlv)	2 700	0.21	0.29	0.37	0.45	0.52	0.67	0.79	1.00	1.26
xlvi)	2 750	0.21	0.29	0.37	0.45	0.52	0.66	0.79	1.00	1.25
xlvii)	2 800	0.21	0.29	0.37	0.45	0.51	0.65	0.78	0.99	1.24
xlviii)	2 850	0.21	0.29	0.36	0.44	0.51	0.65	0.77	0.98	1.23
xlix)	2 900	0.21	0.28	0.36	0.44	0.51	0.64	0.76	0.97	1.22
l)	2 950	0.21	0.28	0.36	0.43	0.50	0.64	0.76	0.96	1.21
li)	3 000	0.20	0.28	0.35	0.43	0.50	0.63	0.75	0.95	1.19
lii)	3 050	0.20	0.28	0.35	0.43	0.49	0.63	0.75	0.95	1.19
liii)	3 100	0.20	0.27	0.35	0.42	0.49	0.62	0.74	0.94	1.18
liv)	3 150	0.20	0.27	0.35	0.42	0.48	0.62	0.73	0.93	1.17
lv)	3 200	0.20	0.27	0.34	0.42	0.48	0.61	0.73	0.92	1.16
lvi)	3 250	0.20	0.27	0.34	0.41	0.48	0.61	0.72	0.92	1.15
lvii)	3 300	0.19	0.27	0.34	0.41	0.47	0.60	0.72	0.91	1.14
lviii)	3 350	0.19	0.26	0.34	0.41	0.47	0.60	0.71	0.90	1.13
lix)	3 400	0.19	0.26	0.33	0.40	0.47	0.59	0.71	0.90	1.12
lx)	3 450	0.19	0.26	0.33	0.40	0.46	0.59	0.70	0.89	1.11

Table 25 (*Continued*)

Sl No.	**Design Wind Pressure** N/m²	**Nominal Thickness of Heat Strengthened Glass, *T*** mm								
		3	4	5	6	8	10	12	15	19
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
lxi)	3 500	0.19	0.26	0.33	0.40	0.46	0.58	0.70	0.88	1.11
lxii)	3 550	0.19	0.26	0.33	0.40	0.46	0.58	0.69	0.88	1.10
lxiii)	3 600	0.19	0.25	0.32	0.39	0.45	0.58	0.69	0.87	1.09
lxiv)	3 650	0.18	0.25	0.32	0.39	0.45	0.57	0.68	0.86	1.08
lxv)	3 700	0.18	0.25	0.32	0.39	0.45	0.57	0.68	0.86	1.08
lxvi)	3 750	0.18	0.25	0.32	0.38	0.44	0.56	0.67	0.85	1.07
lxvii)	3 800	0.18	0.25	0.32	0.38	0.44	0.56	0.67	0.85	1.06
lxviii)	3 850	0.18	0.25	0.31	0.38	0.44	0.56	0.66	0.84	1.05
lxix)	3 900	0.18	0.24	0.31	0.38	0.44	0.55	0.66	0.84	1.05
lxx)	3 950	0.18	0.24	0.31	0.37	0.43	0.55	0.66	0.83	1.04
lxxi)	4 000	0.18	0.24	0.31	0.37	0.43	0.55	0.65	0.83	1.03
lxxii)	4 050	0.18	0.24	0.31	0.37	0.43	0.54	0.65	0.82	1.03
lxxiii)	4 100	0.17	0.24	0.30	0.37	0.42	0.54	0.64	0.82	1.02
lxxiv)	4 150	0.17	0.24	0.30	0.37	0.42	0.54	0.64	0.81	1.02
lxxv)	4 200	0.17	0.24	0.30	0.36	0.42	0.53	0.64	0.81	1.01
lxxvi)	4 250	0.17	0.23	0.30	0.36	0.42	0.53	0.63	0.80	1.00
lxxvii)	4 300	0.17	0.23	0.30	0.36	0.41	0.53	0.63	0.80	1.00
lxxviii)	4 350	0.17	0.23	0.29	0.36	0.41	0.52	0.62	0.79	0.99
lxxix)	4 400	0.17	0.23	0.29	0.36	0.41	0.52	0.62	0.79	0.99
lxxx)	4 450	0.17	0.23	0.29	0.35	0.41	0.52	0.62	0.78	0.98
lxxxi)	4 500	0.17	0.23	0.29	0.35	0.41	0.52	0.61	0.78	0.98
lxxxii)	4 550	0.17	0.23	0.29	0.35	0.40	0.51	0.61	0.77	0.97
lxxxiii)	4 600	0.16	0.23	0.29	0.35	0.40	0.51	0.61	0.77	0.97
lxxxiv)	4 650	0.16	0.22	0.28	0.35	0.40	0.51	0.60	0.77	0.96
lxxxv)	4 700	0.16	0.22	0.28	0.34	0.40	0.50	0.60	0.76	0.95
lxxxvi)	4 750	0.16	0.22	0.28	0.34	0.39	0.50	0.60	0.76	0.95
lxxxvii)	4 800	0.16	0.22	0.28	0.34	0.39	0.50	0.59	0.75	0.94
lxxxviii)	4 850	0.16	0.22	0.28	0.34	0.39	0.50	0.59	0.75	0.94
lxxxix)	4 900	0.16	0.22	0.28	0.34	0.39	0.49	0.59	0.75	0.94
xc)	4 950	0.16	0.22	0.28	0.33	0.39	0.49	0.59	0.74	0.93

Table 25 (*Continued*)

Sl No.	Design Wind Pressure N/m^2	Nominal Thickness of Heat Strenghtened Glass, *T* mm								
		3	4	5	6	8	10	12	15	19
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
xci)	5 000	0.16	0.22	0.27	0.33	0.38	0.49	0.58	0.74	0.93

6.2 Installation

6.2.1 Basic installation requirements and materials used for glass are given hereunder:

NOTES

1 The provisions under this item do not include the use of other methods or systems for glazing, provided the alternate method or system can be demonstrated to satisfy the requirements for correctly supporting the glass within the frame, or glazing system.

2 Patent and other proprietary systems are not described/ covered here.

3 Installation technique for frameless glazing system is not covered here.

6.2.2 *Site Working and Glass Machining Operation*

6.2.2.1 Heat-strengthened and toughened glass shall not be cut or worked after heat treatment. All necessary cutting, drilling, notching and edge-working shall be carried out to correct dimensions prior to value addition to the glass, such as toughening/tempering/heat strengthening. The edges and surfaces of all glass types shall not be damaged during fixing.

6.2.3 *Dimensional Requirement*

The dimensions for edge clearance, edge cover, front and back clearance, rebate depth is selected in accordance with the requirements in **4.5.2**.

6.2.4 *Glazing Materials*

6.2.4.1 *Compatibility of materials*

A glazing material shall be used only when compatible with contiguous materials, including the rebate surface finish, setting or location blocks, distance pieces and glass type.

6.2.4.2 *Application of materials*

The application of glazing materials shall be in accordance with relevant/available Indian Standard or manufacturer's recommendations.

6.2.4.3 *Life expectancy of materials*

A glazing material shall only be used where its life expectancy (durability) has been established. The manufacturers' advice/guarantee should be sought for information regarding life expectancy.

6.2.5 *Setting Blocks*

The number and location of setting blocks shall be as shown in Fig. 14 and Fig 16. Generally, setting blocks shall be,

a) positioned at quarter points or not less than 30 mm from the corner, whichever is less;

b) the minimum width of each setting block shall be not less than the glass thickness; and

c) if a glazing bridge is used then the thickness of the glazing bridge can be added to the thickness of the setting block to achieve the minimum gap of 6 mm between the edge of glass and the framing member.

Setting blocks shall be located to equally support all panes of glass, and shall be fixed to prevent displacement during installation and service. The minimum length of each setting block (or two blocks side by side) shall be 25 mm in length for every square metre of glass area, with a minimum length of 50 mm. When wood is used as the material for setting blocks, only the seasoned ones should be used as green wood may shrink laterally (in the process of attaining equilibrium moisture content over a period of time) and result in loosened installations.

For example, for a 3.0 m^2 glass area, 3.0 mm × 25 mm = 75 mm long, that is, 75 mm is the length of each setting block.

Setting blocks shall be of resilient, load-bearing, non-absorbent, rot-proof, and material that is compatible with all other glazing materials conforming to available standards (if any) that may come into contact with the blocks.

NOTES

1 Setting blocks are used between the bottom edge of the unit and the frame to centralize and equally support both panes of glass.

2 Setting block width and location should not restrict water drainage.

3 Extruded rubber material with 80 to 90 shore A hardness is recommended.

4 Shaped setting blocks will be required for a glazing platform.

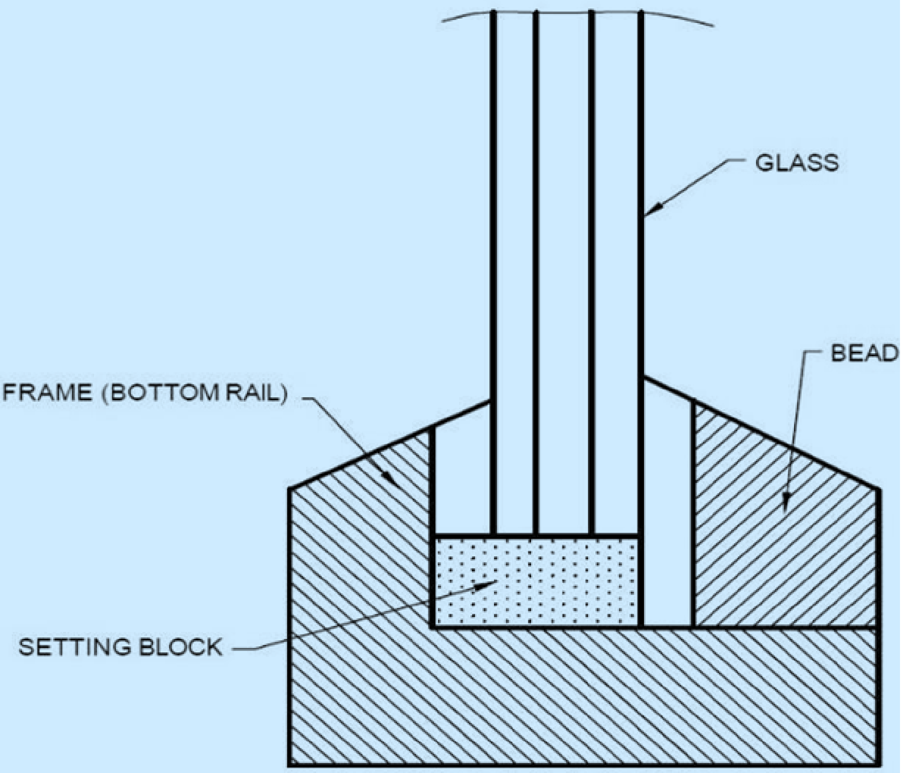


FIG. 14 POSITION OF SETTING BLOCK

6.2.6 *Location Blocks*

The number and position of location blocks shall be as shown in Fig. 15 and Fig 16.

Location blocks shall be,

a) of minimum of 25 mm in length;

b) at least as wide as the glass thickness;

c) positively located to prevent displacement in service; and

d) sufficiently resilient to accommodate movement within the frame, without imposing stress on the glass, and of resilient, non-absorbent material.

NOTES

1 Location blocks are used between the edges of the glass and the frame to prevent movement of the glass within the frame by thermal expansion or when the window or door is opened or closed. They are required to prevent the weight of the glass from causing the frame to become out of square.

2 Extruded rubber material with 55 to 65 shore A hardness is recommended.

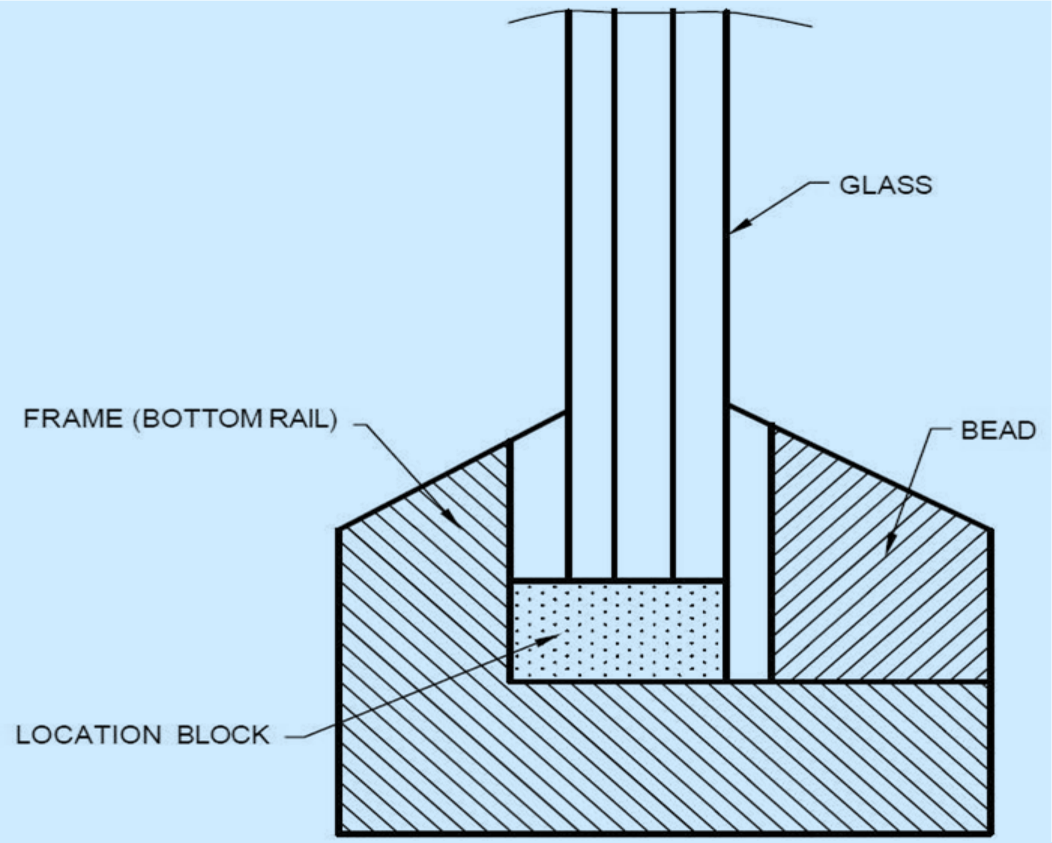


FIG. 15 POSITION OF LOCATION BLOCK

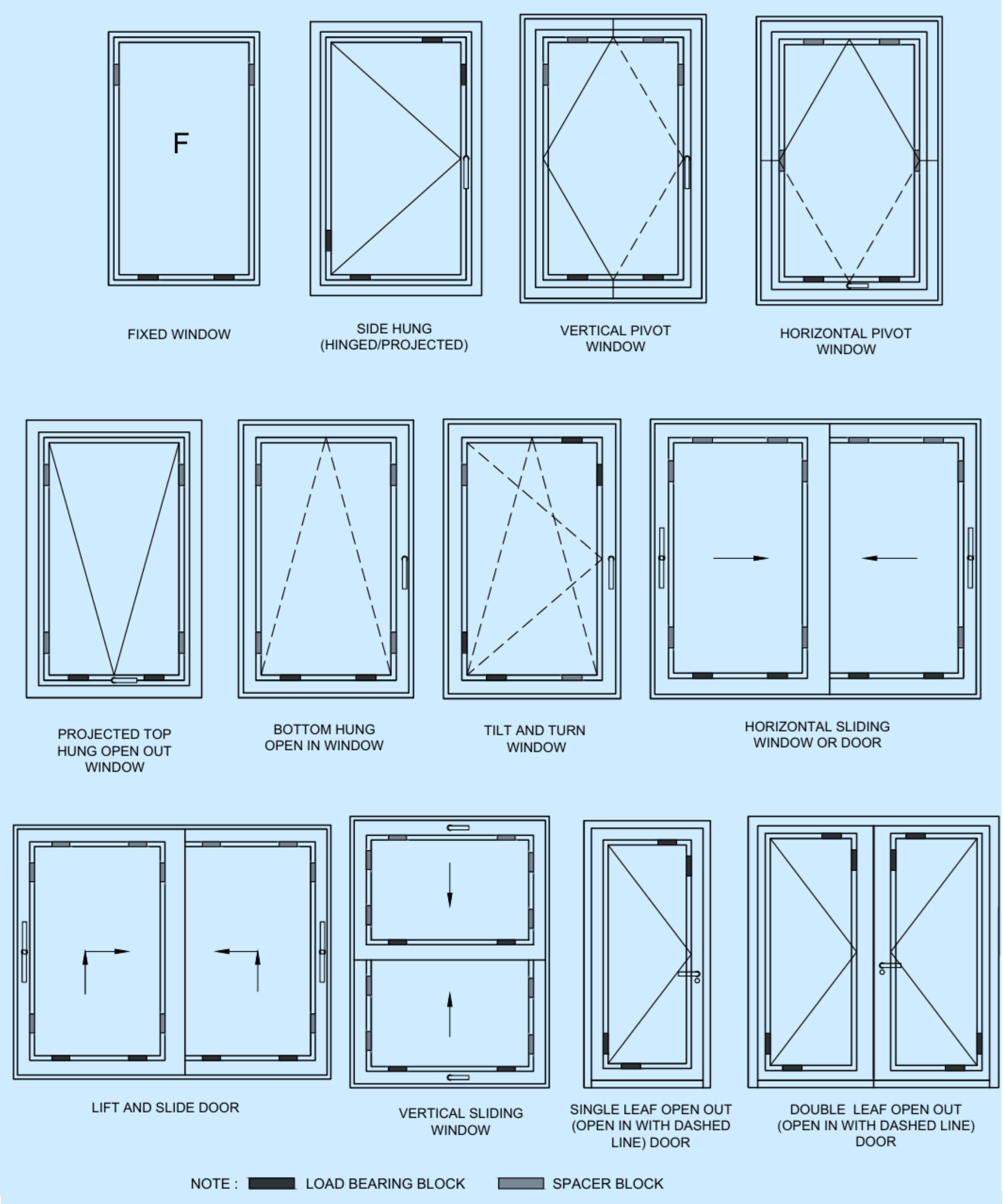

F
FIXED WINDOW
SIDE HUNG (HINGED/PROJECTED)
VERTICAL PIVOT WINDOW
HORIZONTAL PIVOT WINDOW
PROJECTED TOP HUNG OPEN OUT WINDOW
BOTTOM HUNG OPEN IN WINDOW
TILT AND TURN WINDOW
HORIZONTAL SLIDING WINDOW OR DOOR
LIFT AND SLIDE DOOR
VERTICAL SLIDING WINDOW
SINGLE LEAF OPEN OUT (OPEN IN WITH DASHED LINE) DOOR
DOUBLE LEAF OPEN OUT (OPEN IN WITH DASHED LINE) DOOR
NOTE : ■ LOAD BEARING BLOCK ▨ SPACER BLOCK

FIG. 16 NUMBER AND POSITION OF SETTING AND LOCATION/GLAZING BLOCK

6.2.7 *Distance Pieces*

Distance pieces, as shown in Fig. 17, used where required, shall be,

a) of resilient, non-absorbent material;

b) 25 mm long and of a height to suit the depth of the rebate and the method of glazing; and

c) spaced opposite each other, approximately 50 mm from each corner at intervals of not more than 300 mm.

The thickness shall be equal to the front and back clearance, to retain the glass firmly in the frame.

NOTES

1 Distance pieces are required to prevent displacement of glazing compounds or sealant by external loading, such as wind pressure.

2 Extruded rubber material with 55 to 65 shore A hardness is required.

6.2.8 *Rebates and Grooves for Installation*

Rebates, grooves and beads shall be cleaned and free from grease, moisture and other contaminants. All sealant surfaces shall be primed or sealed in accordance with the recommendations of the manufacturer of the glazing material.

The number and location of setting blocks and location blocks shall be as shown in Fig. 14 to Fig. 16, wherever necessary to maintain the requisite edge clearance. Each block shall support the full thickness of the glass.

6.2.9 *Glazing Beads*

Where used, glazing beads shall be capable of restraining the glass under all design forces.

6.2.10 *Structural Sealants*

Structural silicone shall be installed such that a full adhesive bond to the substrate is achieved. Application of structural silicone may require prior cleaning and or priming of the substrate.

Applied structural silicones shall not be installed adjacent to other materials that may be chemically incompatible with the structural sealant and cause a loss of adhesion or adverse chemical changes within the structural silicone that could lead to a loss of strength in the structural silicone. For guidance on the installation of structural silicone, reference to available standards/literatures may be made.

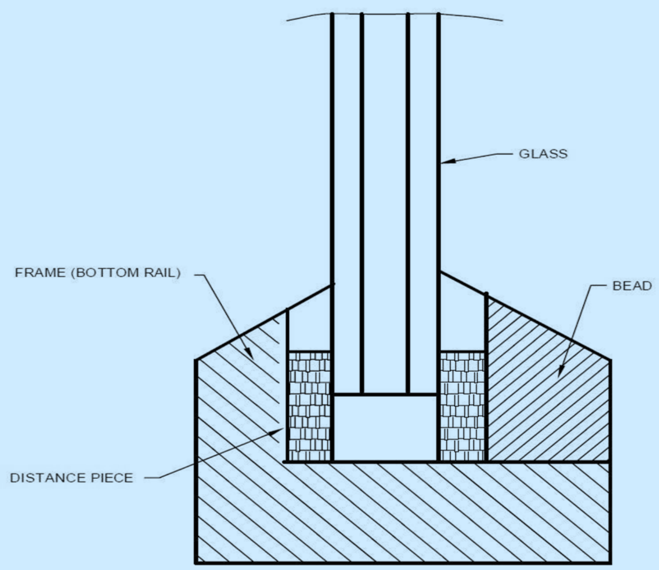


FIG. 17 POSITION OF DISTANCE PIECES

6.3 Design Criteria

6.3.1 *Frame Support Condition*

6.3.1.1 *Maximum area of glass panels subjected to wind loading*

The maximum span for a given standard nominal thickness of ordinary annealed, laminated, heat-strengthened and toughened glass for a given panel size shall be determined in accordance with **6.3.2**, **6.3.3** and **6.3.4** as applicable for the relevant support conditions. For heat strengthened laminated and toughened laminated glass, maximum allowable span shall be determined in accordance with **6.3.5**. For 3 mm monolithic annealed glass, the maximum area shall not exceed 0.85 m^2.

The minimum thickness of the nominal glass size shall be as per the accepted practice in accordance with Indian Standard specifications.

For laminated glass composites, the combined minimum thickness of the glass sheets may be used excluding the interlayer thickness. Alternatively, reference to specialist literature may be drawn for the same purpose.

6.3.2 *Rectangular Glass Supported on All Four Edges*

For rectangular glass supported on all four edges, the maximum area for the design wind pressure shall be determined using the corresponding tables provided for each type of glass. Linear interpolation may be used for any value in between those given therein while maintaining the aspect ratio.

6.3.3 *Rectangles of Glass Supported on Two Opposite Edges*

For rectangles of glass supported on two opposite edges, the maximum glass area for the design wind pressure shall be determined from Table 22 to Table 25 for ordinary annealed, laminated, toughened and heat-strengthened glass, respectively.

6.3.4 *Rectangles of Glass Supported on Three Edges*

For rectangles of glass supported on three edges, the maximum glass area shall be determined as for two-edge support spanning along the unsupported edge. Alternatively, basic engineering principles shall be adopted in determining the glass thickness for all applications where only three edges of the panel are supported.

NOTE — Butt glazing of adjacent panels in the same plane should not be considered as a support.

6.3.5 *Heat-Strengthened Laminated and Toughened Laminated Glass*

For heat-strengthened laminated and toughened laminated glass, the maximum span for a given standard nominal thickness for a given panel size shall be determined from Table 21 and Table 25, and Table 19 and Table 24, respectively with the design wind pressure being divided by the appropriate glass type factor, P_f (*see* Table 14), as applicable for the relevant support conditions.

6.3.6 *Serviceability Checks*

6.3.6.1 Glass complying to Table 17 to Table 25 are deemed to meet, the serviceability deflection limits specified. In the absence of any other specified values, the following values may be used for guidance.

6.3.6.2 *Maximum allowable deflection of framing members*

a) *For mullions*:
   1) Single height glazing — Span/175 or 19 mm, whichever is less.
   2) Double height glazing — For spans up to 4 110 mm, same as single height glazing; and for spans above 4 110 mm, the same shall be (Span/240) + 6.35 mm.

b) *For transoms*:
   1) Span/500 or 3 mm, whichever is the least for dead load.
   2) Span/175 or 19 mm, whichever is the least for wind load.

c) *Deflection at the centre of the glass*:
   1) Monolithic glass –Shortest span/60 or 19 mm, whichever is the least.

   2) Double glazed unit −Shortest span/90 or 19 mm, whichever is the least.

d) *Deflection at edge of the glass*:
   1) Shall be limited to 15 mm.

6.3.6.2.1 *Dielectric separation of dissimilar metals*

When the framing member for the glazing is aluminium and reinforcement is required to meet the deflection criteria, the reinforcement may be of aluminium or galvanized steel (red oxide coating being not recommended) with an insulating material between them at contact points. It is recommended to choose materials as close to each other in the galvanic series as possible.

6.3.7 *Ultimate Stresses*

The ultimate stresses for various types of glass are given in Table 26.

Table 26 Ultimate Limit State Design Stresses for Glass Subjected to Wind Loading

(*Clause* 6.3.7)

Sl No.	**Glass Type**	**Standard Nominal Thickness 'T'** mm	**Ultimate Limit State Design Stress at Given Location**	
			Away from Edge MPa	At Edge MPa
(1)	(2)	(3)	(4)	(5)
i)	Annealed	3	41.00	32.8
		4	38.99	31.19
		5	37.45	29.96
		6	36.2	28.96
		8	34.33	27.46
		10	32.8	26.24
		12	31.57	25.25
		15	30.15	24.12
		19	28.72	22.98
		25	26.96	21.57
ii)	Toughened	4	97.47	77.97
		5	93.61	74.97
		6	90.49	72.39
		8	85.82	68.65
		10	82.01	65.61
		12	78.91	63.13
		15	75.37	60.3
		19	71.81	57.45
		25	67.41	53.93
iii)	Heat strengthened	3	65.6	52.48
		4	62.38	49.9
		5	59.91	47.93
		6	57.91	46.33
		8	54.92	43.94
		10	52.48	41.99
		12	50.51	40.4

Table 26 Ultimate Limit State Design Stresses for Glass Subjected to Wind Loading

(*Clause* 6.3.7)

Sl No.	Glass Type	Standard Nominal Thickness '*T*' mm	Ultimate Limit State Design Stress at Given Location	
			Away from Edge MPa	At Edge MPa
(1)	(2)	(3)	(4)	(5)
iv)	Annealed laminated	5	37.73	30.18
		6	36.43	29.14
		8	34.41	27.53
		10	32.87	26.3
		12	31.62	25.3
		16	29.75	23.8
		20	28.23	22.58
		24	26.99	21.59

6.3.8 *Insulating Glass Units*

6.3.8.1 *Determining bite of structural silicone*

The structural bite requirement is directly proportional to the wind load and the dimension of glass. Higher the wind load and larger the dimensions of the glass are, the greater the amount of structural bite required. The controlling variables which affect the structural bite requirement are the maximum short span dimension of glass and the design wind load which the structural glazing system shall be designed to accommodate.

a) *Structural bite calculation for wind load and glass dimension*

$$\text{Minimum Structural Bite} = \frac{Glass\ Short\ span\ dimension \times wind\ load \times 0.5}{Maximum\ allowable\ design\ stress}$$

NOTES

1 Glass' short span dimension (SSD) is the shorter of the two dimensions (in m) of the rectangular glass panel.

2 Wind load is the maximum wind pressure, in Pascal, for a return period of 10 years based on local regulations.

3 The maximum allowable design stress for type of the structural sealant is selected as per manufacturer's recommendations.

4 The minimum structural bite shall be, not less than 6 mm for single glass and for double-glazed units (DGU) with equal glass thickness.

b) *Determination of thickness of structural silicone* — With a sealed IGU, there may be load sharing between the two panes of glass. If so, and if both panes are of the same thickness, the lateral load (*P*) is shared almost equally; thus the secondary seal bite is calculated as one half of that of the structural sealant bite, but should meet the minimum requirement. If of unequal thickness, the load shared by each pane will vary, depending on the difference in thicknesses. Further details are to be obtained from the manufacturer.

c) *Structural bite calculation for dead load*

$$Minimum\ Bite\ (m) = \frac{Weight\ of\ glass\ (kg)}{Perimeter\ of\ the\ glass\ (m) \times Seleant\ dead\ load\ design\ strength\ (kg/m^2)}$$

$$= \frac{\rho g T A}{Ps}$$

where

ρ = 2 500 kg/m^3 is the specific mass of flat glass corresponding to approximately of specific weight;

g = 9.81 m/s^2;

s = Allowable design stress for dead load (DL) for selected sealant considered for design, Pa;

T = thickness of the bite, m;

P = perimeter (if the horizontal frame members do not support the glass or deflect under the dead load of the glass, consider 2 times of its height only); and

A = area of glass panel, m^2.

6.3.8.2 *Maximum allowable span for glass and type*

Maximum allowable span is dependent on the thickness of the glass selected and type of glass used (for example annealed, toughened or heat strengthened glass). The maximum span is calculated in accordance with **6.1.9** (*see* Fig. 18 for details).

6.3.9 *Safety During Installation*

Glass and the coating layer (if any) should not be exposed to/in direct contact with aggressive materials such as acid, solvent, cement mortar, etc.

The fixing system of the panel should, in no case, cause shear stresses in the panel, and particularly the bonding interface between the glass sheet and the frame, either under the effect of external forces or due to differential expansion of components.

The protection of glass panel by means of a polyethylene sheet is recommended and shall provide ventilation for the glass in order to prevent thermal breakage.

Workers involved in the installation process shall be provided with adequate training and awareness about safety practices related to the handling and installation of glass panels. They shall be equipped with appropriate personal protective equipment (PPE), including but not limited to safety gloves, helmets, safety goggles, and footwear designed for the work environment, to minimize risks of injury during installation activities.

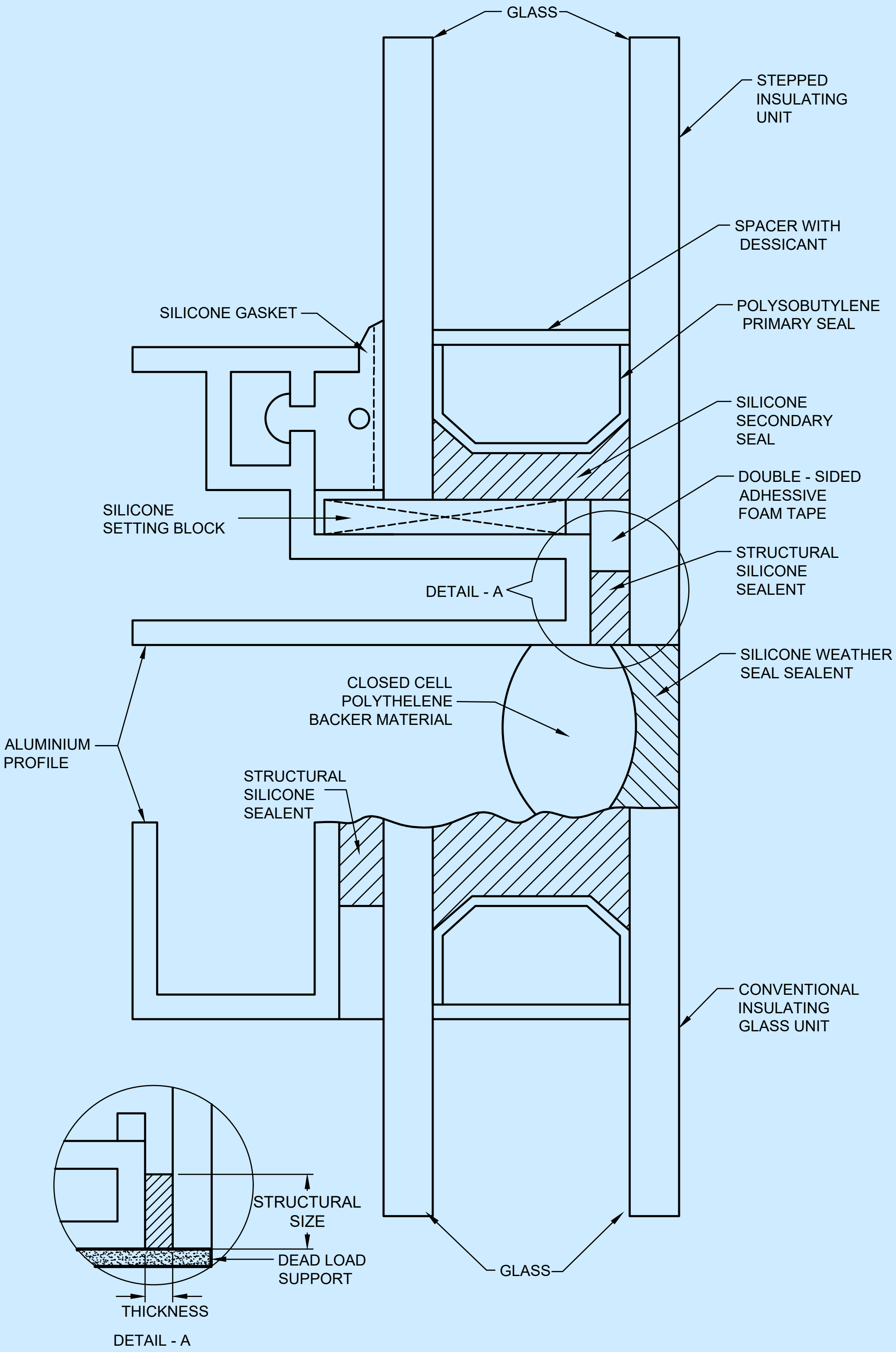

GLASS
STEPPED INSULATING UNIT
SPACER WITH DESSICANT
POLYSOBUTYLENE PRIMARY SEAL
SILICONE GASKET
SILICONE SECONDARY SEAL
DOUBLE - SIDED ADHESIVE FOAM TAPE
SILICONE SETTING BLOCK
STRUCTURAL SILICONE SEALENT
DETAIL - A
SILICONE WEATHER SEAL SEALENT
CLOSED CELL POLYTHELENE BACKER MATERIAL
ALUMINIUM PROFILE
STRUCTURAL SILICONE SEALENT
CONVENTIONAL INSULATING GLASS UNIT
STRUCTURAL SIZE
DEAD LOAD SUPPORT
GLASS
THICKNESS
DETAIL - A

FIG. 18 TYPICAL STRUCTURAL GLAZING DETAIL

NOTE — Dead load support for the glass or infill shall be determined based on 6.3.8.1 (c). Minimum 50 percent of thickness of external glass pane shall be supported at the bottom, in the case of structural glazed systems.

FIG. 18 TYPICAL STRUCTURAL GLAZING DETAIL

6.3.10 *Handling and Transportation*

6.3.10.1 *Transportation*

During the transportation of the flat glass (clear, tinted), coated glass (solar control and mirror), lacquered or painted glass the following methods (if other standard packaging specifications are not available) of storage, packing and interleaving shall be followed:

a) Flat glass shall be transported vertically;

b) Glass panes should not come into direct contact with each other by using appropriate interleaving such as powder or foam or paper. The lacquer opacified/enamel coated/screen printed glasses shall be separated by paper or foam; and

c) The packing and packing material shall be protected from water and if the glass is wrapped and sealed, the seal should remain closed until the product is used and precautions taken to not damage the packing while handling with a hoisting apparatus.

Workers involved in the transportation of glass shall be provided with adequate training on transportation safety practices. They shall be equipped with appropriate personal protective equipment (PPE), including but not limited to safety gloves, helmets, and safety footwear to minimize risks of injury during transportation activities.

6.3.10.2 *Handling*

During the handling of the flat glass (clear, tinted), coated glass (solar control and mirror), lacquered or painted glass, the following guidelines shall be followed:

a) Glass shall be handled with dry, clean gloves, specifically after washing to prevent stain marks on them;

b) Care shall be taken to avoid contact or friction of the coating or the opacified/ enamel/screen printed side with any rough surface or hard objects;

c) better practice is to handle glass with vacuum cups, and ensure that the vacuum cups and the glass are clean; and

d) It is recommended to keep the glass sheets clean if these are to be stored again before their processing or installation in the facade.

6.3.11 *Storage at Site*

To prevent staining, the storage area at site shall be,

a) a dry, well ventilated location at a sufficiently constant temperature;

b) protected from rain and running water;

c) protected from wide changes in temperature or humidity;

d) protected from alkaline material;

e) protected from direct contact of aggressive products such as corrosive vapours, acids, etc; and

f) glass panes are stored vertically on a soft surface such as wooden boards/battens.

6.3.12 *Storage after Cutting*

6.3.12.1 While stacking of coated glass/ mirror in the unpacked condition, the glass surface shall be facing towards the front (paint/coating backing towards the back).

6.3.12.2 Direct stacking of the mirror/coated glass one above the other should be prohibited and suitable inter-leaving material as mentioned in 6.3.10.1 should be used between two glass panes.

6.3.12.3 The support material for glass storage should not have affinity towards moisture absorption.

6.4 Fire Safety

6.4.1 This Section covers the requirement and selection of fire safety glass for buildings. General fire safety provisions for buildings may be drawn from Part F 'Fire and Life Safety' of this NBCS. It is important for any fire rated glass to provide sufficient amount of human impact safety feature even during fire or in general situations. The level of human impact safety of glass in buildings shall be in accordance with **7.1**. It is necessary that the fire rated system shall withstand the standard time-temperature curve during a fire test and shall give adequate time to the occupants for safe evacuation. This Section does not deal with the safety and security of people or goods in relation to risks of,

a) vandalism, riots, burglary or break in protection;

b) protection from explosion (terrorist attack);

c) natural disasters like earthquakes, cyclone, etc; and

d) plastic glazing, safety and security glazing, etc.

The requirements given here are minimum fire resistance requirements. In circumstances wherein the requirements of other Indian Standards exceed the requirements of this Section, the higher requirements shall be applicable.

6.4.2 *Glass for Fire Resistance*

6.4.2.1 Glazing system shall be so constructed, treated, or combined with other materials as to reduce loss of life or property during an event of fire, in comparison with ordinary sheet or flat glass, thereby preventing the passage of flame, hot gases, and smoke.

6.4.2.2 The following are the products in the scope of this Section that may be used for fire resistance provided they meet the requirements of accepted standard [C-8(18)]:

a) Wired fire resistant glass;

b) Glass-ceramic fire resistant glass;

c) Borosilicate fire resistant glass;

d) Thermally super toughened soda lime silicate fire resistant glass;

e) Laminated fire resistant glass;

f) Intumescent interlayer laminated fire resistant glass;

g) Gel-filled fire resistant glass; and

h) Low-E coated fire resistant glass.

6.4.2.3 *Testing procedures*

Any fire rated glazed building element needs to be tested as per accepted standard [C-8(19)]. The fire rating criteria of any building element is given in Part F 'Fire and Life Safety' of this NBCS.

6.4.2.4 *Identification of glass used for fire resistance*

a) All glass used for resisting fire shall conform to and preferably certified against available Indian Standards;

b) Since a fire resistant glass is not easily distinguishable from normal types of glass, it is imperative that every fire rated glass panel/unit should preferably have an indelible mark on all the panels/units of fire resistant glass showing the name of the manufacturer and the name of the product; and

c) Rating of the glass panel may also be provided, although the rating of glazing system is of primary concern.

The glass used for fire resistance should be in accordance with the requirements of Part F 'Fire and Life Safety' of this NBCS.

6.4.3 *Precautions*

6.4.3.1 Fire resistant glass alone shall not be enough to protect occupants from fire. Glass is only one component of the complete system.

6.4.3.2 Fire test report conducted for one application shall not be substituted for any other application. For example, a report for a partition shall not be used for a door application although the glass used and the fire ratings are the same. Similarly, approval in vertical orientation cannot be considered for acceptance in horizontal or inclined orientation.

6.4.3.3 The maximum glass size as mentioned in the test report should not be exceeded in practice with respect to the bigger linear dimension or area, unless otherwise supported with valid third-party tested evidence. The aspect ratio may be modified provided that none of the linear sides has a dimension greater than that of the largest dimension of originally tested glass.

6.4.3.4 The dimensions of the profile need to be the same as that tested. The sheet thickness of the profile can be increased with no change in the tested fire rating.

6.4.3.5 In case of any change in hardware, the new assembly should be retested as per the same standard and/or specification requirements. In the case of replacement of hardware, the same specification and make of the hardware can be used without retesting of the whole assembly.

6.4.3.6 Factors like edge cover, types of gaskets and type of fixtures also play a very vital role in achieving the fire performance of the building element. These have to be used and installed as per the test report/available standards.

6.4.3.7 Buildings having non-structural joints between floor slabs and external perimeter walls, pose an associated risk of smoke and fire traversing between adjacent floors is not uncommon. The use of suitable materials to seal such joints needs careful consideration towards fire safety as the same is part of the compartment/fire barrier.

All gaps between floor-slabs and facade assembly shall be sealed at all levels by tested system of equal fire rating as that of floor slab to prevent fire and smoke propagation from one floor to another. Accepted standard [C-8(20)] specifies the test method to determine the fire resistance performance of perimeter fire barrier joint system based on the length of time the system being tested to resist the fire before development of through openings or flaming and transmission of heat on the unexposed surface.

6.4.4 *Classifications of Fire Resistant Glass*

See **4** of accepted standard [C-8(18)].

6.4.5 *Cleaning and Maintenance of Fire-Rated Glazing System*

Routine maintenance and inspection are essential for fire rated glazing to ensure their optimal performance during a fire emergency. For more details in this regard, Part F ‘Fire and Life Safety’ of this NBCS may be referred.

7 SAFETY RELATED TO HUMAN IMPACT, ANTI-FALLOUT, WINDOW RESTRICTOR FOR CHILDREN AND DYNAMIC WIND RESTRAINT

7.1 Safety Related to Human Impact

7.1.1 *General*

The provisions herein are limited to the behaviour of glass when subjected to various kinds of human impact, precautions against risk of fall and falling glass. Conditions outside of ‘human impact’ are not covered under the scope of this Section.

This Section does not assume that the glass used in accordance to this Section will not break under all human impact conditions, rather,

a) it will not break under most likely forms of human impact; and

b) even if it breaks, the likelihood of cutting or piercing injuries will be minimised by virtue of the protection given to the glass, or by the limited size, or by the fracture characteristics of the glass.

Further, this Section does not deal with the safety and security of people or goods in relation to risks of,

a) vandalism, riots, burglary or break in protection;

b) fire arm protection;

c) protection from explosion (terrorist attack);

d) natural disasters like earthquakes, cyclone, fire, etc; and

e) plastic glazing material, safety and security glazing, etc.

In circumstances wherein the requirements of any referred standard(s) exceeds the requirements of this Section, the higher requirement shall be applicable.

The use of this Section shall also be in conformity with all other relevant standards on fire safety, structural stability, natural disasters, safety and security, etc in force.

7.1.2 *Safety Glass*

Glazing material that are constructed, treated, or combined with other materials shall reduce, in comparison with ordinary sheet/ float/ plate glass, the likelihood of injury to persons by objects from exterior sources or by these safety glasses when they may be cracked or broken.

The following are the products in the scope of this Section that may be used in safety glazing provided they meet the conformity requirements of accepted standard [C-8(7)]. Safety glass according to this Section shall be of following types:

a) Toughened safety (tempered) glass; and

b) Laminated safety glass.

7.1.2.1 All safety glasses shall meet the requirement of tests specified in accepted standard [C-8(7)].

7.1.2.2 In atria where there is no impact loads above 10 m, suitable toughened glass is adequate. *See* **4.2.9**, in case of use of glass fins as a structural member.

7.1.3 *Critical Location*

Where any glazing is within 1.5 m above the floor level of a building, it is considered likely to be subjected to human impact and hence, shall comply with the human impact safety requirements of this Section. Safety glazing should also be used,

a) where there is danger of falling infill glass material(s) from overhead glazing;

b) the danger of falling due to a change in floor level; and

c) in case of balustrades, stairs and floors.

Based on typical accidents in glazed buildings, certain locations in buildings are found to be more vulnerable to human impact than others. Some of such critical locations are given below and shown in Fig. 19, where necessary precautions have to be followed:

1) in-and-around doors, low windows;

2) door side panels;

3) panels mistaken for a doorway or opening;

4) panels at low levels in walls and partitions;

5) bathrooms;

6) building associated with special activities, for example, gymnasia, enclosed swimming pools, etc;

7) schools and child care facilities; and

8) nursing homes and care facilities for the aged and infirmed.

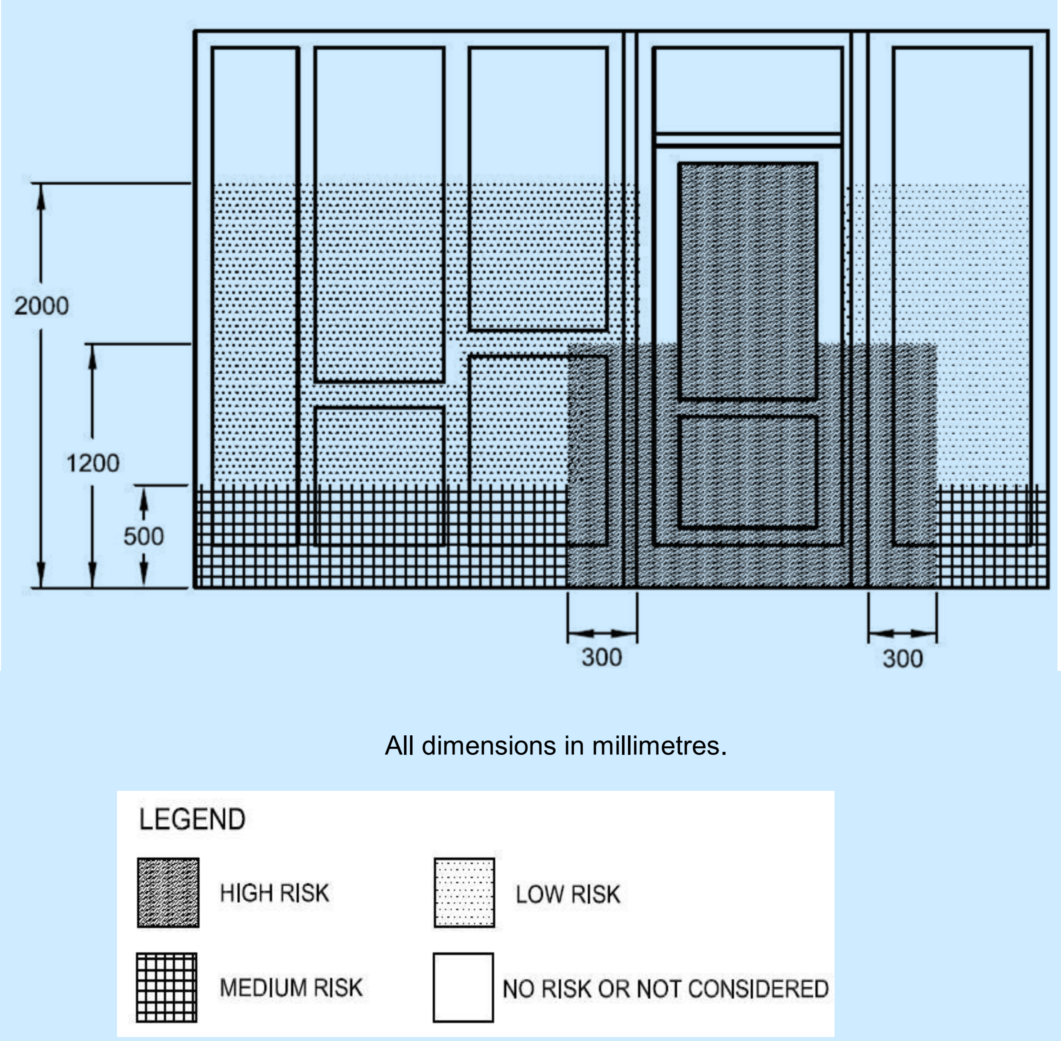
Suitable precautions should be taken to reduce the injuries that can result from glass breakage by,

i) selecting glass of a suitable type, thickness and size;

ii) enhancing a person's awareness of presence of glass by making glass visible (manifestation of glass); and

iii) minimizing manual handling of large pieces of glass during installation.

Based on the above, a comprehensive suggestion on type of glass to be used at different critical location/cases is provided in Table 27 for information.


2000
1200
500
300
300
LEGEND
HIGH RISK
LOW RISK
MEDIUM RISK
NO RISK OR NOT CONSIDERED

All dimensions in millimetres.

FIG. 19 CRITICAL LOCATIONS

Table 27 Type of Glass Suggested for Use at Different Critical Locations/Cases in Buildings

(*Clause* 7.1.3)

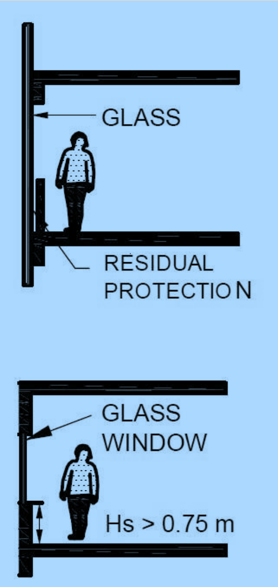
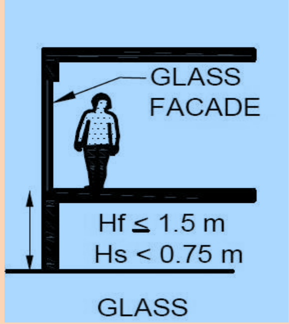
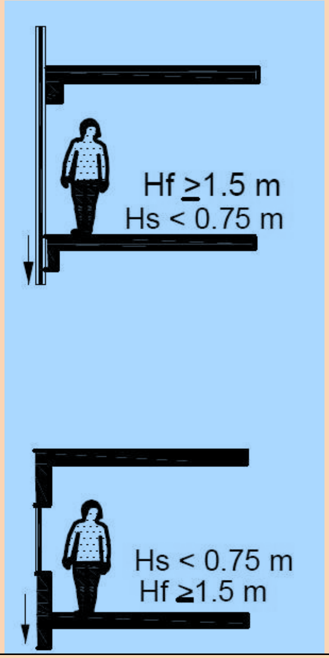
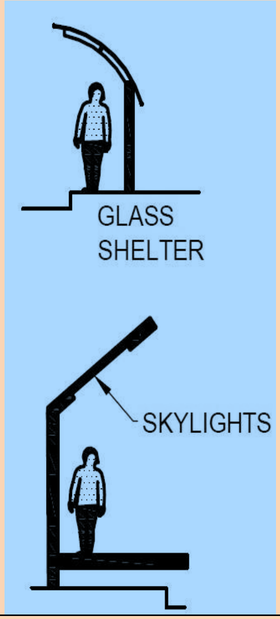
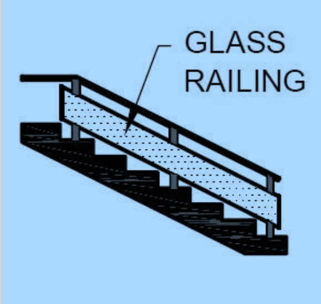
CASE 1		CASE 2	CASE 3	CASE 4	CASE 5
Vertical Walls with Residual Protection or $H_s \geq 0.75$ m (not likely to be Subjected to human impact)		Vertical Walls $H_s < 0.75$m and $H_f \leq 1.5$ m (human impact but no risk of fall)	Vertical Walls $H_s < 0.75$m and $H_f > 1.5$m (human impact and risk of fall)	Horizontal or Sloped Glazing Glass (risk of fall)	Glass Acting as a Balustrade/Railing (human impact and risk of fall)
(1)		(2)	(3)	(4)	(5)
	 GLASS RESIDUAL PROTECTION GLASS WINDOW Hs > 0.75 m	 GLASS FACADE Hf ≤ 1.5 m Hs < 0.75 m GLASS	 Hf ≥1.5 m Hs < 0.75 m Hs < 0.75 m Hf ≥1.5 m	 GLASS SHELTER SKYLIGHTS	 GLASS RAILING
Type of glass	Any glass[1)]	Safety glass[2)]	Safety glass[2)]	Laminated safety glass	Laminated safety glass

Table 27 (*Continued*)

Examples	Residual protection is the safeguard provided to avoid the impact of human being on glass. It is provided on the side of the glass where there are chances of human impact. It can be achieved by providing protection in the form of a sill structure or transom, chair rail or grill work inside.	a) Doors b) Side panels c) Curtain walls d) Glazed area e) Doors in bathroom 1) Fully framed 2) Partially framed 3) Frameless f) Facade g) Windows h) Internal partitions and doors j) External facade and doors on ground floor, above floor with terrace outside.	a) Curtain walls b) Facade c) Spandrels d) High activity area e) High risk area f) To avoid risk	a) Roof (Skylights) b) Ceilings c) Bus shelters d) Floors e) Stairs f) Sloped facade	a) Balustrades b) Balcony c) Railings

[1] Safety glass is not mandatory.

[2] Laminated safety glass is preferred.

NOTES

1 'H_f' corresponds to height of fall of human being or glass in case of change in level and 'Hs' corresponds to the sill height with reference to floor height.

2 In case of mirror glazing, it should conform to the requirements of other safety glasses unless it is fully backed by a solid material.

3 In Case 2 and Case 3, if the smaller dimension of the pane is 250 mm or less and its area is 0.5 m^2 or less, glass other than safety glass may be used, provided that its nominal thickness is not less than 6 mm (applicable to vertical glazing).

4 Toughened or laminated safety glass should meet respective test requirements as given in respective Indian Standards.

5 The effective toughened safety glass thickness and/or laminated safety glass configuration shall be determined case by case with regard to,

a) other solicitations (wind load, snow load, dead load, and human load);

b) the overall dimension (length, width of surface);

c) the aspect ratio of the glass; and

d) the glazing fixing type (framing, bolted system, structural system, etc).

Table 27 (*Concluded*)

6 Precautions against chances of injuries due to broken glass falling on people include:

- a) Broken annealed glass falling on people can cause grievous or even fatal injuries; hence it is recommended to use safety glass in locations other than defined in Case 1 where the risk of people getting hurt by falling glass is high.
- b) Toughened safety (tempered) glass has a safe breakage pattern, as it breaks and disintegrates into small and relatively harmless particles. However, thick toughened glass particles may stay interlocked, and fall as lumps of these multiple particles and can cause a minor or medium injury mainly due to the weight of the cluster.
- c) Laminated safety glass shall generally not fall out of fixing. However, where laminated glass with both glasses toughened, used for horizontal or sloped glazing, in case of failure of both toughened glasses, it may crumble as a blanket and fall out of fixing. This factor needs to be considered while designing horizontal and sloped glazing. Further, when the slope is acute, inner pane facing the floor should be laminated; and when the slope is obtuse, the outer pane facing the ground/floor should be laminated and all obtuse angle sloped glazing shall be continuously capped for safety reasons.
- d) Any broken glass in any glazing should be removed immediately on breakage.
- e) Strength of the glazing system should be such that it has the ability to hold glass in place and prevent it from falling out as a whole.
- f) For over-head applications like skylights and canopies, for the safety of maintenance workers and people underneath, the broken laminated glass shall be capable of sustaining a load of 100 kg for a minimum duration 30 min.

7 In case of external laminated glass facades, openable portions have to be left at regular distances for firefighting and smoke exhaust. This portion should be of toughened (safety tempered) glass and clearly indicated by suitable visible marking. *See also* Part F ‘Fire and Life Safety’ of this NBCS.

8 If insulating glass unit (IGU) is used in situations mentioned in this Section, then one of the following shall apply:

- a) If IGU is installed in areas subjected to human impact on either side, then both the panes of the unit shall meet the requirements of this Section.
- b) In situations where access is restricted to one side of the unit, then only the accessible side should meet the requirements of this Section.

9 Awareness of presence of glass may be by making visible manifestation.

10 For specific provisions relating to smoke evacuation, Part F ‘Fire and Life Safety’ of this NBCS may be referred.

7.1.4 *Manifestation* (*Making Glass Visible*)

7.1.4.1 Presence of glass in a door, side panel or a panel capable of being mistaken for a doorway or opening, which is not made apparent by transoms, colonial bars, door frames, large door handles, stall or other components of glazing system, should be made apparent by some form of manifestation. Decorative treatment, such as being opaque, or patterned are the other common manifestation options.

The manifestation employed should be of a sufficient size to make it immediately obvious. The manifestation should preferably be permanent, for example etching of the glazing; alternatively, if applied materials are used, they should be durable and not easily removed.

7.1.4.2 A band or marking may not be required, where any one of the following apply:

a) Width of the glass is not greater than 500 mm at any part (this applies to overall panel assembly – not individual glass pieces as in faceted glazing).

b) Glass is provided with at least one fixed glazing bar, firmly attached to the styles to locate and protect each face of the glass. At least one transom (glazing bar) shall be located with its upper edge not less than 500 mm and its bottom edge not more than 1 000 mm above the floor level. The glazing bar shall have a face of width 40 ± 3 mm; and

c) Alternatively, patterns may be used as an acceptable form of marking provided it meets the other criteria in this Section.

7.1.5 *Identification*

All safety glasses shall be procured from certified manufacturers and the product shall conform to relevant Indian Standards and shall carry all relevant information through the approved label/permanent (indelible) markings on the glass surface.

7.1.6 *Test Requirements*

7.1.6.1 Safety glass shall confirm to all the test requirements mentioned in the accepted standard [C-8(7)].

7.1.6.2 *Mechanical strength*

The required mechanical strength values (*see* Table 28) apply to quasi-static loading over a short time like wind loading relate to 5 percent probability of breakage at the lower limit and 95 percent confidence intervals.

If the glass satisfies the relevant impact test performance requirements (or fragmentation test for toughened glass), in addition to all other appropriate tests mentioned in available Indian Standards or as listed in Table 28, these materials can be classified as safety glass.

Table 28 Minimum Mechanical Strength Required for Fully Toughened Glass

(*Clause* 7.1.6.2)

Sl No. (1)	**Type of Glass** (2)	**Mechanical Strength** N/mm^2 (3)
i)	Float (clear/ tinted/ coated/ mirror)	120
ii)	Enamelled flat (based on enamelled surface in tension)	75
iii)	Patterned glass	90

7.2 Anti-Fallout

The following shall apply:

a) For all open out windows in buildings up to 5 storey height (< 15 m) anti-fallout secondary safety device is optional; and

b) For all open out windows in buildings more than 5 storey height (> 15 m) anti-fallout secondary safety device is mandatory.

7.2.1 In the case of a fall out due to the sash getting completely disengaged from the hinges/stay arms/restrictors, the anti-fallout device shall be capable of withstanding the self-weight of the sash. The drop height for the test shall be 100 mm. Design and testing for the mechanism to take into consideration jerk load with a factor of safety 2.0. Both static tensile test and a drop test with the mechanism installed in a window to be carried out to validate the compliance of the hardware to the design requirements.

7.3 Window Restrictor for Children

For windows which are non-emergency exits, projected top hung window, parallel opening window, vertical sliding hung window, side hung window and pivot window (except when used as an access door), the window restrictor shall be located such that the clear opening shall not exceed 100 mm (for human life safety especially for anti-fallout for children). When a force of 250 N is applied in opening condition to any part of the sash a sphere of 100 mm shall not pass through any part of the opening. Key releasable window restrictor can be used for the purpose of cleaning/maintenance. The side hung opening shall be restricted to be used in low rise buildings {< 15 m, *see* good practice [C-8(15)]}. For buildings above ≥ 15 m height, projected top hung or parallel opening with an opening restriction of 100 mm shall be used.

NOTES

1 For fire access panels/window, the local authority regulations will be applied and same will supersede the above.

2 The above requirement of window restrictor for children is mandatory for residential apartments and optional for commercial establishment. However, it is recommended to limit the opening to 100 mm for commercial establishments as well, especially for high rise buildings.

7.4 Dynamic Wind Restraint

This is applicable for open out windows in buildings more than 5 storey height (> 15m) and where the dynamic wind load is high due to the adjacent structures or terrain. Installed hardware shall be capable of self-locking the open window upon first time closure of the window due to wind conditions; in order to avoid fatigue failure on the hinges and stays. The mechanism can be releasable either using existing handle or additional release trigger. Design shall be to serviceability conditions.

8 GLAZING SYSTEM

8.1 The provisions relating to glazing system are covered hereunder. The details and procedure for selection, design, fabrication, installation, testing and maintenance of glazing system and its materials, considering the performance factors, including structural, seismic, acoustic insulation, fire resistance and energy efficiency are covered here under.

For classification of glazing system, reference may be made to **6** of accepted standard [C-8(14)].

8.2 Design and Selection

The design considerations and parameters for the design and selection of a glazing system and the components involved, along with its associated materials used in buildings are given below.

8.2.1 *Design Considerations*

Table 29 covers the various design considerations for glazing systems.

Table 29 Design Considerations

(*Clause* 8.2.1)

Sl No. (1)	Design Considerations/Criteria (2)	Reference Standards (3)
i)	**Structural aspects and parameters:**	
	a) Design load and wind load classification	As per good practice [C-8(15)] and accepted standard [C-8(14)]
	b) Other Loads — Live load, dead load, etc	As per good practice [C-8(21)]
	c) Air infiltration/Exfiltration and its classification	As per accepted standard [C-8(14)]
	d) Deflection	As per **6** and accepted standards [C-8(14)] and [C-8(12)]
	e) Seismic performance	As per **6.1.6** and good practice [C-8(16)]
	f) Water tightness and its classification	As per accepted standard [C-8(14)]
	g) Glass thickness	As per good practice [C-8(22)]
	h) Structural sealant	As per **4.4.1**
	j) Frame/profile specifications:	
	1) Aluminium	As per accepted standard [C-8(12)]
	2) uPVC	As per accepted standard [C-8(23)]
	3) Steel	As per accepted standard [C-8(24)]
	k) Hardware and fixing	As per **5.4** of accepted standard [C-8(12)]
ii)	**Energy aspects and parameters:**	
	a) Window to wall ratio	As per relevant guidelines/best practices (Handbook on ‘Sustainability in Buildings’)
	b) Building orientation	
	c) Window to floor ratio	
	d) Thermal performance (roofs and fenestration):	
	1) U-Value of glazing	As per relevant guidelines/best practices (Handbook on ‘Sustainability in Buildings’)
	2) Solar heat gain Co-efficient (SHGC)/Solar factor of glazing	
	3) Visible light transmittance (VLT)	
	4) Glass – Thermo – Optical properties: U value, solar heat gain co-efficient, visible light transmittance, internal and external (heat and light) reflectance and transmittance, shading co-efficient	As per **5**

Table 29 (*Concluded*)

Sl No. (1)	Design Considerations/Criteria (2)	Reference Standards (3)
	e) Lighting	As per Part D 'Building Services, Section 1, Lighting and Natural Ventilation' of this NBCS
iii)	**Safety**	
	a) Safety related to human impact	As per **7.1**
	b) Window restrictor for children	As per **7.3**
	c) Anti-fallout	As per **7.2**
	d) Fire safety	As per **6.4** and Part F 'Fire and Life Safety' of this NBCS
	e) Security glazing:	
	1) Bullet resistance	As per **9**
	2) Ballistics resistance	As per **9**
	3) Resistance to explosion	As per **9**
	4) Burglar resistance	As per **9**
iv)	**Acoustics parameters**	
	a) Airborne sound insulation	As per accepted standard [C-8(25)
	b) Impact sound insulation	As per accepted standard [C-8(26)]

8.2.2 *Design Parameters*

To achieve the performance criteria, care should be taken so that components in the system are selected and designed for the following parameters, such that the necessary performance criteria is met both individually and as a system:

a) Loading;

b) Deflections and allowable stress;

c) Movements;

d) Impact resistance;

e) Acoustic and sound insulation; and

f) Energy performance.

8.2.2.1 *Loading*

Wind load, live load, dead load, load combinations as per good practice [C-8(27)], seismic load as per good practice [C-8(16)], and other consequential loading may be considered.

8.2.2.2 *Deflections and allowable stress*

The deflection of framing members, members supporting brittle materials, metal panels, glass panels and the allowable stress shall be in accordance with 6.3.6.2. The allowable stress shall be in accordance with good practice [C-8(27)].

8.2.2.3 *Movements*

The glazing system (and its framing elements) shall be able to accommodate the movements caused due to wind loads, seismic loads, live loads, dead load deflection, thermal expansion and contraction of members, slab deflection, etc.

8.2.2.4 *Impact resistance*

Any glazing (in the glazing system) within 1 500 mm above the floor level of a building is considered likely to be subjected to human impact and hence, shall comply with the human impact safety requirements given in 7.1.

8.2.2.5 *Acoustics and sound insulation*

The recommendations on acoustics and sound insulation given in Part D 'Building Services, Section 4 Acoustics, Sound Insulation and Noise Control' of this NBCS shall be applicable.

8.2.2.6 *Energy performance*

The recommendations on the principal energy performance characteristics of the glazing system shall meet the provisions given in 5.

The primary characteristics required in general are reducing thermal losses and solar gains. For additional reference to visible light transmittance (VLT), solar heat gain coefficient (SHGC) and thermal transmittance (U-factor) features, relevant guidelines/best practices (Handbook on 'Sustainability in Buildings') may be referred.

8.2.3 *Types of Structural Frame Materials*

For the framed/semi-framed systems, materials such as aluminium, stainless steel, uPVC and timber, which are commonly employed are given hereunder.

8.2.3.1 *Aluminium alloy*

Extruded aluminium alloy used for structural framing members, shall be fabricated from the most appropriate grade of alloy complying with the relevant standard(s). The thickness of the aluminium sections should be in accordance with structural and hardware fastening requirements and shall be capable enough to meet the design requirements and satisfy the performance requirements.

Such extrusions in framing members and trims shall preferably be extruded aluminium grade 6063-T5, 6063-T6, 6060-T66, similar or stronger. Where 6063-T5 is to be used in shaped structures, supporting structural calculations particularly the stress criteria be ensured. Extrusion alloy 6061 or 6105 are commonly used for higher strength. Aluminium brackets shall be extruded aluminium grade 6061-T6 or approved equivalent. All aluminium alloys used as extruded rods/bars, tubes and profiles shall be compliant with accepted standard [C-8(28)].

Sheets and plates may be obtained from the following alloys of aluminium along with their primary characteristics:

a) 1100 — A low strength alloy suitable for applications requiring a high degree of formability.

b) 1135 — Brighter finish when anodized.

c) 3003 — General purpose sheet alloy with fair mechanical properties and excellent formability, but susceptible to structural streaking when anodized (noticeable in large flat areas).

d) 5005 — Excellent workability, weldability and corrosion resistance.

e) 5052 — Slightly better mechanical properties and excellent corrosion resistance and weldability.

Other alloys can be used provided that they meet the required physical properties and the specified performance requirements.

8.2.3.2 *Stainless steel*

Mullions, panels, fascia, column covers, windows, doors, trim, roofing, gutters, flashing, hardware and other items where minimum maintenance is anticipated, shall be of austenitic stainless steels of Type 301, 302 and 304 complying with accepted standard [C-8(29)] and employed for their mechanical properties as they are highly corrosion resistant for all normal exposures.

For interior decorative applications, where regular maintenance will be provided, Type 430 may be used as it has lesser corrosion resistance properties. For external applications like in coastal regions where maximum resistance to corrosion is required, stainless steel shall be of Type 316. Particular attention shall be paid to the direction of the rolling grain on self-finished stainless steel components where the finish is aesthetically important. All screws, nuts, bolts, washers, self-tapping screws and other fastenings, including those used for the hardware, shall be of stainless steel Type 304, 316, 430 complying with accepted standard [C-8(29)]. Type 316 based steel fasteners, etc shall be preferable when they are used in coastal regions on the exposed side.

8.2.3.3 *uPVC*

A relatively flexible material, PVC which is internally reinforced with steel or aluminium to give it the required strength and stiffness may also be used. The inherent ability to make a variety of profiles, easier maintenance, corrosion resistance and heat resistance when used may be considered when choosing uPVC sections.

8.2.3.4 *Timber*

Timber frames are relatively stiff and particularly treated timber combined with good design and workmanship give an acceptable life. They are adopted for their inherent thermal insulation property, light weight and improved sound insulation. Tenderness to absorb moisture, if not carefully treated prior to use can lead to possible rotting or even warping resulting in air and water infiltration and regular painting and maintenance are the factors to be considered while choosing timber as the framing material.

8.2.4 *Surface Finishes*

The commonly employed surface finishes are listed hereunder:

a) *Aluminium frames* — The main types of aluminium frame coatings are as follows:
   1) Anodized finish,
   2) Powder paint finish, and
   3) PVDF coating.

b) *Steel frames* — Surface finish on stainless steel frames plays a major role in its resistance to corrosion and hence it is an important design aspect to be clearly specified. The types of surface finishes listed here shall be in accordance with applicable relevant standards:
   1) Mill,
   2) Ground,
   3) Brushed,
   4) Polished,
   5) Bead blasted,
   6) Electro polished,
   7) Coloured, and
   8) Patterned.

Electro polishing of steel frames shall be done in accordance with available standards.

c) *Timber frames* — The function of finishes on timber is two-fold, first to improve the durability of the frame and second to add to the aesthetics. Unfinished, unprotected timber weathers as a result of gradual changes to its physio-chemical structure brought about by temperature and moisture content variations. The finishes may be of the following types:

   1) *Conventional opaque systems* — Water and solvent borne;
   2) *Natural finishes* — Semi-transparent and opaque; and
   3) Water repellent preservatives, wood primers, undercoats and finishing coats (gloss, semi-gloss, flat and low sheen).

Based on the application, the appropriate type of finish shall be chosen.

8.2.5 *Types of Anchorages*

Post-installed anchors are used primarily to join the mullions and transoms to the beam or slab through an appropriate bracket. The most common types of post-installed anchors are torque controlled expansion anchors and adhesive anchors. The selection of the appropriate anchor depends on the load requirement. For details on the types of post-installed anchors, reference may be made to good practice [C-8(30)].

There are different factors which influence the selection of anchors and to ensure proper performance of the anchor during its service life. These include:

a) *Diameter* — The following parameters shall be calculated for the selection of the anchor diameter:

   1) Dead load acting on the anchor;
   2) Live load incident to the anchor (wind load- tensile or shear);
   3) Weight of bracket, aluminium channels and other associated components; and
   4) Performance against earthquake load.

b) *Length* — The overall length of the anchor is based on the effective embedment length into the concrete and the total thickness of the glazing components which have to be fastened to the base material. Insufficient embedment length shall lead to pull-out failure of the anchor;

c) *Material* — Stainless steel and galvanized iron are the two main types of materials used in the manufacturing of anchors. The selection of anchor material shall be based on the location of the anchors, considering factors such as interior or exterior application, exposure to weather, or enclosed conditions;

d) *Coating* — The following type of coating shall be used based on the specific environmental condition met with:

Sl No. (1)	*Environmental Condition* (2)	*Coating to be Used* (3)
i)	Particular influence of moisture	Zinc plated
ii)	Occasional exposure to condensation and in coastal areas/slightly corrosive	Hot-dip galvanized
iii)	Heavy condensation/corrosion and in coastal areas:	
	a) areas with high corrosion risk	Stainless steel (SS 316)
	b) risk of exposure to corrosion is medium	Stainless steel (SS 304)

e) *Load Direction* — Based on the orientation of the anchor, they are incident to shear loading, tensile loading and combined loading;

f) *Base material* — The material characteristic of the base material (concrete) also plays a major role in avoiding failure in the anchorage. The material shall be of suitable grade, have minimum thickness, shall be properly cured and have the necessary compressive stress. Unless otherwise mentioned by the concerned structural engineer, the concrete shall be considered as cracked for all design purposes. Reference shall be made to good practice [C-8(30)] for more details in this regard;

g) *Anchor spacing and edge distance* — Anchor spacing is the centre to centre distance between the anchors. Edge distance is the distance from the centre of the anchor perpendicular to the respective edge of the concrete member. Reference shall be made to good practice [C-8(30)] for more details in this regard;

h) *Effective embedment depth* — It is the effective depth which actually transfers the forces passing through the anchor into the concrete. Reference shall be made to good practice [C-8(30)] for more details in this regard;

j) *Environmental condition* — Environmental conditions like temperature, humidity, salinity, etc will affect the performance of the anchors and may lead to pre-mature failure. Hence, careful selection of the material and coating should be done when selecting anchors which are to be installed in location subjected to adverse environmental impact such as coastal region; and

k) All the anchors shall be designed as per the recommendations of good practice [C-8(30)].

8.2.6 *Hardware Materials*

The material, geometry and finish of all the hardware materials shall be as per the requirement and should not affect the performance of the glazing system. All materials and finishes shall be as per relevant Indian Standards and tested before installing into the system in accordance to relevant Indian Standards.

8.3 Fabrication

8.3.1 *Factory*

The manufacturer shall ensure that proper internal control and documentation including records of test results performed be maintained about the production. The above shall enable quality assurance of the materials and process involved.

NOTE — For fabrication tolerance of aluminium systems, reference shall be made to **6** of accepted standard [C-8(12)].

8.3.2 *Handling of Materials on Site*

The following lists among others, the important features to be considered:

a) All materials shall be handled by workers who have been provided appropriate training and awareness on the techniques to handle the materials and shall operate with a full set of personal protection equipment (PPE);

b) Large glass panes or panels shall be handled with vacuum cups. Care shall be taken to ensure that the vacuum cups and the glass are perfectly clean. An additional rope or belt is recommended to support the dead load as a fall arrestor;

c) All materials shall be handled with dry, clean, gloves and shall not come in contact with rough surfaces or hard objects, in order to avoid scratches, dents or breakage; and

d) Labels and marking shall not be put on the coated side of glass, and any relative movement of the coating with the next glass pane shall be avoided.

8.3.3 *Transportation and Logistics*

While transporting materials from vendor to factory, within the factory, to and from surface finish coater, finished goods to site and moving finished goods at site, care should be taken to ensure the following:

a) Finished surface is adequately protected with a protective tape which can be easily removed without leaving any residue;

NOTE — Most protective tapes either peel off or adhere to the substrate when exposed to UV for more than three months.

b) Suitable blocking, edge protection, crating, etc are done to avoid dents and gouges;

c) Hardware is secured and not damaged in transit;

d) Material is adequately secured in the truck/container especially when the goods are sent as loose container load (LCL) or partial shipment, avoiding any damages;

e) Lifting equipment shall be adequately engineered for capacity, safety and balance (especially when units are very heavy);

f) Suitable 'A' frames or customized transport support shall be used; and

g) Recommendations from glass supplier towards the use of protective film shall be followed.

8.4 Installation

8.4.1 *Site Survey of Building*

a) Measuring the elevation width and height, ascertaining the grid pattern including position of vision and spandrel frames, the levels of concrete and masonry in x, y and z axis, checking and recording the presence of any difference in plumbness of jambs, beam and column fascia and steel structures are the key activities necessary in deciding the final fabrication measurements;

b) Levelling (setting x-axis, common sill level for all elevation and adjustment in bracket depth) and surveying (measuring x-axis distance and setting the width and height for all elevation) are involved in the process of site survey of building. The key processes are listed below:

   1) *Processes in levelling*:

      i) The sill bottom level of all the glazing elevations are to be checked by fixing a common benchmark and the reading should be recorded at minimum one metre distance;

      ii) After taking the reading the highest and lowest point can be located and a decision on the common level of all glazing elements made;

      iii) The benchmark shall be a permanent mark, using oil paint mark in form of upside triangle;

      iv) The levels of all beam bottoms and up stand, if any, coming across the glazing elevations at all floors are to be measured; and

      v) Any other point that can affect fabrication drawings is to be noted.

   2) *Processes in surveying*:

      i) The total width shall be measured using a theodolite and recorded at one plane;

      ii) It shall be cross checked by measuring existing column to column (at other plan) distance; and

      iii) The two end point RCC shall be measured for plumbness. If any difference is observed, the readings of first two steps shall be adjusted.

8.4.2 *Installation Tolerance*

The effect of installation tolerance is vital for any type of glazed system to perform as per the requirement and the specified performance. For structural glazing, the installation tolerances shall be strictly followed in order to assure that the sealant joint opening meets the specified minimum and maximum joint opening dimensions.

NOTE — For installation tolerance of aluminium systems, reference shall be made to **5.2** of accepted standard [C-8(14)].

8.4.3 *Good Installation Practices*

The good practices involved in installing a glazing system have been categorized hereunder.

8.4.3.1 *Anchorage*

The anchor installation shall be undertaken by installers who have been adequately trained by the manufacturer to install the specific type of anchor. The installer should be familiar with the correct installation procedures and ensure that the correct drilling and setting tools are available for the proper installation of the anchor.

For details with respect to the right installation procedure, reference shall be made to good practice [C-8(31)].

8.4.3.2 *Sub-structures*

a) In order to avoid physical contact with the panels and frames during sealant application, which might cause adhesion loss, powder-free latex gloves shall be used during panel placement;

b) Proper alignment and setting out of the sub-frame is critical in ensuring the ease of operation of the window/door;

c) Anchor/bolt heads and joints between external wall and sub-frame should be sealed with sealant for effective water tightness;

d) Prior to fixing the main frame, the sub frame should be checked for any physical damages and any damaged sub-frame should be repaired or replaced;

e) Setting out of the sub-frame should also be verified before the installation of the main frame; and

f) The sub-frame shall be properly cleaned before assembly as dust and debris accumulated in the sub-frame could affect the alignment and fixing of the main frame and may also cause blockage to the weep holes, resulting in overflow of any incidental water into the interior.

8.4.3.3 *Sealants*

a) All components (glass and framing member such as aluminium) receiving the structural glazing silicone sealant shall be wiped thoroughly with a clean cloth dampened with a cleaner recommended by the manufacturer, and immediately followed by a dry wipe, using clean cloth;

b) All surfaces once cleaned/primed shall be handled carefully so as not to contaminate the surface;

c) The substrates shall be kept free from moisture, condensation, dust and other impurities;

d) An application temperature range of + 10 °C to + 40 °C (or as specified by the manufacturer) is recommended and shall be adhered to;

e) Substrate temperatures in excess of + 50 °C will adversely affect curing process and also the adhesion of the sealant to the substrate;

f) Minimal time shall be taken for cleaning, placement and sealing of panels since environment conditions at job site cannot be controlled;

g) Temporary fasteners may be used to keep the joints stable during the curing process of the sealants and they shall be removed only after complete cure and adhesion has been achieved by the sealant;

h) Tooling of the sealant shall be done with light pressure, within 5 to 10 min, before a skin forms on the sealant;

j) The use of wet tooling aids such as soaps and solvents shall be avoided. Dry tooling is appropriate;

k) Masking tape shall be used in ensuring neat straight-line application and avoiding smears;

m) The masking tape shall be removed immediately after tooling has taken place and before the sealant starts to cure;

n) The general recommendation for the application of structural sealant required for a 4-sided system, bonding the glass to the aluminium frame should be done in a factory atmosphere;

p) Complete quality control process with respect to surface preparation, storage, sealant application and quality check are to be implemented in the factory with full traceability. In most cases sealant manufacturers have quality requirements and documentation process related to warranties which need to be followed; and

q) *In-situ* application may be required for 2-sided system, retrofit, repair and small areas in a facade. Sealant manufacturers should be contacted to get specific recommendation on sealant application for *in-situ* application.

8.4.3.4 *Installation*

The framing and fixing system of the panel should, in no case, cause shear stresses in the panel, either under the impact of external forces or due to differential expansion of components. The following shall be taken care of:

a) All framing shall be checked prior to glazing to assure that the opening is square, plumb and secure so that the uniform sealant bite, face and edge clearances are maintained;

b) Inspection of all butt and mitre joints shall be carried out and if found open, they shall be sealed using sealants prior to glazing;

c) Minimum edge clearances shall be maintained between glass and sash, as mentioned by the manufacturer;

d) Setting blocks shall be used to support the glass unit which shall prevent the addition of stress applied on the structural tensile bead due to the self-weight of glass; and

e) Adhesion tests shall be performed by the contractor/agency at the beginning and during the installation process.

8.5 Testing

8.5.1 *Laboratory Testing*

The glazing system is subjected to various adverse environmental conditions and impacts during its service life. A properly designed and installed glazing system may be able to resist any major damage to its stability or performance under any condition within its effective life time. The glazing system and its component materials shall be tested for the required parameters and performance.

8.5.2 *Field/On-Site Testing*

Testing of the glazing system as a whole unit in site (the field) subject to loads and effects such as water infiltration, wind (air) infiltration, acoustic insulation, fire insulation, thermal performance, structural performance, etc may be carried out for specific cases as mutually agreed to between the parties concerned, to ensure homogeneity.

The Table 30 lists the tests to be carried out for glazing systems including curtain walls, windows, skylights, sliders, doors, etc. The frequency of these tests shall be mutually agreed upon by the parties concerned.

Table 30 Testing of Glazing Systems including Curtain Walls, Windows, Skylights, Sliders, Doors, etc

(*Clause* 8.5.2)

Sl No. (1)	Test Parameters (2)	Testing Method (3)
i)	Air permeability	As per accepted standard [C-8(32)]
ii)	Water penetration — Static air pressure difference	As per accepted standard [C-8(33)]
iii)	Water penetration — Dynamic air pressure difference	As per accepted standard [C-8(34)]
iv)	Standard operating forces	As per accepted standard [C-8(35)]
v)	Window and doors resistance to repeated opening and closing	As per accepted standard [C-8(36)]
vi)	Wind resistance for curtain walls, windows, sliders and skylights	As per accepted standard [C-8(37)]

Table 30 (*Concluded*)

Sl No. (1)	Test Parameters (2)	Testing Method (3)
vii)	Structural load test (100 percent design wind load)	As per accepted standard [C-8(37)]
viii)	Structural proof load test (150 percent design wind load and seismic force, if applicable)	As per accepted standard [C-8(37)]
ix)	Seismic racking test	As per Annex F
x)	Water penetration — Field	As per accepted standard [C-8(32)]
xi)	Thermal performance of windows, doors and shading devices — Detailed calculations	As per accepted standard [C-8(38)]
xii)	Calculation of thermal transmittance — Numerical method of frames	As per accepted standard [C-8(39)]
xiii)	Mechanical tests for standard windows and door height windows	As per accepted standard [C-8(40)]
xiv)	Fire resistance of perimeter fire barrier joint system	As per accepted standard [C-8(20)]
xv)	Fire resistance tests — Door and shutter assemblies	As per accepted standard [C-8(41)]
xvi)	Fire resistance test for glass walls	As per accepted standard [C-8(42)]
xvii)	Fire resistance test for doors with glass panes, openable glass windows and sliding glass doors	As per accepted standard [C-8(43)]
xviii)	Forced entry security glazing	As per accepted standard [C-8(44)]
xix)	Bullet resistant glass	As per accepted standard [C-8(45)]
xx)	Acoustics — Sound insulation	As per accepted standard [C-8(25)] and [C-8(26)]
xxi)	Blast resistant security glass	As per **9.4.3**

8.6 Maintenance

8.6.1 *Maintenance Infrastructure*

Regular maintenance of the building facades plays an important role in the holistic building maintenance. The access systems shall provide sufficient approach which enables all parts of the facade to be reached safely for the purpose of cleaning, inspection and maintenance and also offer high work efficiency to the maintenance workers, without also hindering the aesthetics of the building. The provisions of relevant guidelines/best practices (Handbook on 'Asset and Facility Management in Buildings') may also be referred.

The means of access and supporting infrastructure should be established at the design stage so that the loads are properly envisaged for.

Facade access requirements come in many varieties and may present challenges. Powered access cradles for facade access, cleaning of the glass directly from the ground, hoists based access and window based cleaning/access from inside the building are some of the common techniques employed. Recently, access techniques using ropes have been used for facade access and are generally considered to be safe, provided the workers have been trained and are using all the correct safety equipment and precautions.

In nearly all cases, facade access and maintenance requires a worker to be exposed to working at height with its associated risks. Therefore, use of height safety equipment, anchor point attachments (like the fall restraint or fall arrest system) and those given below should be employed:

a) *Roof guardrails* — When choosing equipment for working at heights, collective protection like roof guardrails may also be considered. Roof guardrails ensure that all users are protected from falling without the need for specialised training and/or equipment. They also eliminate the need for rescue procedures to be put in place. Roof guardrails are available as fixed, free standing, straight upright, cranked upright or collapsible; and

b) *Fall arrest systems and fall prevention cable systems* — Fall arrest systems allow safe access to roof areas for maintenance and inspections to be carried out by workers. Users of the fall arrest systems require wearing of full body harnesses and attachment to the cable/fall arrest system via a lanyard (rope) and shuttle device which allows them to walk the full length of the system without having to detach from the system. Fall arrest systems shall be of horizontal, overhead, sloping and vertical lifeline type and shall comply to the relevant/available standards.

Depending on the project requirement, the maintenance infrastructure shall consist of the following systems:

1) *Roof trolley/Cradles* — Fixed or adjustable jib, telescopic jib and cradle with pantograph.
2) *Rail systems* — Hooked, anchored, turntables and rotary plates.
3) *Other systems* — Additional winches for glass replacement and parking positions/lifting platforms.

8.6.2 *Maintenance of Materials*

The glazing system and the associated materials require a suitable degree of maintenance, if they are to fulfil their intended working life. Early detection of defects can mitigate expensive repairs or replacement later. The degree of inspection and maintenance required will depend on the type of glazing system and its intended design life.

8.6.3 *Common Practices for Maintenance*

The common principle maintenance practices to be followed shall be as given below:

a) When using the cleaning equipment or carrying out maintenance on the exterior of the building, the risk to personnel and property, prior to the start of work shall be assessed at first;

b) Where applicable, qualified personnel to carry out routine or complex maintenance shall be employed;

c) Power supplies may need to be isolated prior to maintaining electrically operated equipment such as motors to opening vents, roller blinds to atrium roof and main entrance pass doors;

d) While accessing the external facade, fall arrest systems shall always be used even while working in the house cradle;

e) Manufacturer's instructions shall be followed when using cleaning fluids and shall not be mixed up with drinking water or the like. To deal with instances of contact with eyes, skin, etc necessary eyewash arrangement and first aid equipment shall be in place;

f) Loosened fixing or bolts shall be identified, reported and attended to immediately, and shall never be tampered with;

g) Unauthorized loosening or removing of the fixings may prove dangerous and can result in structural damage and displacement of the system;

h) When lifting equipment such as hoists and sucker machines are used, it shall be ensured that they are capable of lifting the loads required. Further, the recommended safe working loads of any equipment shall never be exceeded;

j) When handling any insulation of firebreak material, it shall be ensured that gloves, goggles and masks are worn as fibrous materials (if any) may cause irritation;

k) Prior to the commencement of work involving glues or sealants (particularly in confined spaces), manufacturer's advice/special instructions shall be adhered to before exposing the product to air. Such materials shall preferably be worked with, in a well-ventilated area;

m) In the case of coated glass, the following precautions shall particularly be adhered to:

   1) Any scratching shall be avoided as this may penetrate the surface of the coating and cannot be repaired;
   2) Any excessive mechanical treatment shall be avoided as this might remove the coating in localised areas;

3) Contact with metal objects shall be avoided; and

4) Use of chemicals that may attack the surface and damage it irreparably shall be avoided.

9 SECURITY GLASS

9.1 This clause covers the requirements and selection criteria for security glass in buildings. The general methodology for selecting types of security glass shall be in accordance with **4**. It is essential for any security glass in addition to its required function to provide adequate human impact safety features. The level of human impact safety for glass in buildings shall be in accordance with **7.1**. Furthermore, the security glass shall meet the classification standards to which it has been tested, ensuring the safety and security of occupants and goods. This clause deals with the safety and security of people or goods in relation to risks of,

a) vandalism, riots, burglary or break in protection;

b) protection from firearm shooting;

c) protection from explosion (terrorist attack); and

d) protection from ballistic attacks.

The requirements given below pertain to glass used in areas with high-security needs. In circumstances wherein the requirements of other Indian Standards exceed the requirements of this clause, the higher requirements shall become applicable.

9.2 Glass and Related Material for Security

Glass used for security purpose are laminated glass with different combination of glass panes including annealed glass, heat strengthened glass, toughened glass, and interlayers (including polyvinyl butyral, ethylene vinyl acetate, plastic sheets, polycarbonate sheets, etc) in accordance with **4**.

9.3 Selection Criteria

The selection criteria is based on the threat levels/risks (firearm shooting, ballistic attacks, explosion, burglary, etc) and stages of protection as per the requirements of the buildings and the user.

9.4 Testing procedures

9.4.1 *Burglary Resistance of Glazing Systems*

The framing member along with its hardware and glass should comply for the burglar resistance requirements as a whole. The glass to be used should comply with the testing requirements of accepted standard [C-8(44)]. The following Table 31 lists the minimum requirements for various resistance classes of glazing.

Table 31 Minimum Requirements for Glazing

(*Clause* 9.4.1)

Sl No. (1)	Resistance Class (2)	Minimum Resistance Class of Glazing as per Accepted Standard [C-8(46)] (3)
i)	RC 1 N	Any glass (test is for hardware manipulation for entry)
ii)	RC 1	P4A
iii)	RC 2 N	Any glass (test is for hardware manipulation for entry)
iv)	RC 2	P4A
v)	RC 3	P5A
vi)	RC 4	P1B
vii)	RC 5	P2B
viii)	RC 6	P3B

If a glass unit with a higher security level is used within the specimen used for the tests, it may not be possible to assess the use of glass units with a lower grade within those products without conducting further tests. This is because higher grades of glass can increase the rigidity of the product.

The following Table 32 lists the criteria for the selection of the resistance class (offender type, offender behavior, location, risk and recommendation for use).

Table 32 Criteria for the Selection of the Resistance Class

(*Clause* 9.4.1)

Sl No.	**Resistance Class**	**Expected Offender Type, Suspected Offender Behaviour**	**Recommended Place of Use of the Burglar-Resistant Component**		
			A Residential properties	B Commercial properties, public properties	C Commercial properties, public properties (High risk)
(1)	(2)	(3)	(4)	(5)	(6)
i)	RC 1 N/ RC 1	Components of resistance class RC 1 N/RC 1 provide basic protection against attempts to break in with physical force such as kicking in, jumping, shoulder slamming, pushing up and tearing out (mainly vandalism). Components of resistance class RC 1 N/RC 1 only have a low level of protection against the use of lever tools	If burglar resistance is required, the use of resistance class RC 1 N/RC 1 is only recommended for building components where no direct access (not ground level access) is possible		
ii)	RC 2 N/ RC 2	The occasional offender tries in addition, to break open the component with simple tools such as screwdrivers, pliers and wedges. (RC 2 N is only recommended for building components where no direct attack on the glazing used is to be expected)	Average risk attack on the glazing used is to be expected	Average risk	Not applicable

Table 32 (*Concluded*)

Sl No.	**Resistance Class**	**Expected Offender Type, Suspected Offender Behaviour**	**Recommended Place of Use of the Burglar-Resistant Component**		
			A Residential properties	B Commercial properties, public properties	C Commercial properties, public properties (High risk)
(1)	(2)	(3)	(4)	(5)	(6)
iii)	RC 3		High risk	The offender tries in addition, to break open the component with a second screwdriver and a crow bar.	Not applicable
iv)	RC 4	The experienced burglar uses in addition, tools such as a hand saw, heavy hammer, axe, chisels, and a battery-powered drill.	Not applicable	Not applicable	Low risk
v)	RC 5	The experienced burglar uses in addition, electric tools such as an electric drill, jig saw, or sabre saw and an angle	Not applicable	Not applicable	Average risk
vi)	RC 6	The experienced burglar uses in addition, heavy-duty electric tools, such as a heavy-duty drill, jig saw or sabre saw and angle grinder	Not applicable	Not applicable	High risk

NOTES

1 This table is only an approximate guide. Expert advice, for example, from the local police advice centres, is essential. The assessment of the risk should be on one's own responsibility, taking into account the location of the building (protected/unprotected), use and the value of the goods inside. In case of high risk, tested and certified burglar alarm systems should be used in addition.

2 When selecting burglar-resistant elements of resistance classes RC 4 to RC 6, it should be noted that when selecting such elements in escape and rescue routes, the use of tools by the fire brigade is made more difficult and shall therefore be taken into account.

3 External sockets, for example, in the hallway, in the garden or in the patio (open space) area should be de-energized to prevent their use by the burglar.

In addition, parties to agreement may mutually decide on testing arrangement based on specialist literature.

NOTE — Specialist literature may be EN 1630 : 2021 'Pedestrian doorsets, windows, curtain walling, grilles and shutters - Burglar resistance - Test method for the determination of resistance to manual burglary attempts'.

9.4.2 *Bullet Resistance Glazing*

The framing member along with its hardware and glass shall comply for the bullet resistance requirements as a whole. The glass to be used should comply with the testing requirements of accepted standard [C-8(45)].

The testing of framing member shall follow the same parameters of spall, no spall as well as threat levels (*see* Table 33) described in accepted standard [C-8(45)] but with penetration points in the framing member. Glazing system classification will hold good only if both the framing member and glass complies. In case, either glass or frame achieves a lower classification, then the whole glazing system shall be classified to the lower class that has been achieved.

Table 33 Threat Levels

(*Clause* 9.4.2)

Sl No. (1)	**Threat Level** (2)	**Ammunition** (3)	**Bullet weight** g (4)	**Bullet Type** (5)	**Strike Velocity** m/s (6)	**Distance of Impact** m (7)	**No. of Strikes** (8)	**Remarks** (9)
i)	1	9 mm × 19 mm	7.4 to 8.2	FMJ/Pb	430 ± 15	5 ± 0.5	5	–
ii)	2	7.62 mm × 39 mm	7.45 to 8.05	FMJ/ MSC	710 ± 15	10 ± 0.5	5	–
iii)	3	7.62 mm × 51 mm	9.4 to 9.6	FMJ/Pb	838 ± 15	10 ± 0.5	5	plus compliance with Threat Level 2
iv)	4	5.56 mm × 45 mm	3.5 to 4.0	FMJ/(SI + Pb)	890 ± 15	10 ± 0.5	5	plus compliance with Threat Level 3
v)	5	7.62 mm × 39 mm	7.45 to 8.05	HSC	700 ± 15	10 ± 0.5	5	plus compliance with Threat Level 3
vi)	6	7.62 mm × 54 mm	10.3 to 10.5	API	830 ± 15	10 ± 0.5	1	–
vii)	Special (*see* Notes)	Any other requirement by the user. Complete details of ammunition shall be stored for future upgradation of this NBCS						

NOTES

1 For special threat levels, the bullet velocity specified for the test should be representative of that developed by the weapon and ammunition, preferably at the higher end of the range of possible velocities. The range selected should be sufficient to enable the bullet flight to stabilize.

2 FMJ/Pb = Full metal jacket – Lead core, FMJ/MSC = Full metal jacket – Mild steel core, HSC = Hard steel core, API = Armour-piercing incendiary.

9.4.3 *Blast Resistance Glazing*

The framing member, along with its hardware and glass, shall collectively comply with the blast resistance requirements specified in Annex G. Glazing system classification will hold good only if both the framing member and glass complies. In case either glass or frame achieves a lower classification, then the whole glazing system shall be classified to the lower class that has been achieved.

The test ammunitions specified in this NBCS represent the most frequently faced threats and are classified into six threat levels given in Table 34.

Table 34 Classification, Charge (TNT/Equivalent Charge) Mass, Distance (*d*) and Height of Burst (HOB)

(*Clauses* 9.4.3, G-4.7 *and* G-4.8)

Sl No. (1)	**Threat Level** (2)	**TNT/Equivalent Charge Mass** kg (3)	**Distance of Explosive Charge (TNT/Equivalent Charge) from the Test Specimen (*d*)** m (4)	**Height of Burst (HOB)** m (5)
i)	1	2	4.5	0
ii)	2	3	5.0	0.5 ± 0.05
iii)	3	3	3.0	0.5 ± 0.05
iv)	4	12	5.5	0.8 ± 0.05
v)	5	12	4.0	0.8 ± 0.05
vi)	6	20	4.0	0.8 ± 0.05
vii)	Special		Any other requirement by the user.	

The structural integrity of glass system test specimen is evaluated by visual inspection in the following categories of outcome:

a) *Category A* — No damage to the glass and the frame of glass system;

b) *Category B* — The entire system is bent or deformed leading to the overall jamming or dis-functioning of the system;

c) *Category C* — Formation of cracks on the glass system and no damage to the frame of the glass system;

d) *Category D* — Cracking/shattering of different glass layers and damage to frame of the glass system;

e) *Category E* — Formation of splinters from the glass system or the frame within a distance of 3 m. The size of perforations in the glass or the frame shall not be more than 10 mm; and

f) *Category F* — Total collapse of the glass or frame of the glass system or both.

ANNEX A

(*Clause* 2.15)

TEST METHOD FOR ASSESSING CURTAIN WALLS AND STOREFRONT SYSTEMS UNDER INTER-STOREY DRIFT CONDITIONS

A-1 OBJECTIVE

This test method provides a means of evaluating the performance of window wall, curtain walls and storefront systems when subjected to specified horizontal displacements in the plane of the wall. This test is applicable to window wall, curtain wall and/or storefront mock-ups consisting of supports and components, with glass panels fixed across more than one storey (hereinafter referred to as exterior wall systems). This test method is applicable to window systems only when included as part of a full-size wall mock-up. This test method describes the apparatus and the procedure to be used for displacing a specimen horizontally. The displacement cycle time is not limited and is intended to duplicate the inter-storey displacement rates associated with dynamic building sway or seismic or wind events. This test shall be applicable for seismic Zone IV and Zone V. However, depending upon application and for tall structures, it shall be performed for other seismic zones as well.

This annexure does not support to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this test method to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.

A-2 TERMINOLOGY

A-2.1 Lateral Movement — A sideway displacement of a structure or part of the structure.

A-2.2 Test Specimen — The test element is referred to as the specimen. The test specimen for a wall shall be of sufficient size to determine the required performance of all typical parts of the wall system.

A-2.3 Specimen Area – The area calculated from the overall dimensions of the test specimen.

A-2.4 Floor Height – Height of one floor of the sample to be tested.

A-2.5 Horizontal Displacement – The relative displacement of the curtain wall in the horizontal direction when subjected to horizontal movement.

A-2.6 Window Wall – It sits between floor slabs and are anchored at the sill and head.

A-3 APPARATUS

A-3.1 The description of the apparatus in this section is general. Any suitable apparatus arrangement during the laboratory accreditation process is permitted.

A-3.2 The displacement(s) may be accomplished using hydraulic or pneumatic cylinders or jacks of sufficient load and stroke capacity, or mechanical devices, such as ratchet pulleys or a chain hoist.

A-3.3 Test chamber members that are representative of the building structure shall be designed to accomplish the specified displacement(s). This may be done through a system of sleeves, fixtures, pins, or any system capable of accomplishing the displacement(s) directed by the specifier.

A-3.4 The displacement measuring system shall be accurate to within 1.5 mm (0.06 inch).

A-4 CALIBRATION

All test equipment shall be calibrated periodically, at least once every six months. Calibration should be done from an accredited laboratory providing traceability of calibration to national standards established through a chain of calibration certificates.

A-5 TEST SPECIMEN

A-5.1 The exterior wall system test specimen shall be of sufficient size and configuration to determine the performance of all typical parts of the exterior wall system. A minimum of three vertical bays in two adjoining floors of the exterior wall system shall be tested. If the wall has inside and/or outside corner, one set of corner bays shall also be included in the testing specimen. For glazing that is anchored within the floor/storey such as windows, doors, sliders and horizontal strip facade, the test specimen can be of a single floor.

A-5.2 All parts of the exterior wall system test specimen shall be full size, using the same materials, type of glass, detailing, methods of construction and anchorage as those used on the actual building.

A-5.3 The test chamber structure shall simulate the main structural supports of the actual building. However, the test chamber and/or support structure may differ from the actual building, as required, to perform the required displacement. For multi-storey mock-ups, the test chamber shall be constructed so that the anchorage at the simulated floor structure at an intermediate level of the test specimen is moveable in the horizontal direction(s). For single storey mock-ups, the test chamber shall be constructed so that the anchorage at the top or bottom is moveable in the horizontal direction(s).

A-5.4 The test laboratory shall minimize unintended torsional or flexural movements of chamber and/or support structure that could affect test results.

A-6 PROCEDURE

A-6.1 Prior to conducting the displacement tests, the test specimen shall be, at a minimum, characterized for serviceability by conducting air leakage and water penetration tests. The air leakage and water penetration tests shall be conducted at the differential pressures specified for the project.

A-6.2 Conduct Specified Displacement Test(s)

A-6.2.1 Test chamber elements representing the primary building structure shall be displaced to produce the specified movements. Each test shall consist of minimum three full cycles. A cycle is defined as a full displacement in one direction, back to the originating point, full displacement in the opposite direction, and back to the originating point (*see* Fig. 20).

A-6.2.2 Hold the specimen at displaced position not more than 60 s at each direction.

A-6.2.3 An inspection to be conducted during and after every cycle and recorded.

A-6.2.4 At the conclusion of the test, technicians and witnesses shall visually inspect the mock-up for evidences of failure.

A-6.2.5 The test agency shall record all areas of visual distress, such as disengagement, metal distortion, sealant or glazing failure, gap between framing members, or permanent deformation.

A-6.2.5.1 If glass breakage occurs during displacement tests, the test agency personnel shall carefully examine the test specimen and document the extent of this glass breakage.

A-6.2.6 Elements representing the building structure shall be displaced in a manner and method as determined by the test agency and may be subject to review by the design professional. Movement shall be parallel to the primary plane of the wall.

A-6.2.7 Changes in displacement direction(s) shall allow for movement of equipment, stops, measuring devices, etc. The test agency shall displace the chamber elements in a manner that is not intended to induce sudden acceleration and deceleration.

A-6.2.8 Additional cycles and/or displacement direction(s) may be specified by the design professional. The chamber elements shall be returned to their nominal position after completion of each cycling test, before further tests are conducted.

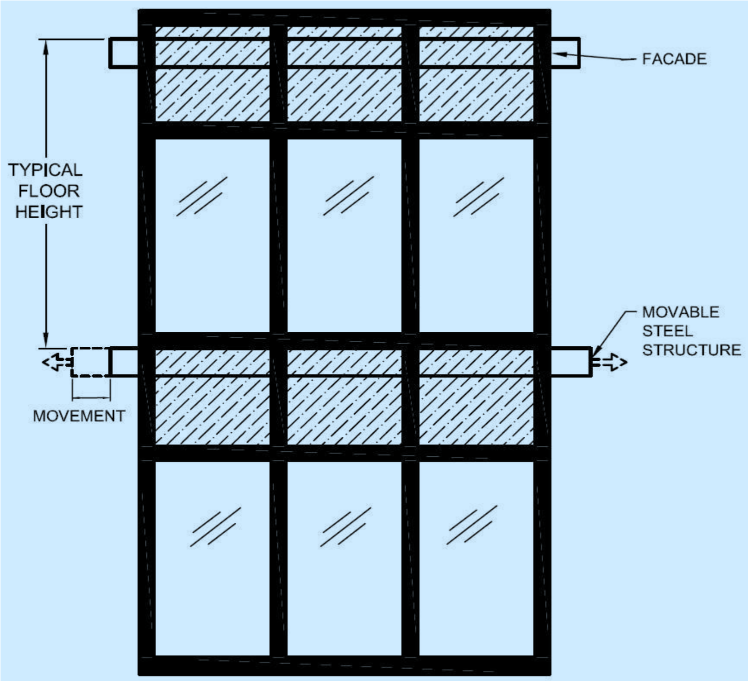


FIG. 20 ILLUSTRATION OF MOVABLE STRUCTURAL ELEMENTS IN CURTAIN WALL SYSTEMS UNDER INTER-STOREY DRIFT CONDITIONS

A-6.2.9 The elastic design displacement shall be as provided by the building engineer of record, determined by elastic analysis or other suitable method for a specific building. The displacement shall be measured at the movable floor element, not at the test specimen. For multi-storey mock-ups, the displacement between levels may vary due to different storey heights. If unspecified in contract documents, for testing, elastic design displacement in each direction shall be H/500, for curtainwall systems that span from floor-to-floor and primarily accommodate movement through racking or tipping.

A-6.3 Serviceability tests for air leakage as per accepted standard [C-8(47)] and static water penetration as per accepted standard [C-8(33)] may be conducted after the static elastic design displacement tests. The air leakage and static water penetration tests should be conducted at the pressures specified for the project.

A-6.4 The displacement shall be measured at the movable chamber member that represents the floor element, not at the test specimen or its anchorage.

A-7 CRITERIA

A-7.1 The project specifications shall state detailed performance criteria for the windows, window wall, curtain wall or storefront system. If detailed performance criteria are not included in the project specification, the criteria outlined in this test method shall be utilized.

A-7.2 Unless otherwise specified, an exterior wall system test specimen subjected to the elastic design displacement test shall be considered as passing the inter-storey drift provisions of this test method if the specimen meets the following criteria:

a) No visible damage to framing or trim components or assemblies is allowed.

b) No glass breakage or glass fallout is allowed.

c) Full disengagement of gaskets or weather seals is not allowed at any location.

d) Any gap between framing members shall be notified.

e) Air infiltration and static water penetration resistance shall remain within specified allowable limits without adjustments or repair for serviceability conditions.

NOTE — If any of air infiltration or static water penetration test fails, then seismic test has to repeated before proceeding with air infiltration or static water penetration retests.

f) No wall components may fall off.

NOTE — If an inter-storey drift (1.5 × storey height) test is conducted, the results shall be recorded and mutually agreed upon with the specifier. In this case, compliance with the above failure criteria is not required.

A-8 REPORTING

The information to be duly reported after testing are given hereunder.

A-8.1 General

Testing agency, date and time of test, and date of report.

A-8.2 Specimen Details

A-8.2.1 *Specimen Description*

Manufacturer, model, operation type, materials, and other pertinent information; description of the locking and operating mechanisms if applicable; glass thickness, type and method of glazing; weather seal dimensions, type, weep holes, and material; and crack perimeter or specimen area, or both.

A-8.2.2 *Drawings of Specimen*

Detailed drawings of the specimen showing dimensioned section profiles, framing location, panel arrangement, installation and spacing of anchorage, weather stripping, locking arrangement, hardware, sealants, glazing details, weep holes, drainage path detail, and any other pertinent construction details. Any modifications made on the specimen to obtain the reported test values shall be noted.

A-8.3 For window and door components, a description of the locking and operating mechanism.

A-8.4 Identification of glass thickness and type and method of glazing.

A-8.5 Test Parameter

A-8.6 List of Equipment Used

List the equipment name, identification number and calibration validity of all the equipment used at the time of testing.

A-8.7 Test Observation

A visual record of the test observations.

A-8.8 Photographs or drawings of the test chamber and the wall system test specimen mock-up indicating location of measuring devices and movement devices.

H-8.9 Compliance Statement

A statement that the tests were conducted in accordance with this test method, or a complete description of any deviation from this test method. When the tests are conducted to check for conformity of the specimen to a particular performance specification, the specification shall be identified.

A-9 INFORMATION OF DESIGN LOADS

In order to design and detail exterior wall systems and their attachments to meet the inter storey drift requirements, the design load shall be as per good practice [C-8(48)].

Inter-storey drift can result from either seismic loads or by wind loads.

ANNEX B

(*Clauses* 5.1, 5.2.11 *and* 5.3.3.6)

MINIMUM PERFORMANCE REQUIREMENT OF GLAZING FOR EXTERIORS

B-1 The panel size design of the exterior glass for the building is done in accordance with this Section considering the effect due to wind load, other imposed load and seismic design. The type of glazing to be installed is determined considering human safety in **7.1**.

In the determination of the energy and thermal performance of the glazing, the three compliance approaches prescriptive in nature, defines the minimum glazing/glazing system requirement to be met.

The prescriptive values are specified with respect to the geographic climatic zone and glazing area of the building.

B-2 BUILDING FENESTRATIONS

The fenestration may comply with the maximum glazing area weighted on *U*-value and solar factor as given in relevant guidelines/best practices (Handbook on 'Sustainability in Buildings').

The window wall ratio (WWR) is defined by the total fenestration area to the total gross area of the building envelope which is limited to 70 percent. The corresponding minimum visible light transmission is given below. For fenestration area greater than 70 percent, a reference may be made to other specialist literature.

Sl No. (1)	*WWR* (2)	*Minimum Visible Light Transmission* Percent (3)
i)	0 to 0.3	27
ii)	0.31 to 0.4	20
iii)	0.41 to 0.5	16
iv)	0.51 to 0.6	13
v)	0.61 to 0.7	11

B-3 WEATHER PERFORMANCE

Air infiltration from the fix litres shall be permitted within 1.5 $m^3/h.m^2$ and from operable sash 2 $m^3/h.m$.

Water should be contained in the gutter and drained back to the exterior. Any uncontrolled water in excess of 15 ml or more on the top surface of any exposed interior shall be considered as leakage.

B-4 In glass facade buildings, it is recommended to have provision for smoke/heat exhaust ventilation that automatically or by manual trigger expels smoke, heat and gases during a fire or emergency. These vents should be integrated into the building's smoke control system to improve evacuation safety, firefighting efforts, and overall air quality. These vents should be part of building facade and may also be located at suitable locations for effective exhaust. For further details in this regard, Part F 'Fire and Life Safety' of this NBCS may be referred.

In glass facade buildings, where airtight construction can restrict natural airflow, it is recommended to have make-up air vent also as a part of ventilation system that automatically or by manual trigger, introduces fresh air into the building to compensate for the air exhausted by smoke vents, HVAC systems, or other ventilation processes. These vents help maintain air balance and indoor air quality which ideally should be 85 percent to 90 percent of vented volume of smoke/heat.

ANNEX C

[*Clause* 5.3.2(b)]

TEST REQUIREMENTS FOR COATED GLASS

C-1 The coated glass that is used for the exterior of commercial and non-commercial (residential building) building should meet the test requirement listed in this Annex.

C-2 MEASUREMENT OF PERFORMANCE

The performance factors and spectral details of the coated glass shall be determined using standard accepted spectrophotometer equipment. The actual size shall be dependent on the type of equipment being used for the measurements. The transmittance of the measurement sample shall be measured with radiation of normal incidence at the following wavelengths:

a) 550 nm (representative wavelength for light and solar transmittance); and

b) 900 nm (representative wavelength for solar transmittance).

For glass claiming to have a low emissivity coating, a measurement of the reflectance shall be made at 8 µm using radiation of nearly normal incidence.

C-3 CONDENSATION RESISTANCE TEST

C-3.1 This test consists of subjecting the coated glass to a water saturated atmosphere at constant temperature. The samples have condensation continually forming on them and it is this condensation that may cause surface degradation.

C-3.2 Test apparatus should have a provision of four test pieces and the materials used for the inner walls shall be corrosion-resistant and shall not affect the test pieces.

C-3.3 Procedure

a) The water tank shall be filled with demineralized water, having conductivity lower than 30 µS and a *p*H higher than 5. The internal temperature of the cabinet shall be controlled by means of the reference thermocouple keeping a temperature of the reference glass piece of 40 ± 1.5 °C;

b) The test cabinet shall be in a room with an ambient temperature of 23 ± 3 °C. Care shall be taken to ensure that draughts, dust, moisture and solar radiation do not interfere with the test cabinet; and

c) The reference temperature shall be reached within 2 h of commencing heating. Condensation shall be seen to form on the glass pieces. The test is continued without interruption for the required time. Both the internal reference and the external air temperature shall be regularly checked.

C-3.4 Requirements

a) No defect, greater than 3 mm length;

b) Maximum one defect between 2 mm and 3 mm length;

c) Maximum five defects between 1 mm and 2 mm length;

d) No scratches, staining of the coating or clusters of pinholes greater than 1 mm;

e) When compared with the reference test piece, in both reflection and transmission, there shall be no significant colour change. This observation shall be made within 20 s; and

f) The transmittance measured at 550 nm and 900 nm shall differ by no more than ± 0.03 from the corresponding measured value on the reference test piece.

C-4 ACID RESISTANCE TEST

C-4.1 This test consists of subjecting the coated glass to a sulphur dioxide saturated atmosphere at constant temperature. The samples shall have condensation continually forming on them. It is this condensation together with the quantity of sulphur dioxide that may cause surface degradation. Test apparatus should have a provision of four test pieces and the material used for the inner walls shall be corrosion-resistant and shall not affect the test pieces.

C-4.2 Procedure

a) The test cabinet contains 2 litre of demineralized water having conductivity lower than 30 µS. When the cabinet is closed 0.2 litre of SO_2 shall be added and the heating system switched on;

b) The test consists of a repetition of 24 h cycles (*see* Fig. 21);

c) Each cycle consists of high temperature plus condensation period and an ambient temperature without condensation period; and

d) The temperature shall increase to 40 °C ± 1.5 °C in less than 1.5 h. During the next 6.5 h the test pieces shall be subjected to condensation in the SO_2 atmosphere.

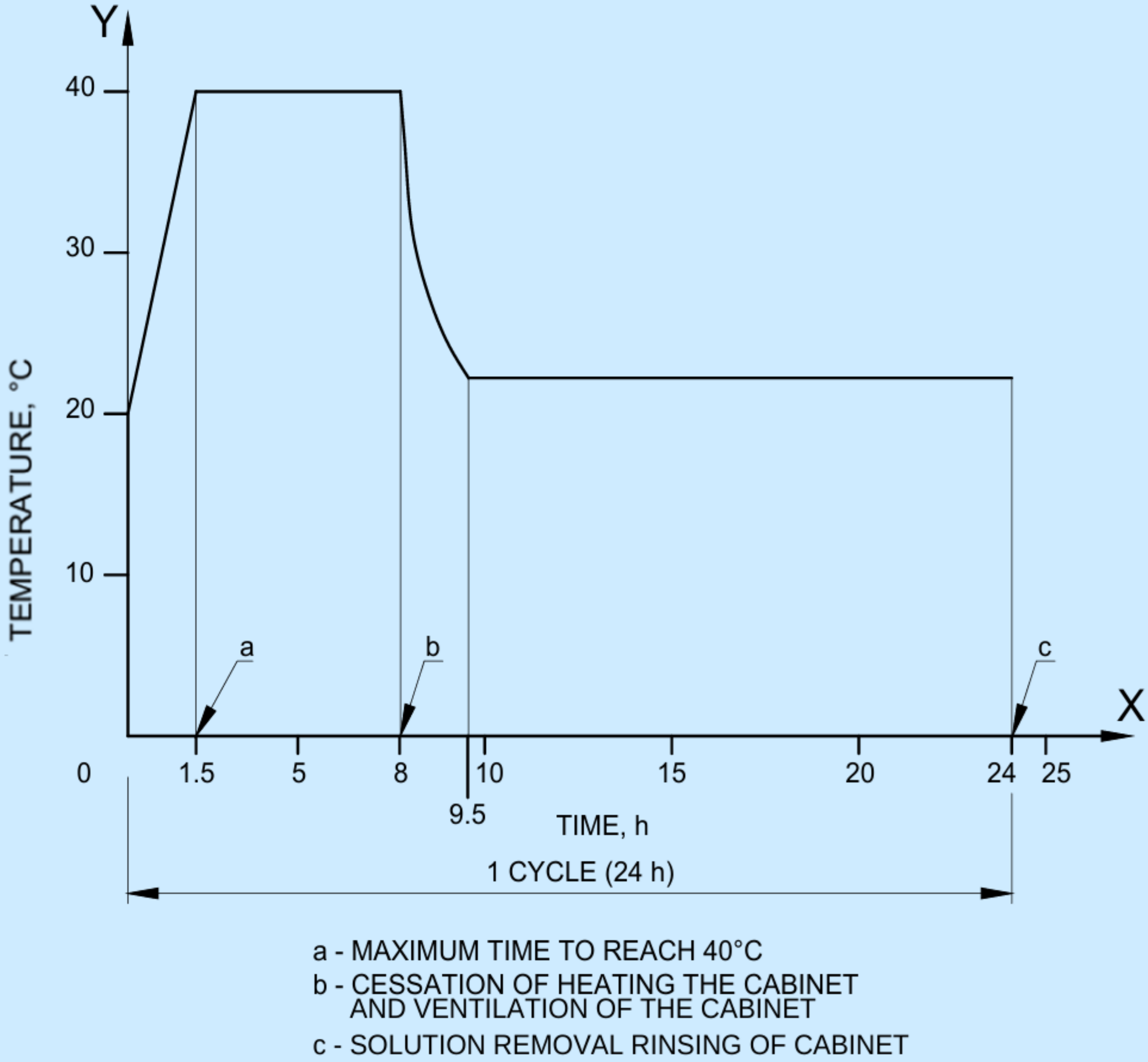


FIG. 21 24-HOUR CYCLE OF HEATING

C-4.3 Requirement

The transmittance measured at 550 nm and 900 nm shall differ by no more than ± 0.03 nm from the corresponding measured value on the reference test piece.

C-5 NEUTRAL SALT SPRAY

C-5.1 This test consists of subjecting the coated glass to neutral, water saline atmosphere at constant temperature. It is the water saline spray that may cause surface degradation.

Test apparatus should have a provision of four test pieces and the material used for the inner walls shall be corrosion-resistant and shall not affect the test pieces.

C-5.2 Procedure

a) The test cabinet shall be prepared and run for a minimum period of 24 h before the test pieces are placed within it. The neutral salt solution is made up by dissolving NaCl in demineralized water having conductivity lower than 30 µS, to produce a concentration of 50 ± 5 g/l at 25 ± 2 °C; and

b) The compressed air supplied to the spray nozzle shall be passed through a filter to remove all traces of oil or solid matter and shall be at an absolute pressure of 70 kPa to 170 kPa through a saturator at 40 ± 1.5 °C. The spray nozzle shall be made of inert material, with baffles to prevent direct impact of spray on the test pieces.

C-5.3 Requirements

a) No defect, greater than 3 mm length;

b) Maximum one defect between 2 mm and 3 mm length;

c) Maximum five defects between 1 mm and 2 mm length;

d) No scratches, staining of the coating or clusters of pinholes greater than 1 mm;

e) When compared with the reference test piece, in both reflection and transmission, there shall be no significant colour change. This observation shall be made within 20 s; and

f) The transmittance measured at 550 nm and 900 nm shall differ by no more than ± 0.03 nm from the corresponding measured value on the reference test piece.

C-6 ABRASION RESISTANCE TEST

C-6.1 This test consists of subjecting the coated surface of the glass to rubbing with a felt pad in dry condition. It is the type of pad, the loading on it and the number of strokes that may cause surface degradation.

C-6.2 Procedure

a) The metal finger shall be approximately 15 mm to 20 mm in diameter and shall be driven so as to produce a frequency of 60 strokes/min + 6 strokes/min, alternating forwards and backwards. The stroke length shall be 120 mm ± 5 mm. The strokes shall be parallel and ensure a constant pressure over the zone to be tested;

b) A circle shape with a diameter of 14.5 mm ± 0.5 mm;

c) The test sequence shall commence within 30 min of the sample being cleaned; and

d) The metal finger containing the felt pad shall be lowered on to the glass surface and a load of 4 N applied perpendicular to the glass surface via the felt pad.

C-6.3 Requirements

a) Ensure that the abraded area is uniform; and

b) The transmittance measured at 550 nm and 900 nm shall differ by no more than ± 0.03 nm from the corresponding measured value on the reference test piece.

C-7 DURATION OF TESTS

The duration of tests shall be as per the following:

Sl No.	*Test*	*Test Duration for Class*		
		A	B	S
(1)	(2)	(3)	(4)	(5)
i)	Condensation resistance	21 days	4 days	14 days
ii)	Acid resistance	5 cycles	1 cycle	5 cycle
iii)	Neutral salt spray	21 days	10 days	–
iv)	Abrasion resistance	500 stokes	50 stokes	500 stokes

NOTES

1 *Class A* – The coated surface of the glass can be positioned on the outer or the inner face of the building.

2 *Class B* – The coated glass can be used as monolithic glazing but the coated surface shall be on the inner face of the building.

3 *Class S* – The coated surface of the glass can be positioned on the outer or the inner face of the building but these types of coated glasses can only be used in specifically defined applications.

ANNEX D

[*Clauses* 6.1.9 *and* E-1.1.1(4)]

PROCEDURE FOR CALCULATING THE APPROXIMATE DEFLECTION AT CENTRE OF GLASS PANEL

D-1 Maximum glass deflection as a function of plate geometry and load may be calculated using the following:

$$\text{Deflection, } w = t \,.\, \exp\,(r_0 + r_1 X + r_2 X^2)$$

where

$X = \ln\{\ln[q(a.b)^2/Et^4]\}$

$r_0 = 0.553 - 3.83(a/b) + 1.11(a/b)^2 - 0.0969(a/b)^3$

$r_1 = -2.29 + 5.83(a/b) - 2.17\,(a/b)^2 + 0.206\,7(a/b)^3$

$r_2 = 1.485 - 1.908(a/b) + 0.815(a/b)^2 - 0.082\,2(a/b)^3$

where

E = Young's modulus of glass, N/mm^2;

q = net pressure on the pane, N/mm^2;

a = longer dimension, mm;

b = shorter dimension, mm; and

t = thickness of the glass pane calculated.

Example:

Lateral Deflection Calculation — Determine the maximum lateral deflection (w) of a vertical 1 200 mm × 1 500 mm × 6 mm rectangular glass plate subjected to a uniform lateral load of 1.80 kPa. The actual thickness of the glass is 5.60 mm as determined through direct measurement.

a = 1 500;

b = 1 200;

$r_0 = -2.689$;

$r_1 = 2.011$;

$r_2 = 0.213$;

$q = 1.80 \times 10^{-3}$ N/mm^2;

$E = 71.73 \times 10^3$ N/mm^2;

t = 5.60; and

x = 1.490.

Therefore, maximum deflection at the centre of glass is:

$$w = 5.6 \text{ x } \exp\,(-2.689 + 2.111 \times 1.490 + 0.213 \times 1.490^2)$$

$$w = 12.2 \text{ mm}$$

ANNEX E

(*Clause* 6.1.9)

MODEL CALCULATION OF GLASS THICKNESS

E-1 MODEL CALCULATION

E-1.1 Glass panel dimension width 1 200 mm and height 1 800 mm for location Chennai for annealed glass type.

E-1.1.1 *General Checks have to be done for Safety Performance*

a) The maximum area of glass panel is restricted to 15 m^2;
b) The maximum span of window is restricted to 4 m;
c) Applicable to normal, reflective, laminated, tempered and insulating glass; and
d) Applicable to rectangular panels properly fixed.

The procedure for calculating glass thickness is described below:

1) *Step* 1 — Calculate aspect ratio (AR_{max}) from Table 15.

Aspect ratio (AR_{max}) = Longer side/shorter side of glass
Aspect ratio = 1 800/1 200 = 1.5

2) *Step* 2 — Wind load calculation

For wind load calculation, reference shall me made to good practice [C-8(15)].

$$p_z = 0.6\ V_z^2$$

$$V_z = V_b.k_1.k_2.k_3.k_4$$

where

V_b = basic wind speed based on location {*see* Fig. 1 of good practice [C-8(15)]}.
k_1 = probability factor (risk co-efficient) {*see* **6.3.1** of good practice [C-8(15)]}.
k_2 = terrain roughness and height factor {*see* **6.3.2** of good practice [C-8(15)]}.
k_3 = topography factor {see **6.3.3** of good practice [C-8(15)]}.
K_4 = importance factor for the cyclonic region {*see* **6.3.4** of good practice [C-8(15)]}.
V_z = design wind speed at height z, in m/s.
p_z = wind pressure at height z, in N/m^2.

The design wind pressure (p_d) can be obtained as:

$$p_d = K_d.\ K_a.\ K_c.\ p_z$$

where

K_d = wind directionality factor {*see* **7.2.1** of good practice [C-8(15)]}.
K_a = area averaging factor {*see* **7.2.2** of good practice [C-8(15)]}.
K_c = Combination factor {*see* **7.3.3.13** of good practice [C-8(15)]}.

The value of p_d, however shall not be taken less than 0.70 p_z.

Design wind speed for Chennai location {Basic wind speed = 50 m/s taken from good practice [C-8(15)]} = 1 750 N/m^2.

3) *Step 3* — Strength factor

Based on the types of glass (laminated/tempered/insulating glass) pressure factor is calculated. To determine the thickness of laminated/ tempered/insulating glass, the design wind pressure P_{net} is modified as below:

$$P_{\text{net}} = p_d / P_f$$

where

P_f = pressure factor dependent on the type of glass.

The values of the pressure factor P_f can be taken from Table 14.

For annealed units, P_f = 1.0, therefore,

P_{net} = 1 750/1.0 = 1 750 N/m^2

At this stage the glass thickness value shall be calculated from the table and then the deflection and stress check be done as described below:

4) *Deflection Check*

The deflection of the glass can be calculated using the formula in Annex D. Actual deflection for the pane shall be obtained as below:

Deflection, $w = t.\ \exp(r_0 + r_1 X + r_2 X^2)$

$X = \ln\{\ln[q(a*b)^2/Et^4]\}$

$r_0 = 0.553 - 3.83(a/b) + 1.11(a/b)^2 - 0.0969(a/b)^3$

$r_1 = -2.29 + 5.83(a/b) - 2.17(a/b)^2 + 0.206\,7(a/b)^3$

$r_2 = 1.485 - 1.908(a/b) + 0.815(a/b)^2 - 0.082\,2(a/b)^3$

where

E = Young's modulus (71.7 x 10^3 N/mm^2);

Q = net pressure on the pane (N/mm^2);

A = longer dimension (mm);

B = shorter dimension (mm); and

T = thickness of the glass pane calculated.

The actual deflection is, 4 mm < 19 mm maximum allowable.

As per **6.3.6.2**, deflection at the centre of the glass for monolithic glass shall be the lesser of shortest span/60 or 19 mm.

Result: As 1200/60 = 20 mm, hence, 19 mm is the maximum allowable deflection.

Hence the glass thickness calculated is safe against deflection.

Glass Thickness Calculation:

$P_{\text{net}}.A = 200.0\ T^k$ (let $T \leq 6$ mm)

P_{net}= 1750

$A = 2.16\ \text{m}^2$

$K = 1.765$

$T = 5.28$ mm, therefore choose the thickness of glass as 6 mm.

ANNEX F

(*Table* 30)

PERFORMANCE TESTS FOR GLAZING SYSTEM

F-1 The following enlists the performance tests for glazing systems. The general test requirements shall be as per **7.1** of accepted standard [C-8(14)].

F-2 SEISMIC RACKING TEST

Criteria shall be the movement of the sub-structure in the horizontal (+/-) directions. Optional testing for vertical movements (+/-) shall be based on sub-structure movement to accommodate live load, long term creep, column shortening and thermal elongation or contraction. No glass breakage or fall out is allowed. No wall component fallout is allowed. The system shall comply with the requirements of air permeability and static water penetration tests as per the designed performance criteria. Post proof load testing, air permeability testing and static water penetration testing shall not be required unless specified otherwise.

F-3 BUILDING MAINTENANCE UNIT (BMU) PULL OUT TEST (WHEN APPLICABLE)

A tensile load of minimum 1.5 kN shall be applied on the BMU restraint in the following directions:

a) Outward and held for a period of 1 min;
b) Horizontally to the right and held for a period of 1 min;
c) Horizontally to the left and held for a period of 1 min;
d) Vertically upward and held for a period of 1 min; and
e) Vertically downward and held for a period of 1 min.

After each step the BMU restrain should not fail or have permanent deformation.

NOTE — If the load on the BMU restraints required by the BMU supplier is higher, the higher load shall apply.

ANNEX G

(*Clause* 9.4.3)

TESTING REQUIREMENTS FOR BLAST RESISTANT GLAZING SYSTEMS

G-1 OBJECTIVE

G-1.1 The purpose of this clause is to provide general guidelines about equipment, range conditions and procedures used to conduct the blast evaluation of glazing systems against the designed blast load and to verify that it meets the defined blast pressure load.

G-1.2 The glazing system is evaluated for its structural integrity by visual inspection only.

G-1.3 The safety precautions and regulations undertaken during blast resistant tests of glazing systems shall be as specified by the test agency.

G-1.4 Blast resistant test of glazing systems shall be carried out only by the accredited institutions/laboratories authorized by the Government of India.

G-2 TERMINOLOGY

G-2.1 Test Sponsor — Party requesting and sponsoring the test. The test sponsor may be its manufacturer or user (or his representative).

G-2.2 Test Agency — Party performing the testing and documenting the test results.

G-2.3 Test Specimen — The test specimen is provided as a complete assembly by test sponsor to the test agency. It may include glazing systems like glass door, glass windows/frames, glass panels, etc.

G-2.4 Trial Officer — Individual identified by the test agency responsible to complete the specified tests as required and to document the results in accordance with this test method. The Test Director shall sign all of the test reports.

G-2.5 Trial Safety Officer — Individual identified by the test agency nominated by the means of trial plan approved by the competent authority. The Trial Safety Officer is responsible for all the safety aspects during the trial time and safe conduct of trials.

G-3 APPARATUS

G-3.1 High Explosive

The high explosive charge (prepared by using TNT/equivalent charge) as mentioned by the test sponsor is used to generate the desired blast parameters for the performance evaluation of test specimen.

G-3.2 Instrumentation

The instrumentation system used for measurement of blast pressure comprises of piezoelectric based pressure sensors, signal conditioner, low noise anti-microphonic cables and data acquisition systems. The details are as follows:

G-3.2.1 *Pressure Sensor*

Pressure sensor is used to record pressure-time history of blast wave. The sensor contains piezoelectric crystal as a sensing element which produces an electric charge proportional to impinging pressure. The pressure sensor has an in-built circuitry that converts pressure to voltage signal. It requires installation control panel (ICP) constant current power supply which is provided by compatible signal conditioner.

G-3.2.2 *Low Noise Cables*

A special low noise anti-microphonic cable is used to transmit the signal from sensor to recording system. These cables are immune to tribo-electric effect and electromagnetic interference.

G-3.2.3 *Data Acquisition System* (*DAS*)

The DAS consists of an analog or digital recording system with a sufficient number of data channels to accommodate the pressure sensor(s) and any other electronic measuring devices. The DAS shall operate at a sufficiently high frequency to record reliably positive pressure and positive phase duration. The triggering of recording system is synchronized with explosion by using transistor-transistor logic system.

G-3.3 Photographic Equipment

Each test is documented with still photography. Video or high speed photography of the testing is deployed, if required.

G-4 PROCEDURE

G-4.1 The Trial Officer along with all team members will be responsible for the execution of the test. The Trial Safety Officer along with the range safety team will take care of the safety of personnel and property during the conduct of test.

G-4.2 The trial site location and range safety distance shall be decided by the test agency.

G-4.3 The parameters (identification number, shape, weight, dimensions, etc) are verified before trial. The documentary proof for the same shall be submitted by the test sponsor to the test agency.

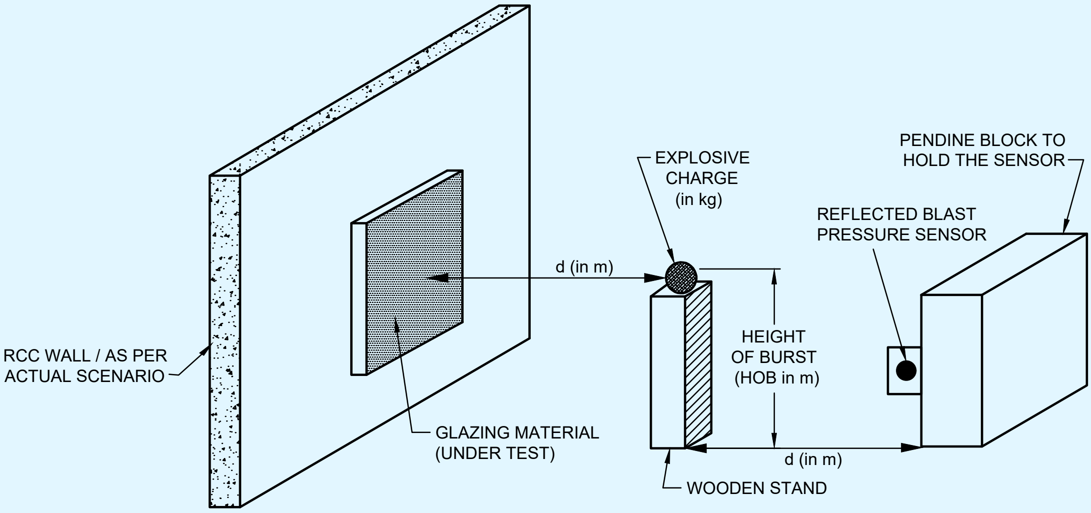
G-4.4 The test specimen is held on to the wall or as per actual scenario like wall having duct with or without room with the help of supporting frame such that no additional pressure gets generated on the glazing system when it is fixed to the frame using nuts and bolts.

G-4.5 The attack face of the test specimen will be towards the explosive charge (TNT/equivalent charge).

G-4.6 Photographic records of details of the glazing assembly and the test configuration are taken prior to the test. If a video photographic record of the response of glazing assembly during the test is desired, video cameras should be deployed.

G-4.7 The explosive charge (TNT/equivalent charge) is prepared as per the threat levels based on weight of explosive and standoff (*see* Table 34) or as defined by the test sponsor.

G-4.8 The explosive charge (TNT/equivalent charge) is positioned at a certain height of burst (HOB) and at distance *d* from the test specimen [as shown in Fig. 22 (isometric view) and Fig. 23 (top view)] (*see* Table 34).


EXPLOSIVE CHARGE (in kg)
PENDINE BLOCK TO HOLD THE SENSOR
REFLECTED BLAST PRESSURE SENSOR
d (in m)
HEIGHT OF BURST (HOB in m)
RCC WALL / AS PER ACTUAL SCENARIO
GLAZING MATERIAL (UNDER TEST)
d (in m)
WOODEN STAND

NOTE — The height of burst (HOB) shall be referenced from the hard stand on which the test specimen support (like RCC wall/test specimen support) stands.

FIG. 22 ISOMETRIC VIEW — SCHEMATIC OF TEST SETUP

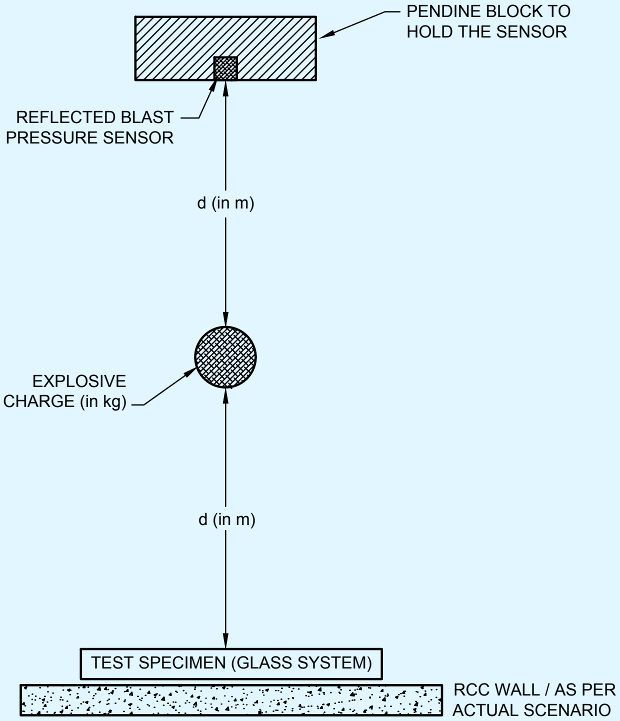

PENDINE BLOCK TO HOLD THE SENSOR
REFLECTED BLAST PRESSURE SENSOR
d (in m)
EXPLOSIVE CHARGE (in kg)
d (in m)
TEST SPECIMEN (GLASS SYSTEM)
RCC WALL / AS PER ACTUAL SCENARIO

FIG. 23 TOP VIEW — SCHEMATIC OF TEST SETUP

G-4.9 The pressure sensor to measure the reflected blast pressure is deployed at distance *d* (as shown in Fig. 22 and Fig. 23). The pressure sensor is deployed in such a way that its sensing element is directed towards the explosive charge (TNT/equivalent charge).

G-4.10 The distance *d* and height of burst (HOB) varies depending on the threat level.

G-4.11 The pressure sensor is then connected to the data acquisition system through signal conditioner via low noise cables and tested to verify proper functioning.

G-4.12 The explosive charge (prepared by using TNT/equivalent) is then detonated by following all safety precautions ensured by trial safety officer and range safety team.

G-4.13 After the test, the visual inspection of the glazing assembly is done to evaluate its structural integrity. Adequate photography is taken after each test.

G-4.14 In case of misfire, the second attempt is done as per misfire drill of the test agency.

G-5 OUTCOMES

The structural integrity of glass system test specimen after the trial is evaluated by visual inspection according to the outcome categories specified in **9.4.3**.

G-6 REPORT GENERATION

G-6.1 Upon completion of the testing, the Test Director assigns a test number and record the test measurement and observations obtained from all test specimen(s) for preparation of test report.

G-6.2 The Trial Officer and the Test Director signs the test report and gets it approved from competent authority of the test agency.

ANNEX H

(*Foreword*)

INSTALLATION OF MIRRORS

H-1 This annex provides general guidelines, which is to be followed during the installation of mirror. Mirrors (Piece of glass silvered on one side, with a protective paint coating) are used in shops, gymnasiums, etc, where it is predominantly used as wall cladding. The mirror panels in such application use large panel size and it is recommended to follow the installation procedure in accordance with this Section.

H-1.1 The mirror should always be mounted on a perfectly flat, clean and dry surface free from acids and aggressive substances such as acid, solvent and cement mortar.

H-1.2 The mirror shall be mounted on wall or plywood and care is taken that the mirror is never stuck over unstable support (painted paper, paint or old plaster). It is recommended that the mirror installation is not done directly on the mirror supports. In order to have good ventilation, the following spacing behind the mirror is recommended depending on the height of the mirror panel:

a) A space of 5 mm for a mirror less than 1 m height; and

b) A space of 10 mm for a mirror greater than 1 m height.

Figure 24 gives typical details of the installation of mirrors. During the installation of mirror panels at several levels that is, one above the other, it is recommended to provide a space of 10 mm at the top and at the bottom for circulation of air. The side of the mirror is designed with a minimum 1 mm or 2 mm of interleaving space. When mirror is fixed in a profile (frame), care is to be taken to maintain perfectly dry and clean frame. It is recommended that mirror is supported on hard non-metallic/plastic wedges of at least 3 mm, to raise the mirror and thus avoid contact with the condensed water which could accumulate in the profile. If the mirror is screwed on, the screws of a suitable dimension is designed, with the interleaving and washers (*see* Fig. 25) made of plastic to avoid any direct glass-metal contact. To minimize the risk of breakage, cracks and splinters during screw-mounting the mirror, it is recommended to use synthetic protective collars.

H-1.3 For the adhesive used to mount mirrors, care should be taken to ensure that the adhesive is compatible with the protective coatings on the mirror. It is recommended to use only neutral binding agents such as alkoxy silicone, oxime silicone, etc. Avoid use of acid silicones, such as acetoxy silicones which contain acetic acid or water/rubber/polyurethane-based glues.

H-1.4 In the high humidity areas (for example bathrooms), it is recommended to seal the edges with neutral silicone to protect the backing paint from damage due to moisture and enhanced protection from moisture. It is recommended to use double sided adhesive tapes to fix the mirror on the mounting surface (*see* Fig. 26). The adhesive tapes used for installation shall be certified to be compatible with the mirror and the adhesive or the adhesive tapes shall always be fixed vertically.

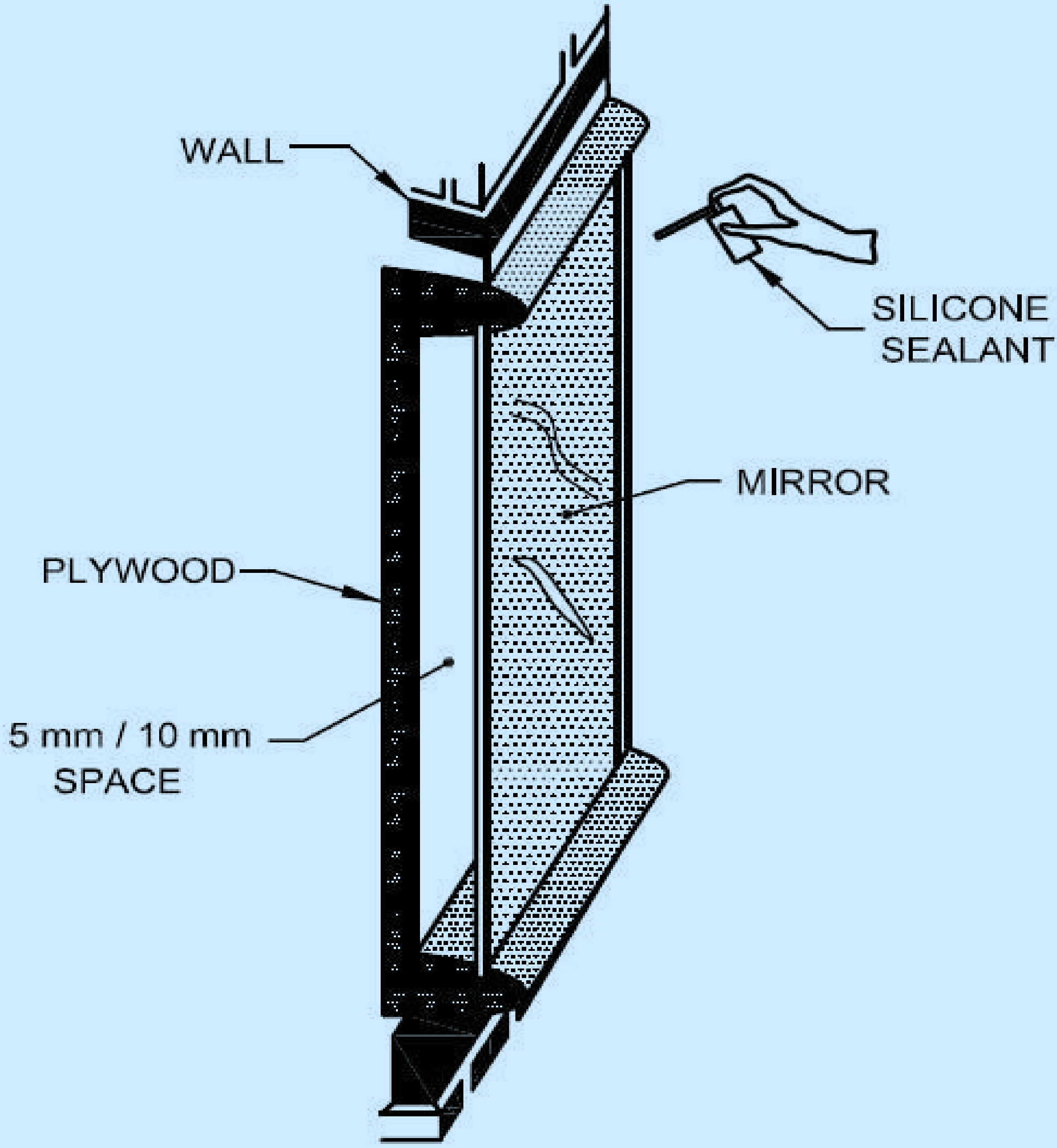

WALL
SILICONE SEALANT
MIRROR
PLYWOOD
5 mm / 10 mm SPACE

FIG. 24 INSTALLATION OF MIRRORS

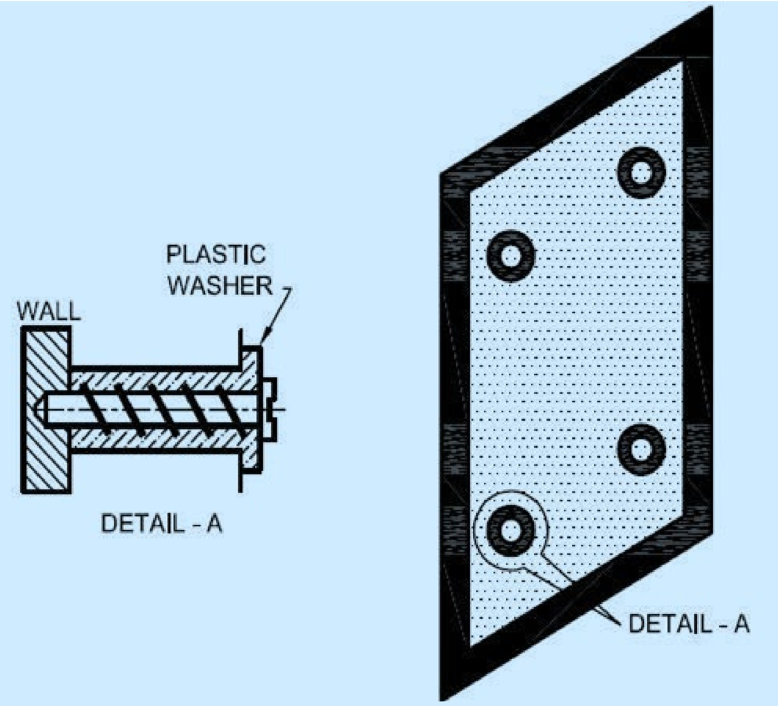

PLASTIC
WASHER
WALL
DETAIL - A
DETAIL - A

FIG. 25 DETAILS OF USE OF SCREWS AND INTERLEAVING WASHERS FOR INSTALLING MIRRORS

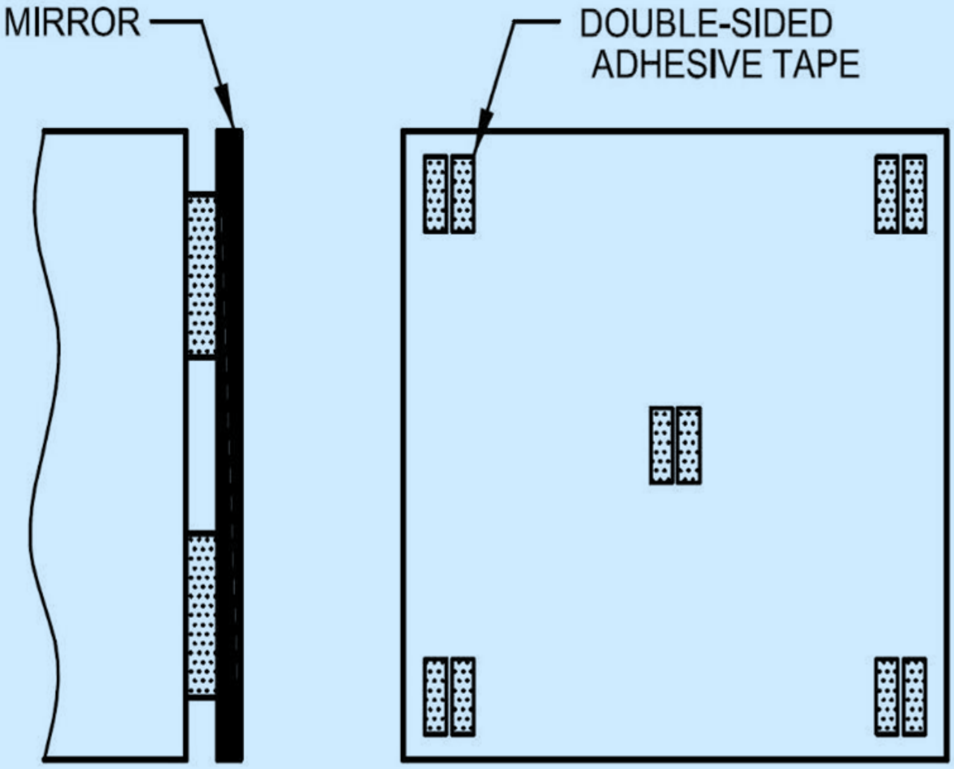

MIRROR
DOUBLE-SIDED
ADHESIVE TAPE

FIG. 26 DETAILS OF USE OF DOUBLE SIDED ADHESIVE TAPES FOR INSTALLING MIRRORS

ANNEX J

(*Foreword*)

GLASS RAILINGS

J-1 GENERAL

Glass railings are generally sought in institutional, commercial, residential buildings and special structures like stadiums, foot over bridges, etc. Glass of appropriate thickness when used as a railing can provide transparency and when engineered properly can provide structural performance too. In public places such as stadiums, foot over bridges, shopping malls, etc, use of frameless glass railing shall be avoided and framed systems with vertical balustrades and glass infill panel may be used with proper design as per the design provisions.

The basic requirement of a parapet, which a glass railing (if so used) intends to substitute, shall be met with. This includes protecting people from falling and in some cases to control movement. Careful consideration, including in design, shall be made/determined where glass railings are used.

> NOTE — Notwithstanding the above, the potential benefits including safety (through psychological aspects) of regular railings shall be borne in mind.

J-2 PRELIMINARY CONSIDERATIONS

In the assessment of the need for a railing and the type of railing to be provided, the designer should give consideration to the likely hazards, the building use and the risks to building users. Where, in a building, more than one use of the building is anticipated, either the railing design should be chosen to suit the worst case, or more than one type of railing should be provided, as appropriate, to the location. Generally, when there is a change in adjacent levels (600 mm in dwellings, 380 mm in other buildings) a railing is needed to restrict movement of people.

The railing adopted should be designed so as to minimize the risk of persons falling, rolling, sliding or slipping through gaps in the railing. In dwellings and other buildings which can be accessed by children, gaps in railing or infill should not be large enough to permit a sphere of 100 mm diameter to pass through, making due allowance for deflection under load.

The designer should ensure all the elements of the railing system satisfy the criteria given in available relevant standards.

For general safety, the finished barrier should have no sharp edges or projections that could cause injury to persons or clothing. Infill panels and balusters are intended to provide support and protection to users, and should be designed to restrain people without causing additional injury from sharp edges, thin sections, open-ended tubes, projecting details, etc.

The design shall be based on the horizontal uniformly distributed load (UDL) applied at a notional height of 1.1 m above finished floor level, even though the minimum permissible height of the railing may be less (the notional design height of 1.1 m is chosen as being representative of the height of the centre of gravity of a human being above the datum level).

J-3 GLASS RAILING TYPES

There are four common types of railings that are used to fix glass.

a) *Full Height Railing* — Where glass forms part or whole of a wall element, the railing should be carefully designed as per the relevant standards and as per this Section, if any part of the glass comes below the minimum railing height (*see* Table 35 and Fig. 27).

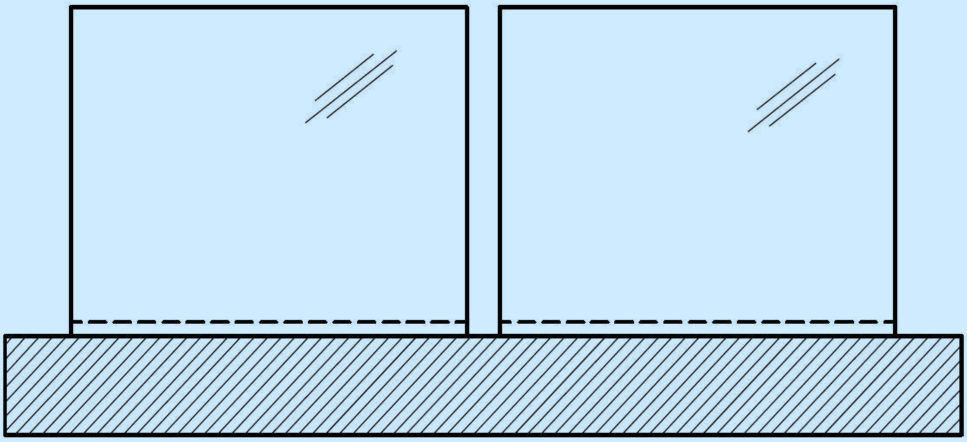


FIG. 27 FULL HEIGHT RAILING

b) *Railings with a Glass Infill Panel* — In this type of railing, the main frame of the railing (that is, top rail and baluster) should be designed to withstand the loads applied to the top rail and the glass should be used to form infill panels. It should be noted that the glass provides no support to the main frame. The designer shall ensure that, irrespective of the fixing type, in the event of glass breakage, the broken glass remains securely attached to its framing or supporting structure, thereby preventing safety hazards. This can be further sub-categorized into 4 types:

1) *Glass supported on vertical edges only* — This may involve the vertical edges of the glass being supported in a rebate into the side of each vertical post. The top and bottom edges of the glass are exposed. The glass may also be supported by patch fittings fixed to the posts. In all cases a handrail is required (*see* Fig. 28).

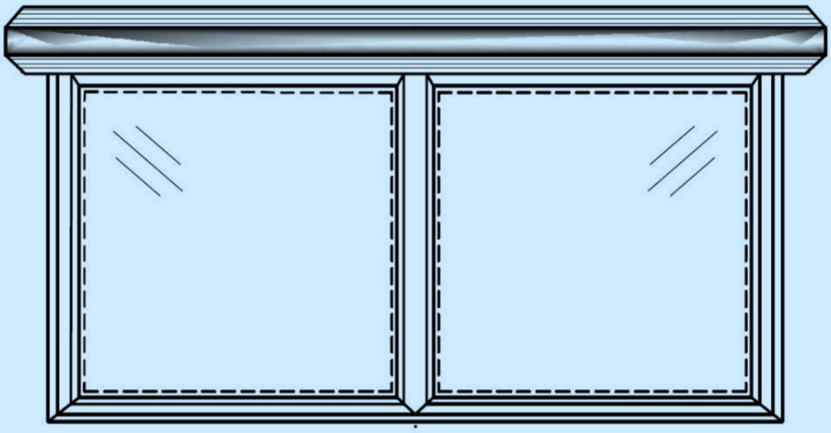


FIG. 28 GLASS SUPPORTED ON VERTICAL EDGES ONLY

2) *Glass supported on horizontal edges only* — This may involve a handrail at the top, and a channel or a rail at the base of the glass. In this case the handrail should be designed to carry the railing load with the glass designed to carry the infill load (*see* Fig. 29).

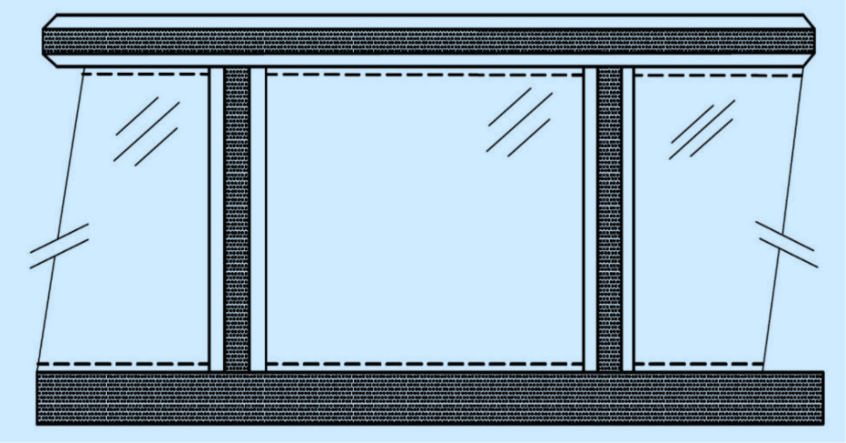


FIG. 29 GLASS SUPPORTED ON HORIZONTAL EDGES ONLY

3) *Glass supported on all four edges* — (*See* Fig. 30)

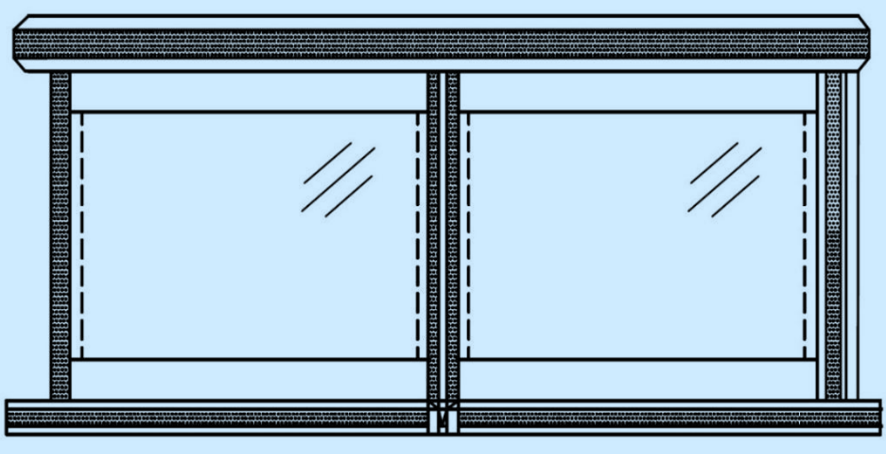


FIG. 30 GLASS SUPPORTED ON ALL FOUR EDGES

4) *Glass fixed by patch/bolted fittings* — This system requires the use of two rows of bolts (commonly) to provide a stiff fixing which minimizes panel deflection. There are a variety of bolt fixing types available in the market, so design and performance information should be sought for each type. The purpose of these fixings is to transfer the force applied to the railing into the support structure. These fixings occupy a small surface area on the glass which can produce high stresses in the glass, so careful analysis is required to determine suitable glass thickness, fixing spacing and size. Glass fixings shall be designed to avoid high local stresses and minimize the risk of failure. Minimum fixing sizes shall be used, and for large panels exceeding 2 m in dimension or under high wind pressure exceeding 2.5 kPa, fixings shall accommodate rotations by using articulated fixings (*see* Fig. 31).

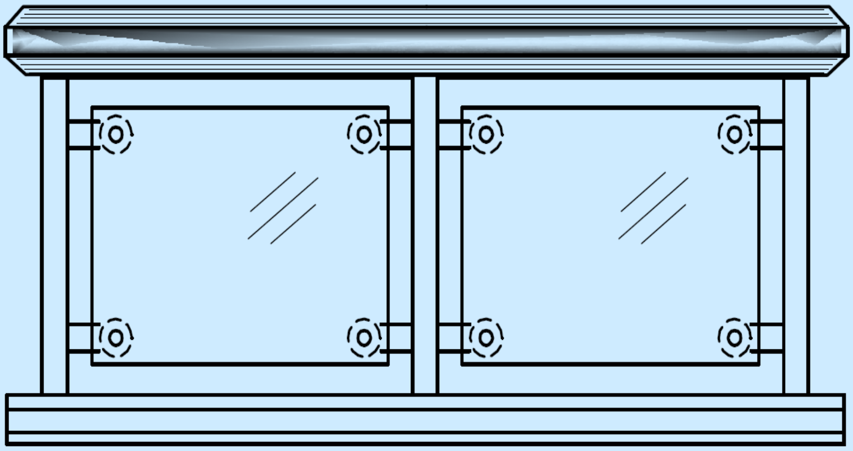


FIG. 31 GLASS FIXED BY PATCH/BOLTED FITTINGS

c) *Free Standing Glass Protective Railing* — In this type of railing, the glass should be designed to withstand the design loads. Each glass plate should be rigidly clamped to the structure along its bottom edge, the handrail attached to the top edge of the glass and there should be no balusters. In the event that a free standing railing is supplied without a handrail, each panel should be able to withstand the entire appropriate design load. This applies to vertical glazing and glass within 15º of vertical. Adequate provision for drainage of water should be made in the base structure to avoid any water ponding which may cause delamination issue. Laminated safety glass shall be used for this application. Clamping and brackets shall be designed with adequate anchorage, and the main supporting building elements (beam/slab) shall be verified to meet the required minimum thickness. The bottom glass clamping embedment shall be a minimum of 100 mm, regardless of railing size. The bottom clamping member shall provide continuous support along the glass bottom edge. In the event of glass breakage, the glass panel shall remain securely in place without risk of detachment or falling (*see* Fig. 32).

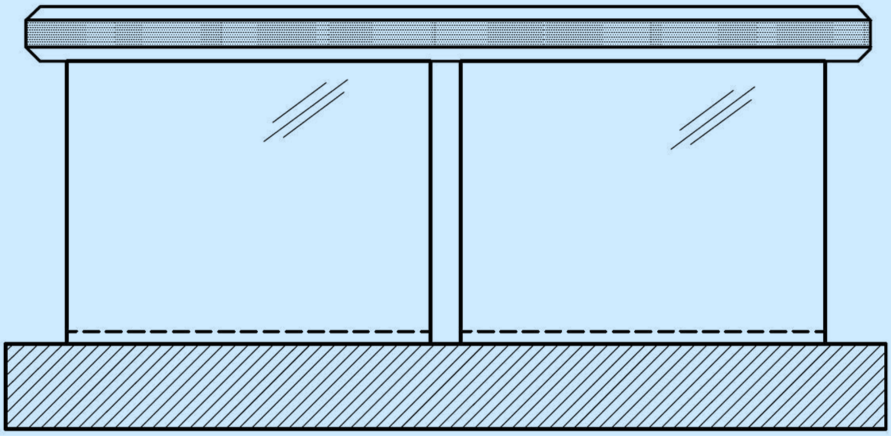


FIG. 32 FREE STANDING GLASS PROTECTIVE RAILING

d) *Bracket Systems* — These systems are an extension of the bolt fixed system where the bolts are part of a bracket and the bracket is fixed to the floor or the face of a concrete slab, steel or timber structure. The use of these systems shall be investigated carefully as they can develop very high stresses in the glass where the brackets are located. The design shall balance glass thickness and bracket location to produce an adequate system. Some systems may be designed to produce test data, to justify their use. This data shall be studied carefully as there have been some cases where such data has been shown to be inadequate. Proper interpretation of these test data shall also become necessary (*see* Fig. 33).

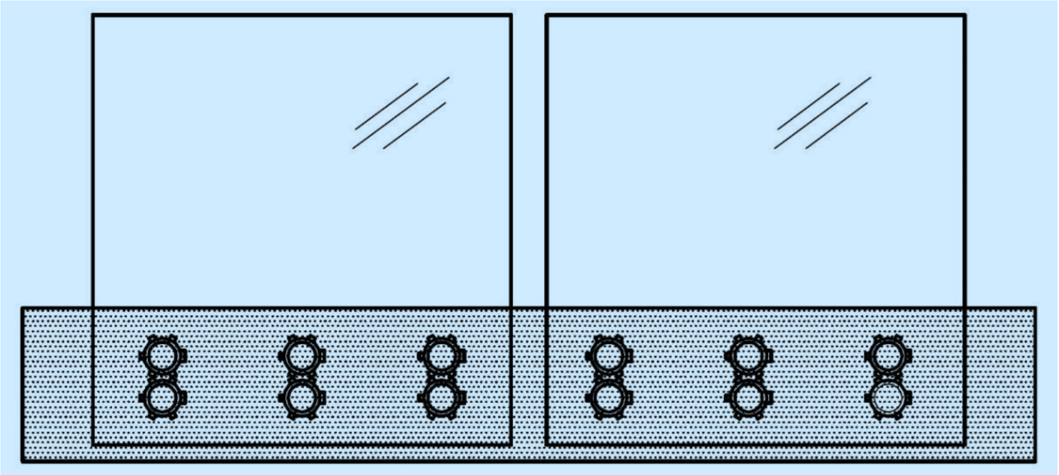


FIG. 33 BRACKET SYSTEMS

e) *Bracket Systems* — Bottom supported with surface attached/bolted Handrail — Glazing as structural member (*see* Fig. 34).

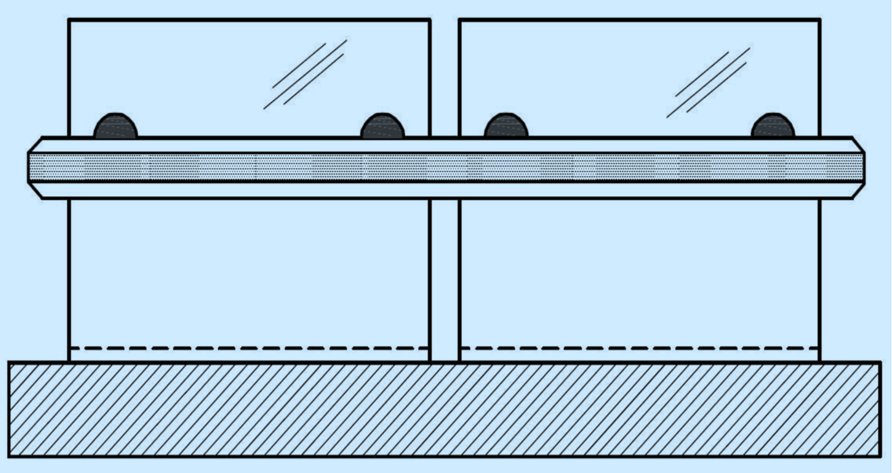


FIG. 34 BOTTOM SUPPORTED WITH SURFACE ATTACHED/BOLTED HANDRAIL — GLAZING AS STRUCTURAL MEMBER

Table 35 Minimum Barrier Heights

[*Clauses* J-3 (a), J-4.1, J-5.4.1 *and* J-6.1]

Sl No.	Use	Position	Height mm
(1)	(2)	(3)	(4)
i)	Single-family dwelling	a) Barriers in front of a window up to 10 floors	800
		b) Barriers in front of a window from 11th floor to 20th floor	1 100
		c) Barriers in front of a window above 21st floor	1 200
		d) Stairs, landings, ramps, edges of internal floors	900
		e) External balconies including *balconet*, edges of roofs:	
		1) up to 20th floor	1 100
		2) 21st floor and above	1 200
ii)	All other uses	a) Barrier in front of a window	800
		b) Stairs	900
		c) Balconies and stands, etc having fixed seating within 530 mm of the barrier	800
		d) Balconies and stands, etc having fixed seating within 530 mm of the barrier, provided the sum of the barrier width and the barrier height is greater than 975 mm	750
		e) Other positions including balconets	1 100

NOTE — Height shall be measured from the top edge of the railing to the highest point of the floor where occupants can stand. This measurement shall be from the top of any ledges, up-stands, or toe walls, if present at the base.

J-4 DESIGN CONSIDERATIONS

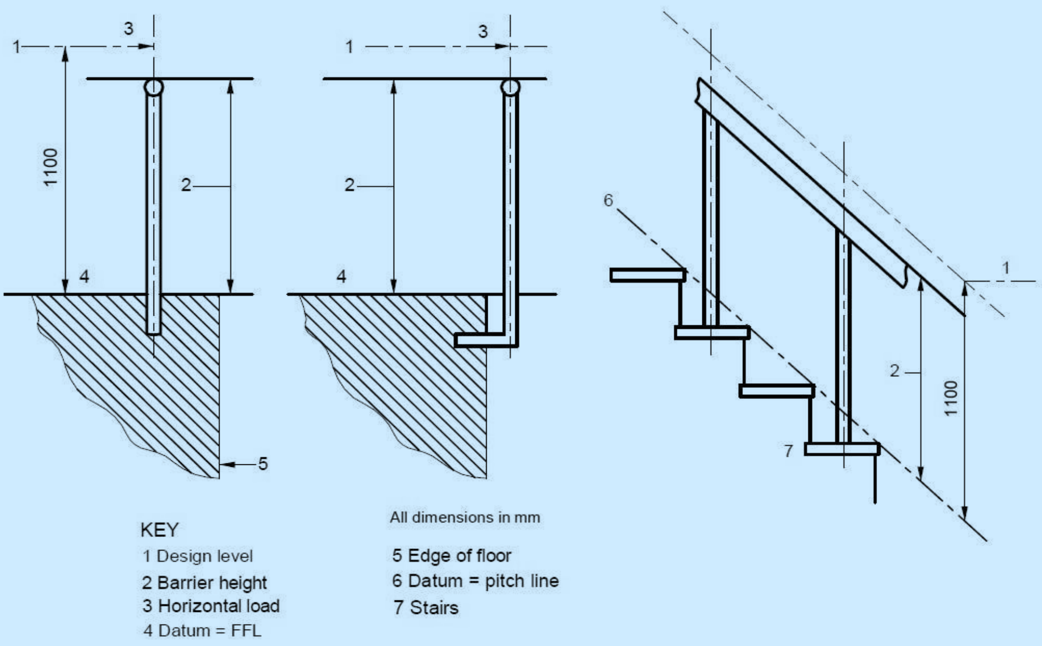
The designer shall first determine the purpose of the railing. Once this is done, the appropriate load requirement can be derived. Typical values (minimum requirements) of railing loads to be chosen are given in Table 36 (If so desired by the designer, higher values than that in the Table 36 may also be chosen).

J-4.1 General

Railings should be designed to resist the most unfavourable likely imposed loads and wind loads separately without unacceptable deflections or distortions. Heights of railings shall be same as that for parapet walls as per other Parts of this NBCS. The railing height above datum is defined in Fig. 35. The minimum heights for each railing location shall be as given in Table 35.

The height of glass railings installed on top of low parapet walls should be measured from the top of the parapet and not at walk level.

For railings, either permissible stress or limit state design procedure should be used, according to the recommended procedures. When using limit state design, the partial safety factors for loads and materials should be those recommended by the appropriate standard for relevant materials. The deflection of the railing shall be determined as per serviceability limit state.



NOTE — In design, the horizontal uniformly distributed line load acts at a height of 1.1 m above datum level, irrespective of the actual height of the element.

FIG. 35 DATUM, BARRIER HEIGHT AND DESIGN HEIGHT

J-4.2 Loading

Minimum horizontal imposed loads appropriate to the design of parapets, railings, balustrades and other elements of structure intended to retain, stop or guide people, should be determined in accordance with Table 36, which recommends a uniformly distributed line load for the railing and a uniformly distributed and point load applied to the infill.

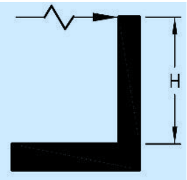
NOTE — These are not additive and should be considered as three separate load cases, all loads being determined according to the type of occupancy which reflects the possible in-service conditions.

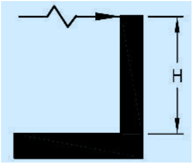
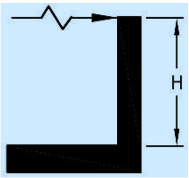
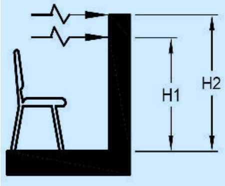
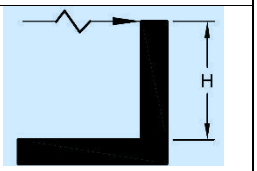
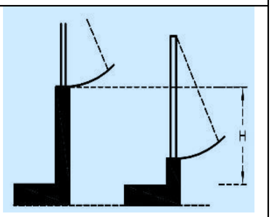
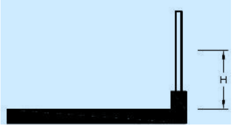
Horizontal uniformly distributed line load should be applied at design height as presented in Table 36 or at design level (1 100 mm) for railings higher than the design height.

Uniformly distributed load should be applied to the area below the design height.

Point load should be applied at the most onerous point anywhere on the railing structure.

NOTE — For clarity, the design level (the level at which the horizontal uniformly distributed line load ought to be considered to act) is shown in Fig. 36.

Sl No.	*Building*	*Element*	*Strength*	*Height* (H)	
(1)	(2)	(3)	(4)	(5)	
i)	Single family dwelling	Stairs landings, ramps edges of internal floors	0.36 kN/m	900 mm for all elements	
		External balconies and edges of roofs	0.74 kN/m	1 100 mm	

Sl No.	*Building*	*Element*	*Strength*	*Height* (H)	
(1)	(2)	(3)	(4)	(5)	(6)
ii)	Factories and warehouses (light traffic)	Stairs, ramps	0.36 kN/m	900 mm	
		Landing and edges of floor	0.36 kN/m	1 100 mm	
iii)	Residential institutional, educational, office and public building	All location	0.74 kN/m	900 mm for flights otherwise 1 100 mm	
iv)	Assembly	Within 530 mm in front of fixed seating	1.5 kN/m	800 mm (H1)	
		All other locations	3.0 kN/m	900 mm for flights elsewhere 1 100 mm (H2)	
v)	Retail	All locations	1.5 kN/m	900 mm for flights otherwise 1 100 mm	
vi)	All buildings	At opening windows		800 mm	
		At glazing to changes of level	To provide containment	Below 800 mm	

NOTE — *H* is the height at which the applied load (horizontal design load) is located and it need not be the height of the barrier itself.

FIG. 36 HEIGHT LIMIT FOR THE UNIFORM LOADING FOR VARIOUS CATEGORY OF BUILDINGS

Table 36 Minimum Horizontal Imposed Loads for Parapets, Barriers and Balustrades

[*Clauses* J-4, J-4.2, J-4.4 *and* J-4.6]

Sl No.	Type of Occupancy for Part of the Building or Structure	Examples of Specific Use	Horizontal Uniformly Distributed Line load	Uniformly Distributed Load Applied to the Infill	A Point Load Applied to Part of the Infill
			kN/m	kN/m^2	kN
(1)	(2)	(3)	(4)	(5)	(6)
i)	Domestic and residential activities	a) All areas within or serving exclusively one single family dwelling including stairs, landings, etc but excluding external balconies and edges of roofs	0.36	0.5	0.25
		b) Other residential, that is houses of multiple occupancy and balconies, including Juliette balconies and edges of roofs in single family dwellings	0.74	1.0	0.5
ii)	Offices and work areas not included elsewhere, including storage areas	a) Light access stairs and gangways not more than 600 mm wide	0.22	—	—
		b) Light pedestrian traffic routes in industrial and storage buildings except designated escape routes	0.36	0.5	0.25
		c) Area not susceptible to overcrowding in office and institutional buildings, also industrial and storage buildings except as given above	0.74	1.0	0.5
iii)	Areas where people might congregate	Areas having fixed seating within 530 mm of the barrier, balustrade or parapet	1.5	1.5	1.5

Table 36 (*Concluded*)

Table 36 Minimum Horizontal Imposed Loads for Parapets, Barriers and Balustrades
[*Clauses* J-4, J-4.2, J-4.4 *and* J-4.6]

Sl No. (1)	Type of Occupancy for Part of the Building or Structure (2)	Examples of Specific Use (3)	Horizontal Uniformly Distributed Line load kN/m (4)	Uniformly Distributed Load Applied to the Infill kN/m^2 (5)	A Point Load Applied to Part of the Infill kN (6)
iv)	Area with tables or fixed seatings	Restaurants and bars	1.5	1.5	1.5
v)	Areas without obstacles for moving people and not susceptible to overcrowding	a) Stairs, landings, corridors, ramps	0.74	1.0	0.5
		b) External balconies including Juliette balconies and edges of roofs. Footways and pavements within building curtilage adjacent to basement/sunken areas	0.74	1.0	0.5
vi)	Areas susceptible to overcrowding	a) Footways or pavements less than 3 m wide adjacent to sunken areas	1.5	1.5	1.5
		b) Theatres, cinemas, discotheques, bars, auditoria, shopping malls, assembly areas, studio. Footways or pavements greater than 3 m wide adjacent to sunken areas.	3.0	1.5	1.5
vii)	Retail areas	All retail areas including public areas of banks/building societies or betting shops	1.5	1.5	1.5
viii)	Vehicular	Pedestrian areas in car parks, including stairs, landings, ramps, edges or internal floors, footways, edges of roofs	1.5	1.5	1.5

In general, the following load combinations as described in **J-4.2.1** to **J-4.2.3** should be applied.

J-4.2.1 *Free Standing Glass Protective Railing* (*Without any Balusters*)

It requires four design loadings to be taken into account:

a) Infill load, in kN;
b) Uniform load, in kN/m;
c) Concentrated load, in kN; and
d) Shot bag test load, in Joules.

J-4.2.2 *Railing with Glass Infill Panel*

It requires four design loadings to be taken into account:

a) Infill load, in kN;
b) Uniform load, in kN/m;
c) Concentrated load, in kN; and
d) Shot bag test load, in Joules.

J-4.2.3 *Full Height railing*

It requires four design loadings to be taken into account:

a) Infill load, in kN;
b) Uniform load, in kN/m;
c) Concentrated load, in kN; and
d) Shot bag test load, in Joules.

J-4.3 Wind Loads

External railings should be designed to resist the wind loads given in good practice [C-8(15)].

J-4.4 Deflection

Railings for the protection of people should be of adequate strength and stiffness to sustain the applied loads given in Table 36. In addition, a railing that is structurally safe should not possess flexibility to such an extent so as to create a false alarm to building users when subject to normal service conditions. Therefore, for serviceability considerations, the limiting condition for deflection appropriate for a railing for the protection of people is that the total horizontal displacement of the railing at any point from its original unloaded position should not exceed the deflection limits determined from the relevant structural design code (where applicable) for the material used, or 25 mm, whichever is the smaller. Where the infill of a railing is subjected to the imposed loads given in Table 36, or if appropriate, other calculated design loads, the displacement of any point of the railing should not exceed H/65 or 25 mm, whichever is lower. These deflection limits shall apply to the deflection of the cantilevered top edge of the railing, measured perpendicular to the glass plane or the direction of the wind load.

J-4.5 Fixings, Attachments and Anchorage

The strength of fixings, attachments and anchorage securing the railing to a substrate should be adequate to sustain a loading greater than that to which the railing will be subjected. All joints should be designed to provide the full strength of the members being joined. To that end, where any uncertainty exists with regard to the strength of any component in the fixing, the design loading factors should be increased by 50 percent.

While designing fixings, particular care should be taken to account for the material into which the fixing is placed, the spacing between fixings, the edge distance, and where the substrate is concrete, the position of reinforcement. Building elements (beam/slab/up-stand) shall have adequate thickness and shall be composed of structural reinforced cement concrete (RCC) or steel. The designer shall exercise caution when the thickness of the concrete element is less than 100 mm, as adequate embedment may not be achievable. The designer shall ensure that the concrete element is cast with high quality and shall refrain from fixing to any loose concrete. Design of anchors shall conform to the requirements of accepted standard [C-8(30)].

NOTES

1 The recommendation of an additional load factor of 1.5 is intended to ensure that under an extreme load condition, railings give an indication of failure by deflection or distortion and not by total collapse, as may be brought about by a failure of the fixing, attachment or anchorage system. Where the design strength of a proposed system of fixing to an existing substrate cannot be determined with reasonable accuracy by theoretical consideration, load testing should be used to validate the design.

2 A factor greater than 1.5 on railing load design might also be chosen based on the importance desired by the designer/parties concerned.

J-4.6 Testing

It is recommended to conduct the tests as detailed in this clause, on railings provided for the type of occupancy classified as 'Areas susceptible to overcrowding', as specified in Table 36. For all other occupancy types, the tests to be conducted on railings for performance evaluation, shall be mutually decided between the parties concerned.

J-4.6.1 *Test Selection*

Load test methods for the uniform load test and the concentrated load test are selected based on the performance specification.

J-4.6.2 *Sequence of Test Method*

Specimens tested for two or more of the loading conditions are subjected first to the in-fill load test, followed by the uniform load test, and then the concentrated load test and shot bag glazing impact test, steel nose pendulum impact, and sphere penetration evaluation, in that order, unless directed otherwise by the performance specification.

J-4.6.2.1 *Apparatus and load application*

a) *Assembly support fixture* — An assembly support fixture shall ensure the rigidity normally provided to an assembly in a building by the ceiling, floor, and walls. The support fixture for the specimen shall consist of a vertical wall section constructed from nominal steel or 2 by 4 wood studs, 400 mm on centre, with a rough opening of sufficient size to support the test specimen in accordance with the manufacturer's specifications. The limiting deflection of the wall shall be L/175 (based on the anticipated loads);

b) *Load attachments* — Brackets, fasteners, or other devices used in performing these tests shall be designed and attached so as to minimize their influence on the test results;

c) *Shot bag, traction and release system* — The shot bag shall be of weight 45.4 kg as described in **6.4.2.5** and **6.4.6** of accepted standard [C-8(3)]. The suspension device shall conform to **6.4.2.6** of accepted standard [C-8(3)] and the Traction Release system shall conform to **6.4.2.7** of accepted standard [C-8(3)];

d) *Load measuring device* — Load and time-measuring devices with an accuracy of ± 2 percent of the full scale shall be incorporated in the test setups. The scale ranges used shall assure that the performance levels are within an accuracy of ± 5 percent; and

e) *Rate of loading* — The rate of loading shall be such that the maximum specified load is achieved in no less than 10 s and no more than 5 min**.** Maintain the maximum specified load for 1 min before releasing. [Warnings: 1) Possible injury to personnel and damage to the test equipment and instrumentation prior to, during, and after load application by any unexpected release of potential strain energy accumulated during testing can occur and shall be given consideration. 2) If tests are conducted in a structure and not in a testing laboratory, exercise caution against unwanted damage to the building, its components, and its finish].

   For in-fill testing, use a bearing plate with appropriate cushioning between the plate and the glazing. The bearing plate should be 0.09 m^2.

Each load test to be performed on a new specimen or the undamaged specimen from the previously applied test. Perform only one test per glazing in-fill type on each of the three specimens at the most critical point of the system.

J-4.6.3 *Sampling*

A minimum of three representative replicate specimens of each type of system shall be tested. Sequential testing of the same specimen shall be permissible provided no breakage of any component occurs during the previously performed tests.

J-4.6.4 *Test Specimens*

The specimen installation, including the post spacing, shall be the same as the actual field installation. The specimen shall have a minimum of three posts or minimum two largest glass panels. Each unique attachment scenario shall be tested.

Multiple types of infill panels shall be qualified within one test, provided each panel is individually glazed into the system prior to the start of the test. No substitution of infill product shall be permitted once testing has commenced.

J-4.6.5 *Installation*

The glass rail, guard, or balustrade system being tested shall be installed in accordance with the manufacturer's or designer's specifications.

J-4.6.6 *Test Procedure*

J-4.6.6.1 *In-fill load test*

The test specimen shall be capable of satisfactorily resisting the required test load applied over a 0.09 m^2 area normal to the in-fill. The test load shall be applied at the intersection of the horizontal and vertical centre lines of the in-fill, unless specified otherwise by the performance specification or the purposes of the test. If it is determined that another location will yield lesser results, that position should be used instead of the indicated intersection point of the centre lines. Record deflection of the in-fill at the point of maximum deflection of the in-fill.

J-4.6.6.2 *Uniform load test*

Subject the top rail or other rail of the test specimen to the required maximum uniform test load applied vertically and horizontally, as required by the performance specification. Required vertical and horizontal test loads shall be applied separately and sequentially, unless otherwise required by the performance specification or to meet the purpose of the test. Record the deflection at mid-span during each test.

J-4.6.6.3 *Concentrated load test*

The top rail or other subject rail of the test specimen shall be subjected to the concentrated test load applied vertically and horizontally, as required by the performance specification. Apply required vertical and horizontal test separately and sequentially, unless otherwise required by the performance specification or to meet the purpose of the test. The required concentrated test load shall be applied at the following three critical locations – rail mid-span between posts, top rail adjacent to a post (maximum 75 mm from post) and top of a single post. Test loads are to be applied and deflection recorded sequentially, one location at a time. The load applied on the rail adjacent to the post can be applied to the opposite post from which the top-of-post-test was performed. In the case of swing gates, if the structure of the gate requires locating the test load more than 75 mm from a post due to hinge or latch construction, the load should be located as close to the 75 mm maximum distance from the post as is possible. Record the deflection at the point of application of the load.

J-4.6.6.4 *Shot bag impact test*

Any protective masking or decorative components shall be removed from the glazing material.

To position the impactor at the selected drop height, a traction force shall be applied to raise the impactor such that the axis of the impactor shall be aligned with the suspension cable, with the cable remaining taut. To ensure this, the top and bottom ends of the impactor shall be connected to the release device by a suitable link.

To reduce bag deformation during testing, the bag shall be rotated about the axis of its suspension device before each specimen or sample set, by no less than 30º, and by no more than 90º.

To reduce bag damage during testing, a thin homogeneous or non-woven plastic film no more than 0.13 mm thick or a loosely draped woven cloth towel weighing no more than 0.05 g/cm^2 shall be permitted to be suspended vertically from its top edge directly in front of the surface of the specimen at a distance no more than 10 mm.

The impactor shall be suspended from an overhead support, located so when at rest it will, at its maximum diameter, be located no more than 12 mm from the surface of the specimen and no more than 50 mm from the impact location of the glazing infill specimen.

Raise the impactor to the required height (460 mm, 1 220 mm or 1 525 mm) and stabilize it. The suspension device shall be taut and the axes of the impactor and cable shall be aligned.

The impactor, stabilized in the launch position in a vertical plane normal to the test specimen, shall be released and falls without initial velocity or axial rotation.

If the glazing does not break, the impactor is to be raised to the next designated height and glazing impacted from the new height. Glazing found to be unbroken and remaining completely in the frame after impact shall be recorded as intact.

J-5 GLASS

The use of glass in railings, the type and thickness of glass required for various support conditions shall be as given below. If designed properly, glass can form a structural component of the railing, or the railing may be designed to have a structural component made from another material such as steel or aluminium, with glass acting as an infill panel only. This places a lesser load on the glass as the major load is taken by the structural component.

NOTE — There are certain situations, particularly under some lighting conditions, where the presence of transparent glass is not readily evident and suitable manifestation should be provided.

J-5.1 Types of Glass

It is recommended to use laminated safety glass for all types of glass railing applications, whether framed or frameless. In the event of glass breakage, the glass panel shall remain in place without falling from its position.

J-5.2 Working of Glass

When toughened glass or heat-strengthened glass is used in laminated glass, it shall conform to accepted standard [C-8(7)] for toughened glass and accepted standard [C-8(8)] for heat-strengthened glass.

J-5.3 Fixing of Glass

Contact between glass and any other hard material (including other glass parts) should be prevented. Rubber gaskets or other glazing materials should be used with frame sections. The frame section should give a minimum of 15 mm edge cover to the glass unless it can be shown by test or calculation that the frame will retain the glass under load while conforming to design requirements.

The frame and/or fastenings should be designed so that they do not tend to distort the glass panel. This is particularly important with bolted connections, which can exert considerable forces on the glass, where particular attention should be paid to the alignment and position of the fasteners in order to avoid unnecessary stresses being developed.

J-5.3.1 *Bolt Fixing of Infill Panels*

At the bolted connections there should be clamping plates and gaskets on both sides of the glass that provide a minimum of 50 mm diameter cover to the glass. These plates should be not less than 6 mm thick in steel or 10 mm thick in other suitable metals.

Where the length of a glass pane is greater than the span between the bolted connectors, giving rise to a cantilevered portion of the pane, the cantilevered portion should be less than one-quarter of the span between the bolted connectors.

Under the design loads, the railing should be designed so that the relative in-plane movement of the bolted connections in the same panel is not greater than 2 mm.

The glass, framing system and connections of railings and infill panels should be capable of sustaining and safely transmitting the design loads to the supporting structure.

J-5.4 Design of Glass

J-5.4.1 *Design of Glass in Full Height Protective Railings*

Glass partly or totally below the minimum railing height should be designed to satisfy the appropriate design criteria. Any part of a glass pane below the minimum railing height should sustain the infill loads. Where there is glass at the minimum railing height given in Table 35, the glass should also sustain the line load applied at the design level.

For any specific information on the glass size relative to the glass type, support system, loadings and thickness, available standards or the manufacturer recommendations should be sought.

J-5.4.2 *Design of Glass Infill Panels*

Infill panels should be designed to satisfy the appropriate design criteria as below:

a) *Fully framed infill panels* — The deflection of the glass in fully framed infill panels should be as per recommended deflections;

b) *Two-edge framed infill panels* — The deflection of the glass in two-edge framed infill panels should be as recommended under **J-4.4** taking *L* as the distance between the supports;

c) *Clipped infill panels* — The clips should be positioned around the periphery of the infill panel, at a maximum spacing of 600 mm. Each clip should be not less than 50 mm in length and should give a minimum depth of cover to the glass of 25 mm;

d) *Bolt fixing of glass infill panels* — Where glass is supported by bolted connections through holes in the glass, toughened/toughened laminated glass should be used; and

e) *Position of infill panels relative to the main frame* — Infill panels should be fully contained within the supporting structure. In order not to apply unintended loads to the infill panels, they should have handrails above the glass or attached to the side to which the public have access.

J-5.4.3 *Design of Free-Standing Glass Protective Railings*

The glass should be designed to satisfy the appropriate design criteria given in **J-4**. The deflection of the glass should not be more than 25 mm at any point.

J-5.4.3.1 *Handrail attachment*

Where the railing protects a difference in level greater than 600 mm, a handrail shall be used unless a laminated safety glass construction is used that remains *in-situ*, if a panel fails. Continuous fixing should be used for fixing the handrail to the glass, or individual fixings where calculations or tests demonstrate that component failure will not occur.

Where handrail is not desired, the laminated safety glass should stay in place in the event of any glass panel breakage.

The handrail should be attached to the glass in such a manner that, should a glass panel gets fractured, the handrail,

a) will remain in position; and

b) will not fail if the design load is applied across the resulting gap.

NOTE — The above condition (b) can be relaxed where the glass pane is an end pane and protects a difference in level of 600 mm or less, for example at the foot of a flight of stairs. In cases where an end pane protects a difference in level greater than 600 mm, there may normally be some adjacent structure to which the handrail could be attached, thus enabling it to meet condition (b).

J-5.4.4 *Base Fixing of Free-Standing Railings*

J-5.4.4.1 *Point of fixing clamps*

The fixing clamps on each side of the glass should be not less than 100 mm to 150 mm and should be made of a suitable metal of minimum thickness 12 mm. The number and design of fixing clamps shall be in accordance with structural requirements.

J-5.4.4.2 *Continuous fixing clamps*

The fixing clamps on each side of the glass should be not less than 100 mm wide and should be made of a suitable metal of minimum thickness 12 mm. The clamps should be continuous for the entire length of the glass pane and have a maximum bolt spacing of 500 mm.

J-5.4.4.3 *Other clamping systems*

Different clamping methods could be used, provided they cater for an effective continuous clamping over the length of the glass pane. Where a clamping system that does not rely on bolts through the glass is used, the depth over which the clamping force operates should be not less than 75 mm, unless specific tests have been carried out to prove the integrity of the system and that it meets the design criteria given.

J-5.4.4.5 *Structural movement*

The structural movement due to live or dead loads or creep of the structure to which a railing pane is clamped should be not greater than 2 mm over the length of any railing panel, if more than two bolts are used to clamp that panel.

J-5.4.4.6 *Fixing clamps*

The attachment of the fixing clamps to the structure should be capable of withstanding the turning moment induced at the fixing clamps.

J-6 IMPACT RESISTANCE AND CONTAINMENT

J-6.1 General

In addition to resisting the design loads given, glass below the minimum railing height (*see* Table 35) should also be able to resist impact forces appropriate to whether the railing indicates a route or protects people from a hazard.

J-6.2 Glass in Full Height Railings

The glass in full height railings should be selected to resist the appropriate design loads given and for its impact performance in accordance with the safety glazing recommendations.

J-6.3 Railing with Glass In-fills or Free-Standing Balustrades

The glass in railings with glass in-fills or free-standing should be selected to resist the appropriate design loads given, and to provide containment, that is, it should meet the recommended impact class without penetration.

J-7 INSTALLATION

The installation of a railing should be supervised by a suitably qualified person or persons, who should ensure that the design assumptions have been effectively implemented. Inspections and investigations should be carried out as necessary to establish the integrity of the materials and the elements of construction used.

J-7.1 Fasteners and Fittings

Fasteners and fittings should be of stainless steel, or should be hot-dip galvanized. Thin zinc plated or cadmium plated coatings should not be used for external exposure without additional protection.

J-8 MAINTENANCE

All glass should be regularly cleaned and fixings should be checked for corrosion and loosening. Maintenance recommendations, and the frequency at which railings should be inspected, are be governed by environment, usage, incidence of malicious damage and the protection applied. Protective railings assembled entirely from metal-coated steel and situated in normal environments should not require any maintenance for a very long period. They should, however, be inspected regularly and the residual coating thickness should be measured.

ANNEX K

(*Informative*)

(*Foreword*)

CONFORMITY ASSESMENT SHEET FOR GLASS AND GLAZING SYSTEM

K-1 For the purpose of conformity assessment by building regulator for glass and glazing aspects, following sheet shall be used.

Sl No. (1)	Parameters (2)	Details (3)
i) GENERAL		
	a) Building typology	
	b) Location (City, State)	
	c) Orientation	
	d) Climate zone	
	e) Window wall ratio (WWR)	
ii) GLASS		
	a) Component of building (Glass on roof/floor/wall/railing/glass fin)	
	b) Type of Glass:	
	Combination (if needed)	
	c) Tinted/Clear/Coated:	
	if yes, Side (Outer/Inner)	
	Description	
	d) Patterned/Non- patterned:	
	if yes, Side (Outer/Inner)	
	Dimension of Glass (L × B) (mm)	
	e) Thickness and Deflection:	
	Calculated Deflection as per this NBCS	
	Calculated Thickness (mm) as per this NBCS	
	Actual Thickness (mm)	
	Glass specifications as per this NBCS	**Yes/No**
	f) Safety:	

Sl No.	**Parameters**	**Details**
(1)	(2)	(3)
	Glass Height from Ground	
	Presence of Residual Protection? (Yes / No)	
	Presence of Window Restrictor for children?	
	Anti-Fallout norms followed? (Yes / No)	
	Safety glass norms followed as per this NBCS	**Yes/No**
	g) Energy Performance:	
	U-value	
	SHGC/Solar factor	
	Visible light transmittance (VLT)	
	Shading co-efficient	
iii) FRAME		
	a) Thickness	
	b) Dimension	
	c) Frame Material	
	d) Frame supported sides (Glass inside structures can also be considered as framed)	
	e) Deflection of frames	
	f) Face width	
	g) U-value of frame	
	h) Depth of the profile	
	Frame specifications as per this NBCS	Yes/No
iv) GLAZING SYSTEM		
	a) Thickness and Dimension	
	Dimension	
	Thickness	
	b) Energy	
	U-factor	

Sl No.	Parameters	Details
(1)	(2)	(3)
	Solar Factor / SHGC	
	Visible Light Transmittance (VLT)	
	Energy efficiency specifications as per this NBCS	Yes/No
	c) Structural parameters	
	Design load and wind load	
	Other loads	
	Air Permeability	
	Deflection	
	Seismic parameters	
	Water tightness (classification)	
	Structural aspects as per this NBCS	Yes/No
	d) Glazing Material	
	Front and back clearance	
	Edge clearance	
	Edge cover	
	Rebate depth	
	e) Fire Resistant Glazing system:	
	If Fire Resistant, Category (E/EW/EI)	
	Duration of resistance to fire (in min)	
	Thickness of glazing system	
	f) Acoustics	
	Airborne Sound Insulation	
	Impact Sound Insulation	
v) THIRD PARTY TEST CERTIFICATES (FOR ALL PRESCRIBED PROPERTIES)		

Sl No.	Parameters	Details
(1)	(2)	(3)
	a) Glass	Yes/No
	b) Frames	Yes/No
	c) Glazing systems — Energy performance	Yes/No
	d) Glazing systems — Structural aspects	Yes/No
	e) Glazing systems — Fire resistance (if applicable)	Yes/No
	f) Glazing systems — Acoustics	Yes/No

LIST OF STANDARDS

The following list records those standards which are acceptable as ‘good practice’ and ‘accepted standards’ in the fulfilment of the requirements of this NBCS. The latest version of a standard shall be adopted at the time of enforcement of this NBCS. The standards listed may be used for conformance with the requirements of the referred clauses in this NBCS.

In the following list, the number appearing in the first column within parentheses indicates the number of the reference in this Section:

	IS No.	*Title*
(1)	IS 14900 : 2018	Transparent float glass — Specification (*first revision*)
	IS 2553 (Part 1) : 2018	Safety glass — Specification: Part 1 Architectural, building and general uses (*fourth revision*)
(2)	IS 3808 : 1979	Method of test for non-combustibility of building materials (*first revision*)
(3)	IS 17004 : 2018	Testing methods for processed glass
(4)	IS 19331 : 2025	Tinted float glass — Specification
(5)	IS 2835 : 1987	Specification for flat transparent sheet glass (*third revision*)
(6)	IS 14900 : 2018	Specification for Transparent float glass (*first revision*)
(7)	IS 2553 (Part 1) : 2018	Safety glass — Specification: Part 1 Architectural, building and general uses (*fourth revision*)
(8)	IS 16982 : 2018	Heat strengthened glass — Specification
(9)	IS 17346 : 2020	Insulating glazing unit — Specification
(10)	IS 5437 : 2024	Rolled glass — Patterned, extra clear patterned, wired and wired-patterned glass — Specification (*second revision*)
(11)	Doc no. CED 13 (27189)	Structural glazing silicone sealants – Specification (*under preparation*)
(12)	IS 1948 : 2024	Aluminium framed doors, windows and sliders — Specification (*first revision*)
(13)	SP 32 : 1986	Handbook on functional requirements of industrial buildings (lighting and ventilation)
	SP 41 : 1987	Handbook on functional requirements of buildings (other than industrial buildings)
(14)	IS 18648 : 2024	Classification and performance requirements for doors, windows and sliders — Specification
(15)	IS 875 (Part 3) : 2015	Design loads (other than earthquake) for buildings and structures — Code of practice: Part 3 Wind loads (*third revision*)
(16)	IS 1893 (Part 1) : 2016	Criteria for earthquake resistant design of structures: Part 1 General provisions and buildings (*sixth revision*)
(17)	IS 875 (Part 2) : 1987	Code of Practice for design loads (other than earthquake) for buildings and structures: Part 2 Imposed loads (*second revision*)
(18)	IS 19328 : 2025	Fire resistant glass — Specification
(19)	IS/ISO 834-1 : 1999	Fire-resistance tests — Elements of building construction: Part 1 General requirements
	IS/ISO 834-4 : 2000	Fire-resistance tests — Elements of building construction: Part 4 Specific requirements for load bearing vertical separating elements

	IS No.	*Title*
	IS/ISO 834-5 : 2000	Fire-resistance tests — Elements of building construction: Part 5 Specific requirements for load bearing horizontal separating elements
	IS/ISO 834-6 : 2000	Fire-resistance tests — Elements of building construction: Part 6 Specific requirements for beams
	IS/ISO 834-7 : 2000	Fire-resistance tests — Elements of building construction: Part 7 Specific requirements for columns
	IS/ISO 834-8 : 2002	Fire-resistance tests — Elements of building construction: Part 8 Specific requirements for non-load bearing vertical separating elements
	IS/ISO 834-9 : 2003	Fire-resistance tests — Elements of building construction: Part 9 Specific requirements for non-load bearing ceiling elements
	IS 17518 (Part 1) : 2022/ ISO 3008-1 : 2019	Fire resistance tests — Door and shutter assemblies: Part 1 General requirements
	IS/ISO 3009 : 2003	Fire-resistance tests — Elements of building construction — Glazed elements
	IS 16945 : 2018	Fire resistance test for glass walls
	IS 16947 : 2018	Fire resistance tests for doors with glass panes, openable glass windows and sliding glass doors
(20)	IS 18190 : 2023	Fire resistance of perimeter fire barrier joint system — Method of tests
(21)	IS 16231 (Part 3) : 2019	Use of glass in buildings — Code of practice: Part 3 Fire and loading (*first revision*)
	IS 875	Code of Practice for design loads (other than earthquake) for buildings and structures:
	(Part 1) : 2026	Dead loads — Unit weights of building, construction and stored materials (*third revision*)
	(Part 2) : 1987	Imposed loads (*second revision*)
(22)	IS 16231 (Part 3) : 2019	Use of glass in buildings — Code of practice: Part 3 Fire and loading (*first revision*)
(23)	IS 17953 : 2023	uPVC profiles for windows and doors — Specification
(24)	IS 1038 : 1983	Specification for steel doors, windows and ventilators (*third revision*)
(25)	IS 11050 (Part 1) : 2023/ ISO 717-1 : 2020	Rating of sound insulation in buildings and of building elements: Part 1 Airborne sound insulation (*first revision*)
(26)	IS 11050 (Part 2) : 2023/ ISO 717-2 : 2020	Rating of sound insulation in buildings and of building elements: Part 2 Impact sound insulation (*first revision*)
(27)	IS 875	Code of practice for design loads (other than earthquake) for buildings and structures:
	(Part 1) : 2026	Dead loads — Unit weights of building, construction and stored materials (*third revision*)
	(Part 2) : 1987	Imposed loads (*second revision*)
	(Part 3) : 2015	Wind loads (*third revision*)
	(Part 5) : 1987	Special loads and load combinations (*second revision*)

	IS No.	*Title*
(28)	IS 733 : 2025	Wrought aluminium and aluminium alloy bars, rods, sections, extruded tubes, hollow sections and profiles for general engineering purposes — Specification (*fourth revision*)
	IS 738 : 1994	Specification for wrought aluminium alloys, drawn tube for general engineering purposes (*third revision*)
(29)	IS 6911 : 2026	Stainless steel plate, sheet and strip – Specification (*third revision*)
(30)	IS 1946 (Part 2) : 2025	Design of post-installed anchorage to concrete — Code of practice
(31)	IS 1946 (Part 5) : 20xx	Installation and on-site inspection of post-installed anchorage to concrete — Code of practice (*under preparation*)
(32)	IS 18434 : 2023	Field measurement of air permeability and water penetration through installed curtain wall, windows, doors, sliders and skylights under static air pressure difference — Method of test
(33)	IS 18459 : 2024	Water penetration of curtain walls, windows, sliders, doors and skylights by uniform static air pressure difference — Method of test
(34)	IS 18647 : 2024	Water penetration of curtain walls, windows, sliders and doors by dynamic air pressure — Method of test
(35)	IS 18268 : 2023/ ISO 9379 : 2005	Operating forces — Test methods — Doors
(36)	IS 17909 : 2022/ ISO 8274 : 2005	Windows and doors — Resistance to repeated opening and closing — Test method
(37)	IS 18473 : 2024	Wind resistance for curtain walls, windows, sliders, doors and skylights — Method of test
(38)	IS 17911 : 2022/ ISO 15099 : 2003	Thermal performance of windows, doors and shading devices — Detailed calculations
(39)	IS 17920 : 2022/ ISO 10077-2 : 2017	Thermal performance of windows, doors and shutters — Calculation of thermal transmittance — Numerical method for frames
(40)	IS 19006 : 2023/ ISO 8248 : 1985	Windows and door height windows — Mechanical tests
(41)	IS 17518 (Part 1) : 2022/ ISO 3008-1 : 2019	Fire resistance tests — Door and shutter assemblies: Part 1 General requirements
(42)	IS 16945 : 2018	Fire resistance test for glass walls
(43)	IS 16947 : 2018	Fire resistance tests for doors with glass panes, openable glass windows and sliding glass doors
(44)	IS 16978	Glass in building — Forced-entry security glazing: Part 1 Test and classification by repetitive ball drop (*first revision*)
	(Part 1) : 2022/ ISO 16936-1 : 2020	Test and classification by repetitive ball drop (*first revision*)
	(Part 2) : 2018/ ISO 16936-2 : 2005	Test and classification by repetitive impact of a hammer and axe at room temperature
	(Part 3) : 2018/ ISO 16936-3 : 2005	Test and classification by manual attack
	(Part 4) : 2018/ ISO 16936-4 : 2005	Test and classification by pendulum impact under thermally and fire stressed conditions
(45)	IS 18518 : 2023	Bullet resistant security glass — Quality and performance requirements

	IS No.	*Title*
(46)	IS 16978	Glass in building — Forced-entry security glazing:
	(Part 1) : 2022/ ISO 16936-1 : 2020	Test and classification by repetitive ball drop (*first revision*)
	(Part 2) : 2018/ ISO 16936-2 : 2005	Test and classification by repetitive impact of a hammer and axe at room temperature
(47)	IS 18472 : 2024	Air permeability for curtain walls, windows, sliders, doors and skylights — Method of test
(48)	IS 875	Code of Practice for design loads (other than earthquake) for buildings and structures:
	(Part 1) : 2026	Dead loads — Unit weights of building, construction and stored materials (*third revision*)
	(Part 2) : 1987	Imposed loads (*second revision*)
	(Part 3) : 2015	Wind loads (*third revision*)
	(Part 4) : 2021	Snow loads (*third revision*)
	(Part 5) : 1987	Special loads and load combinations (*second revision*)
	IS 1893 (Part 1) : 2016	Criteria for earthquake resistant design of structures: Part 1 General provisions and buildings (*sixth revision*)
	IS 16700 : 2023	Criteria for structural safety of tall concrete buildings *(first revision)*

INDEX OF TERMS

(Lists the terms appearing in the Part/Section of the NBCS)

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NATIONAL BUILDING CONSTRUCTION STANDARDS 2026

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FOREWORD

This NBCS (Part D/Section 1) covers the lighting and natural ventilation requirements in buildings. Thermal comfort conditions for the building occupants and illumination levels for different tasks are recommended to be achieved either by daylighting or artificial lighting or a combination of both. This section, read together with Part D 'Building Services, Section 2 Electrical and Allied Installations' of this NBCS, adequately covers the thermal comfort conditions for naturally ventilated buildings and mixed mode operation buildings, and the illumination levels required and methods of achieving the same.

Ventilation requirements to maintain air quality, control body odours and pollutants in terms of air changes per hour and to ensure thermal comfort and heat balance of body are laid for different occupancies and the methods of achieving the same by natural means or mixed mode operations means are covered in this Section. The provisions on mechanical ventilation are covered in Part D 'Building Services, Section 3 Air Conditioning, Heating and Mechanical Ventilation' of this NBCS.

Climatic factors which normally help in deciding the orientation of the buildings to get desirable benefits of lighting and natural ventilation inside the buildings are also covered in this section.

This section was first published in 1970 as a part of National Building Code of India. The first revision of the section was brought out in 1983. In the second revision of 2005, some provisions were updated based on the information given in the SP 41 : 1987 'Handbook on functional requirements of buildings (other than industrial buildings)'; other major changes in the 2005 revision included rationalization of definitions and inclusion of definitions for some more terms; inclusion of climatic classification map of India based on a new criteria; updating of data on total solar radiations incident on various surfaces of buildings for summer and winter seasons; inclusion of design guidelines for natural ventilation; reference to Part 8 'Building Services, Section 3 Air Conditioning, Heating and Mechanical Ventilation' of the Code for guidelines on mechanical ventilation, made, where these provisions were covered exhaustively; inclusion of rationalized method for estimation of desired capacity of ceiling fans and their optimum height above the floor for rooms of different sizes; incorporation of design sky illuminance values for different climatic zones of India, etc. Energy efficiency was another important aspect which was considered. Accordingly, the relevant requirements for energy efficient system for lighting and natural ventilation were duly included in the concerned provisions under the section.

In third revision of the Code in 2016, the changes that were incorporated include; elaboration of the calculation for solar load, and inclusion of 'Method of calculating solar load on vertical surfaces in different orientation' in Annex A; inclusion of provisions on sky component calculation procedure along with examples in Annex B; inclusion of reference to SP 41 : 1987 for obtaining coefficient utilization for determination of luminous flux; updation of provisions relating to efficient artificial light source and luminaires; inclusion of modern lighting techniques such as LED and induction light in comparison with their energy consumption; updation of provisions relating to photocontrols for artificial lights; inclusion of definitions and enabling provision for lighting shelves and light pipes; elaboration of the provisions related to thermal comfort including indices such as effective temperature, adaptive thermal comfort along with elaborations on tropical summer index; elaboration of design guidelines for natural ventilation with illustrations; elaboration of provisions related to determination of rate of ventilation particularly on combined effect of wind and thermal actions; and inclusion of provision on colour rendering in line with that in SP 72 : 2010 'National Lighting Code 2010'.

In this revision, this publication has been renamed as National Building Construction Standards (NBCS).

As a result of experience gained since the implementation of the 2016 version of this NBCS and feedback received as well as revisions of Indian Standards on which this Section was based, a need was felt to revise this Section. The significant changes incorporated in this revision include the following:

a) Terminology clause has been updated with new terms and definitions;

b) Orientation of building clause has been renamed to site planning and building placement; and

c) The clause on aspects of daylighting has been updated;

d) Provisions for spatial and environmental consideration in building design; and operable windows and UV exposure have been added;

e) The aims of good lighting clause has been updated;

f) Table 6 for illuminance and lighting performance parameters have been updated;

g) Provisions for planning and design guidelines for circadian lighting including supplementary artificial circadian lighting have been introduced;

h) Planning and design guidelines for outdoor lighting and its energy efficiency aspects have been introduced;

j) Detailed provisions on design charts for natural ventilation and acceptable air temperature with the increase in the air speed have been added;

k) Provisions of the adaptive thermal comfort mode of ventilation have been reviewed and updated;

The provisions of this Section are without prejudice to the various acts, Rules and Regulations including the *Factories Act*, 1948 and Rules and Regulations framed thereunder.

The information contained in this Section is largely based on the following Indian Standards/Special Publications:

IS 2440 : 1975	Guide for daylighting of buildings (*second revision*)
IS 3103 : 1975	Code of practice for industrial ventilation (*first revision*)
IS 3362 : 1977	Code of practice for natural ventilation of residential buildings (*first revision*)
IS 3646 (Part 1) : 2025	Interior illumination — Code of practice: Part 1 General requirements and recommendations for working interiors (*second revision*)
IS 7662 (Part 1) : 1974	Recommendations for orientation of buildings: Part 1 Nonindustrial buildings
IS 11907 : 1986	Recommendations for calculation of solar radiation on buildings
SP 32 : 1986	Handbook on functional requirements of industrial buildings (lighting and ventilation)
SP 41 : 1987	Handbook on functional requirements of buildings other than industrial buildings

Provisions given in National Lighting Code of India, 'SP 72 : 2025' (*first revision*) may also be referred.

All standards, whether given herein above or cross-referred to in the main text of this Section, are subject to revision. The parties to agreement based on this Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

Assistance has been taken from the following documents in the revision of this Section:

'Report on Energy Conservation in Buildings', submitted to Department of Power, Ministry of Energy by CSIR-Central Building Research Institute, Roorkee.

'Adaptive thermal comfort model based on fields studies in five climate zones across India', Building and Environment, Volume 219, 1 July 2022 by Rawal, R., Shukla, Y., Vardhan, V., et al. (2022)

'Field studies of thermal comfort across multiple climate zones for the subcontinent: India Model for Adaptive Comfort (IMAC)', *Building and Environment*, 98 (March 2106), (pp. 55–70) by Manu, S., Shukla, Y., Rawal, R., Thomas, L. E., and De Dear, R. (2016)

'Low Energy Cooling and Ventilation for Indian Residences: Design Guide', Loughborough University, UK and CEPT Research and Development Foundation (CRDF), India by Cook, M., Shukla, Y., Rawal, R., Loveday, D., Faria, L. C., and Angelopoulos, C. (2020).

As the regulation of land development and buildings is a State subject and is dealt by the States and local bodies such as urban local bodies within their jurisdiction through building regulatory documents like building regulations, building byelaws, and fire regulations, this document is voluntary in nature and is non-binding. The implementation depends on adoption by concerned parties or stipulations in a contract or by appropriate adoption by the concerned authorities.

For the purpose of deciding whether a particular requirement of this Section is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 ‘Rules for rounding off numerical values (*second revision*)’. The number of significant places retained in the rounded off value should be the same as that of the specified value in this Section.

Important Explanatory Note for Users of this NBCS

In any Part/Section of this NBCS, where reference is made to **'good practice'** in relation to design, constructional procedures or other related information, and where reference is made to **"accepted standard"** in relation to material specification, testing, or other related information, the Indian Standards listed at the end of the Part/Section shall be used as a guide to the interpretation.

At the time of publication, the editions indicated in the standards were valid. All standards are subject to revision and parties to agreements based on any Part/ Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

In the list of standards given at the end of a Part/Section, the number appearing within parentheses in the first column indicates the number of the reference of the standard in the Part/Section. For example:

a) Good practices [D-1(1)] refers to the Indian Standard(s) give at serial number (1) of the list of standards given at the end of this Part D/Section 1, that is, IS 7662 (Part 1) : 1974 'Recommendations for orientation of buildings: Part 1 Non-industrial buildings'

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART D BUILDING SERVICES

SECTION 1 LIGHTING AND NATURAL VENTILATION

1 SCOPE

1.1 This NBCS (Part D/Section 1) covers requirements and methods for lighting and natural ventilation of buildings.

1.2 For all buildings and facilities open to and used by the public, including all forms of public housing by the government/civic bodies and private developers, adequate lighting and natural ventilation for barrier-free access and movement within and around buildings by elderly and persons with disabilities and of different age groups shall be ensured. The ventilation through the building envelope elements such as windows, skylights, ventilators for thermal comfort and better air quality requirements are included in this section.

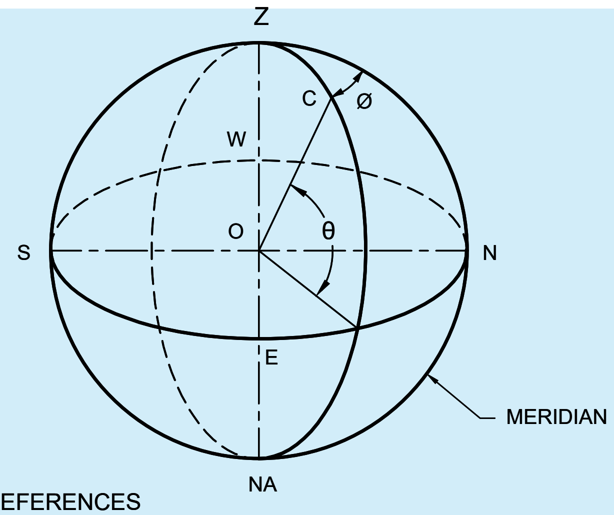
2 TERMINOLOGY

For the purpose of this Section, the following definitions shall apply.

2.1 Lighting

2.1.1 *Altitude* (θ) — The angular distance of any point of celestial sphere, measured from the horizon, on the great circle passing through the body and the zenith (*see* Fig. 1).

2.1.2 *Azimuth* (Φ) — The angle measured between meridians passing through the north point and the point in question (point C in Fig. 1).



REFERENCES

O - Observer's station

C - Celestial body

Z - Zenith

NA - Nadir

S - Geographical south

E - Geographical east

W - Geographical west

N - Geographical north

FIG. 1 ALTITUDE AND AZIMUTH OF A CELESTIAL BODY

2.1.3 *Brightness Ratio or Contrast* — The variations or contrast in brightness of the details of a visual task, such as white print on blackboard.

2.1.4 *Candela* (*cd*) — The SI unit of luminous intensity.

Candela = 1 lumen per steradian

2.1.5 *Central Field* — The area of circle around the point of fixation and its diameter, subtending an angle of about 2 degrees at the eye. Objects within this area are most critically seen in both their details and colour.

2.1.6 *Clear Design Sky* — The distribution of luminance of such a sky is non-uniform; the horizon can be brighter than the zenith depending on the sun position, and when L_z is the brightness at zenith, the brightness at an altitude (θ) in the region away from the sun, is given by the expression:

$$L_\theta = L_z \operatorname{cosec} \theta \ (\text{for } 15^\circ < \theta \leq 90^\circ)$$

$$L_\theta = L_z \operatorname{cosec} 15^\circ \ (\text{for } 0^\circ \leq \theta \leq 15^\circ) = 3.863\ 7\ L_z$$

2.1.7 *Circadian Lighting* — A lighting means that uses electric lights in a way that supports natural sleep and wake cycle of humans. This is done by changing how bright the light is and what colour it is throughout the day, so it matches what the body expects from natural daylight and night time.

2.1.8 *Colour Rendering Index* (*CRI*) — Measure of the degree to which the psychophysical colour of an object illuminated by the test illuminant conforms to that of the same object illuminated by the reference illuminant, suitable allowance having been made for the state of chromatic adaptation.

2.1.9 *Correlated Colour Temperature* (*CCT*) (*K*) — The temperature of the Planckian radiator whose perceived colour most closely resembles that of a given stimulus at the same brightness and under specified viewing conditions.

2.1.10 *Daylighting* — The strategic use of natural optical radiation from the sun and sky to illuminate interior spaces, enhancing visual comfort and supporting human circadian regulation. In this context, daylight encompasses the portion of solar radiation within the visible spectrum, typically between 380 nm and 780 nm. Effective daylighting design aims to maximize natural light penetration, minimize reliance on electric lighting, and promote occupant health and well-being.

2.1.11 *Daylight Area* — The portion of an interior space where the working plane receives natural light at or above a specified daylight factor or meets a defined minimum illuminance threshold. This area is typically delineated by a daylight factor contour, representing zones with adequate daylight levels for visual tasks.

2.1.12 *Daylight Factor* — The ratio, expressed as a percentage, of the illuminance at a specific point on a given plane indoors to the simultaneous illuminance on a horizontal plane outdoors under an overcast sky. This factor measures the amount of daylight reaching the indoor point relative to outdoor conditions, providing an indication of natural light availability in interior spaces.

2.1.13 *Daylight Penetration* — The maximum distance to which a given daylight factor contour penetrates into a room.

2.1.14 *Direct Solar Illuminance* — The illuminance from the sun without taking into account the light from the sky.

2.1.15 *External Reflected Component* (*ERC*) — Daylight illuminance at a point which is received by direct reflection from external surfaces.

2.1.16 *Glare* — A condition of vision in which there is discomfort or a reduction in the ability to see significant objects or both due to an unsuitable distribution or range of luminance or due to extreme contrasts in space.

2.1.17 *Illuminance* — At a point on a surface, the ratio of the luminous flux incident on an infinitesimal element of the surface containing the point under consideration to the area of the element.

NOTE — The unit of illuminance (the measurement of illumination) is lux which is 1 lumen per m^2.

2.1.18 *Indoor Artificial Lighting* — Artificial lighting powered by electricity, designed to enhance visual comfort, task performance, and occupant well-being in indoor environments. Its effectiveness is assessed using several key parameters:

a) *Spectral power density* (*SPD*) — Describes the relative power of a light source at each wavelength across the visible spectrum. SPD influences colour rendering, visual perception and biological effects, including circadian response;

b) *Colour tuning* — The capability to dynamically adjust the correlated colour temperature (*CCT*) and spectral content of the light source, allowing adaptation to user preferences, visual tasks, or time-of-day considerations to support circadian health;

c) *Light flicker* — Rapid fluctuations in luminous intensity that may be visible or invisible to the human eye. Flicker can cause visual fatigue, headaches, or reduced task performance. The P_{st}^{LM} value (short-term flicker severity measured by the light flickermeter method) is used to quantify flicker in lighting systems; and

d) *Unified glare rating* (*UGR*) — A standardized metric that quantifies discomfort glare in indoor spaces. Lower UGR values indicate better visual comfort and help prevent visual strain without reducing task visibility.

2.1.19 *Internal Reflected Component* (*IRC*) — Daylight illuminance at a point in a given plane which is received by direct reflection or inter-reflection from the internal surfaces.

2.1.20 *Light Output Ratio* (*LOR*) *or Efficiency* (η) — The ratio of the luminous flux emitted from the luminaire to that emitted from the lamp(s) (nominal luminous flux). It is expressed in percent.

2.1.21 *Light Pipe* — A conduit made of a highly reflective material, which is capable of channelling light from one end to the other through successive internal reflections. Such a pipe may be flexible or rigid.

2.1.22 *Light Shelf* — A daylighting system based on sun path geometry used to bounce the light off a ceiling, project it deeper into a space, distribute it from above and diffuse it to produce a uniform light level below.

2.1.23 *Lumen* (*lm*) — SI unit of luminous flux. The luminous flux emitted within unit solid angle (one steradian) by a point source having a uniform intensity of one candela.

2.1.24 *Luminance* (*at a Point of a Surface in a Given Direction*) (*Brightness*) — The quotient of the luminous intensity in the given direction of an infinitesimal element of the surface containing the point under consideration by the orthogonally projected area of the element on a plane perpendicular to the given direction. The unit is candela per square metre (cd/m^2).

2.1.25 *Luminous Flux* (ϕ) — The quantity characteristic of radiant flux which expresses its capacity to produce visual sensation evaluated according to the values of relative luminous efficiency for the light adapted eye:

a) *Effective luminous flux* (ϕ_n) — Total luminous flux which reaches the working plane; and

b) *Nominal luminous flux* (ϕ_o) — Total luminous flux of the light sources in the interior.

2.1.26 *Maintenance Factor* (*d*) — The ratio of the average illuminance on the working plane after a certain period of use of a lighting installation to the average illuminance obtained under the same conditions for a new installation.

2.1.27 *Meridian* — It is the great circle passing through the zenith and nadir for a given point of observation.

2.1.28 *North and South Points* — The point in the respective directions where the meridian cuts the horizon.

2.1.29 *Orientation of Buildings* — In the case of non-square buildings, orientation refers to the direction of the normal to the long axis. For example, if the length of the building is east-west, its orientation is north-south.

2.1.30 *Outdoor Artificial Lighting* — Lighting systems specifically designed for exterior environments, intended to enhance visibility, safety and security during nighttime hours while minimizing adverse environmental and ecological impacts. Key considerations include:

a) *Fully shielded* — Luminaire designs that emit light only in the downward direction, preventing upward light emissions. This helps control glare and limits contributions to light pollution;

b) *Full cut-off* — A luminaire classification where zero light is emitted at or above the horizontal plane of the fixture. This design minimizes sky glow and enhances lighting efficiency by directing light only where it is needed;

c) *Light trespass* — The unintended or intrusive illumination of areas beyond the target zone, such as neighbouring properties, streets, or natural habitats. Light trespass can lead to discomfort, sleep disruption and privacy issues; and

d) *Sky glow* — The diffuse illumination of the night sky caused by artificial lighting, particularly from urban areas. Sky glow reduces the visibility of stars, interferes with astronomical observations and disrupts nocturnal ecosystems.

2.1.31 *Peripheral Field* — It is the rest of the visual field which enables the observer to be aware of the spatial framework surrounding the object seen.

NOTE — A central part of the peripheral field, subtending an angle of about 30º on either side of the point of fixation, is chiefly involved in the perception of glare.

2.1.32 *Reflected Glare* — The adverse impact on visual comfort and efficiency caused by unwanted reflections in the task area, which can hinder the ability to see clearly or cause discomfort, regardless of the source of the glare.

2.1.33 *Surface Reflectance* (*Reflectance*) — The ratio of the luminous flux reflected by an opaque surface (with or without diffusion) to the flux it receives. Here the term is used for lighting. Some symbols used for surface reflectance of common indoor surfaces are:

r_c = reflection factor of ceiling.

r_w = reflection factor of parts of the wall between the working surface and the luminaires.

r_f = reflection factor of floor.

2.1.34 *Reveal* — The side of an opening for a window.

2.1.35 *Room Index* (k_r) — An index relating to the shape of a rectangular interior, according to the formula:

$$k_r = \frac{L \times W}{(L + W)\, H_m}$$

where

L and W = length and width respectively of the interior; and

H_m = mounting height, that is, height of the fittings above the working plane.

NOTES

1 For rooms where the length exceeds 5 times the width, L shall be taken as $L = 5W$.

2 If the surface reflectance of the upper stretch of the walls is less than half the surface reflectance of the ceiling, for indirect or for the greater part of indirect lighting, the value H_m is measured between the ceiling and the working plane.

2.1.36 *Sky Component* (*SC*) — Daylight illuminance at a point on a given plane which is received directly from the sky.

2.1.37 *Solar Load* — The amount of heat received into a building due to solar radiation which is affected by orientation, materials of construction and reflection of external finishes and colour.

2.1.38 *Utilization Factor* (*Coefficient of Utilization*) (μ) — The ratio of the total luminous flux which reaches the working plane (effective luminous flux, ϕ_n) to the total luminous flux of the light sources in the interior (nominal luminous flux, ϕ_o).

2.1.39 *UV-A* — Ultraviolet radiation with wavelengths between 315 and 400 nm. UV-A penetrates the skin more deeply than UV-B and contributes to photoaging, oxidative stress, and potential DNA damage through indirect mechanisms. While it plays a role in skin ageing and long-term health effects, UV-A is significantly less effective for germicidal and disinfection purposes due to its lower energy.

2.1.40 *UV-B* — Ultraviolet radiation with wavelengths between 280 nm and 315 nm. UV-B plays a critical role in the synthesis of pre-vitamin D3 in the human skin upon exposure. It has higher biological activity than UV-A and can also cause sunburn and DNA damage with excessive exposure.

2.1.41 *Visual Field* — The visual field in the binocular which includes an area approximately 120º vertically and 160º horizontally centering on the point to which the eyes are directed. The line joining the point of fixation and the centre of the pupil of each eye is called its primary line of sight.

2.1.42 *Working Plane* — A horizontal plane at a level at which work will normally be done (*see* **4.1.4.4** and **4.1.4.5**).

2.2 Ventilation

2.2.1 *Air Change per Hour* — The amount of air leakage into or out of a building or room in terms of the number of building volume or room volume exchanged.

2.2.2 *Axial Flow Fan* — A fan having a casing in which the air enters and leaves the impeller in a direction substantially parallel to its axis.

2.2.3 *Centrifugal Fan* — A fan in which the air leaves the impeller in a direction substantially at right angles to its axis.

2.2.4 *Contaminants* — Dusts, fumes, gases, mists, vapours and such other substances present in air that are likely to be injurious or offensive to the occupants.

2.2.5 *Dilution Ventilation* — Supply of outside air to reduce the airborne concentration of contaminants in the building.

2.2.6 *Dry Bulb Temperature* — The temperature of the air, read on a thermometer, taken in such a way so as to avoid errors due to radiation.

2.2.7 *Effective Temperature* (*ET*) — An arbitrary index which combines into a single value the effect of temperature, humidity and air movement on the sensation of warmth or cold felt by the human body and its numerical value is that of the temperature of still saturated air which would induce an identical sensation.

2.2.8 *Exhaust of Air* — Removal of air from a building or a room and its disposal outside by means of a mechanical device, such as a fan.

2.2.9 *Fresh Air or Outside Air* — Air of that quality, which meets the criteria of Table 1 and in addition shall be such that the concentration of any contaminant in the air is limited to within one-tenth the threshold limit value (TLV) of that contaminant.

NOTES

1 Where it is reasonably believed that the air of quality is not expected as indicated above, sampling and analysis shall be carried out by a competent authority having jurisdiction and if the outside air of the specified quality is not available, filtration and other treatment devices shall be used to bring its quality to or above the levels mentioned in Table 1. Odour is to be essentially unobjectionable.

2 The above list of contaminants is not exhaustive and available special literature may be referred for data on other contaminants.

2.2.10 *General Ventilation* — Ventilation, either natural or mechanical or both, so as to improve the general environment of the building, as opposed to local exhaust ventilation for contamination control.

2.2.11 *Globe Temperature* — The temperature measured by a thermometer whose bulb is enclosed in a matt black painted thin copper globe of 150 mm diameter. It combines the influence of air temperature and thermal radiations received or emitted by the bounding surfaces.

2.2.12 *Humidification* — The process whereby the absolute humidity of the air in a building is maintained at a higher level than that of outside air or at a level higher than that which would prevail naturally.

Table 1 Maximum Allowable Contaminant Concentrations for Ventilation Air

(*Clause* 2.2.9)

Sl No.	Contaminants	Annual Average (Arithmetic Mean) µg/m^3	Short Term Level (Not to Exceed More than Once a Year) µg/m^3	Averaging Period h
(1)	(2)	(3)	(4)	(5)
i)	Suspended particulates	60	150	24
ii)	Sulphur oxides	80	400	24
iii)	Carbon monoxide	20 000	30 000	8
iv)	Photochemical oxidant	100	500	1
v)	Hydrocarbons (not including methanes)	1 800	4 000	3
vi)	Nitrogen oxide	200	500	24

2.2.13 *Humidity*, *Absolute* — The mass of water vapour per unit volume.

2.2.14 *Humidity*, *Relative* — The ratio of the partial pressure or density of the water vapour in the air to the saturated pressure or density respectively of water vapour at the same temperature.

2.2.15 *Local Exhaust Ventilation* — Ventilation effected by exhaust of air through an exhaust appliance, such as a hood with or without fan located as closely as possible to the point at which contaminants are released, so as to capture effectively the contaminants and convey them through ducts to a safe point of discharge.

2.2.16 *Make-up Air* — Outside air supplied into a building to replace the indoor air.

2.2.17 *Mechanical Ventilation* — Supply of outside air either by positive ventilation or by infiltration by reduction of pressure inside due to exhaust of air, or by a combination of positive ventilation and exhaust of air.

2.2.18 *Natural Ventilation* — Supply of outside air into a building through window or other openings due to wind outside and convection effects arising from temperature or vapour pressure differences (or both) between inside and outside of the building.

2.2.19 *Positive Ventilation* — The supply of outside air by means of a mechanical device, such as a fan.

2.2.20 *Propeller Fan* — A fan in which the air leaves the impeller in a direction substantially parallel to its axis designed to operate normally under free inlet and outlet conditions.

2.2.21 *Spray-Head System* — A system of atomizing water so as to introduce free moisture directly into a building.

2.2.22 *Stack Effect* — Convection effect arising from temperature or vapour pressure difference (or both) between outside and inside of the room and the difference of height between the outlet and inlet openings.

2.2.23 *Tropical Summer Index* (*TSI*) — The temperature of calm air at 50 percent relative humidity which imparts the same thermal sensation as the given environment.

2.2.24 *Threshold Limit Value* (*TLV*) — Refers to air-borne concentration of contaminants currently accepted by the American Conference of Governmental Industrial Hygienists and represents conditions under which it is believed that nearly all occupants may be repeatedly exposed, day after day, without adverse effect.

2.2.25 *Velocity*, *Capture* — Air velocity at any point in front of the exhaust hood necessary to overcome opposing air currents and to capture the contaminants in air at that point by causing the air to flow into the exhaust hood.

2.2.26 *Ventilation* — Supply of outside air into, or the removal of inside air from an enclosed space.

2.2.27 *Wet Bulb Temperature* — The steady temperature finally given by a thermometer having its bulb covered with gauze or muslin moistened with distilled water and placed in an air stream of not less than 4.5 m/s.

3 SITE PLANNING AND BUILDING PLACEMENT

3.1 The aim of site planning and building placement for optimum building orientation is to provide physically and psychologically comfortable living inside the building by creating conditions which suitably and successfully ward off the undesirable effects of severe weather to a considerable extent by judicious use of the recommendations and knowledge of climatic factors.

3.2 Climate Zones

3.2.1 For the purpose of design of buildings, the country may be divided into the major climatic zones as given in Table 2, which also gives the basis of this classification.

Table 2 Classification of Climate

(*Clause* 3.2.1)

Sl No.	Climatic Zone	Mean Monthly Maximum Temperature °C	Mean Monthly Relative Humidity Percent
(1)	(2)	(3)	(4)
i)	Hot-dry	Above 30	Below 55
ii)	Warm-humid	Above 30	Above 55
		Above 25	Above 75
iii)	Temperate	25 to 30	Below 75
iv)	Cold	Below 25	All values
v)	Composite	*See* **3.2.2**	*See* **3.2.2**

The climatic classification map of India is shown in Fig. 2.

3.2.2 Each climatic zone does not have same climate for the whole year; it has a particular season for more than six months and may experience other seasons for the remaining period. A climatic zone that does not have any season for more than six months may be called as composite zone.

3.3 Climatic Factors

From the point of view of lighting and natural ventilation, the following climatic factors influence the optimum orientation of the building:

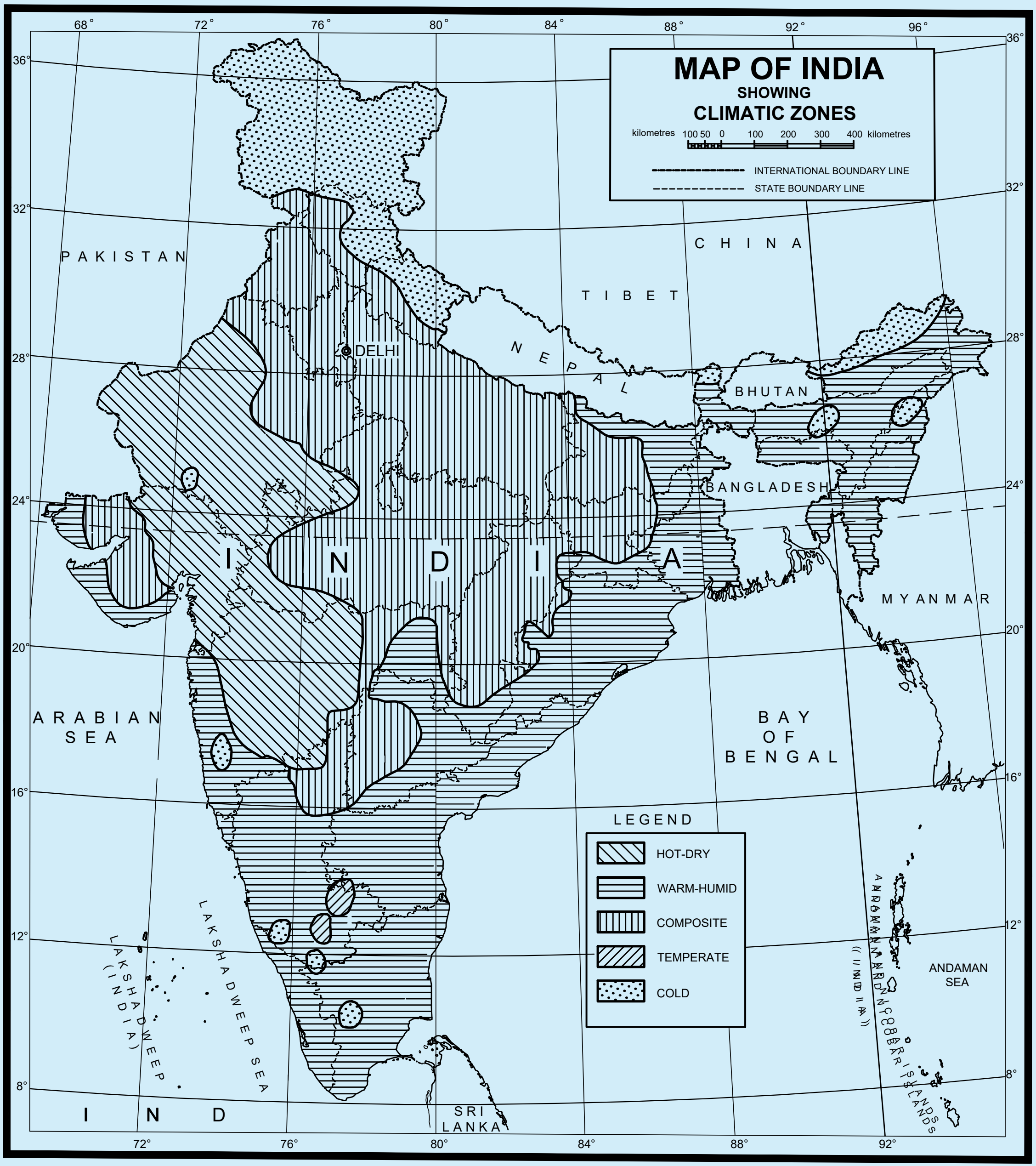
a) Solar radiation and temperature;

b) Relative humidity; and

c) Prevailing winds.

3.4 Solar Radiation

3.4.1 The best orientation from a solar point of view requires that the building as a whole should receive the maximum solar radiation in winter and the minimum in summer. For practical evaluation, it is necessary to know the duration of sunshine and hourly solar intensity on the various external surfaces on representative days of the seasons. The total direct plus diffused diurnal solar loads per unit area on the vertical surface facing different directions are given in Table 3 for two days in the year, that is, 22 June and 22 December, representative of summer and winter, for latitudes corresponding to some important cities all over India. From Table 3, the total heat intake can be calculated for all possible orientations of the building for these extreme days of summer and winter. Solar load on vertical surfaces of different orientations can be calculated as per the method given in Annex A.


MAP OF INDIA
SHOWING
CLIMATIC ZONES
kilometres 100 50 0 100 200 300 400 kilometres
INTERNATIONAL BOUNDARY LINE
STATE BOUNDARY LINE
LEGEND
HOT-DRY
WARM-HUMID
COMPOSITE
TEMPERATE
COLD
PAKISTAN
CHINA
TIBET
NEPAL
BHUTAN
BANGLADESH
MYANMAR
DELHI
INDIA
ARABIAN SEA
BAY OF BENGAL
ANDAMAN SEA
LAKSHADWEEP (INDIA)
LAKSHADWEEP SEA
ANDAMAN AND NICOBAR ISLANDS (INDIA)
SRI LANKA
IND
68°
72°
76°
80°
84°
88°
92°
96°
36°
32°
28°
24°
20°
16°
12°
8°

Based upon Survey of India Political map printed in 2002.

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The territorial waters of India extend into the sea to a distance of twelve nautical miles measured from the appropriate baseline.

The interstate boundaries between Arunachal Pradesh, Assam and Meghalaya shown on this map are as interpreted from the North-Eastern Areas (Reorganization) Act, 1971, but have yet to be verified.

The external boundaries and coastlines of India agree with the Record/Master Copy certified by Survey of India.

The responsibility for the correctness of internal details rest with the publisher.

FIG. 2 MAP OF INDIA SHOWING CLIMATIC ZONES

3.4.1.1 Except in cold climatic zone, suitable sun-breakers have to be provided to cut off the incursion of direct sunlight to prevent heat radiation and to avoid glare. A location (latitude) and weather specific approach to sizing of shading devices should consider the annual start and end date of the summer season for the building. Table 3 shows irradiation (W/m^2) received per unit of the facade area in each orientation. Irradiation values maybe used for prioritizing shading devices and other measures of solar protection (for example, planting of vegetation).

Table 3 Total Solar Radiation (Direct Plus Diffused) Incident on Various Surfaces of Buildings, in W/m^2/day, for Summer and for Winter Seasons

(*Clause* 3.4.1, 3.4.1.1 *and* A-2.1.3)

Sl No.	Orientation	Season	Latitude					
			9° N	13° N	17° N	21° N	25° N	29° N
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
i)	North	Summer	1 494	1 251	2 102	1 775	2 173	1 927
		Winter	873	859	840	825	802	765
ii)	North-East	Summer	2 836	2 717	3 144	3 092	3 294	3 189
		Winter	1 240	1 158	1 068	1 001	912	835
iii)	East	Summer	3 344	3 361	3 475	3 598	3 703	3 794
		Winter	2 800	2 673	2 525	2 409	2 211	2 055
iv)	South-East	Summer	2 492	2 660	2 393	2 629	2 586	2 735
		Winter	3 936	3 980	3 980	3 995	3 892	3 818
v)	South	Summer	1 009	1 185	1 035	1 117	1 112	1 350
		Winter	4 674	4 847	4 958	5 059	4 942	4 981
vi)	South-West	Summer	2 492	2 660	2 393	2 629	2 586	2 735
		Winter	3 936	3 980	3 980	3 995	3 892	3 818
vii)	West	Summer	3 341	3 361	3 475	3 598	3 703	3 794
		Winter	2 800	2 673	2 525	2 409	2 211	2 055
viii)	North-West	Summer	2 836	2 717	3 144	3 092	3 294	3 189
		Winter	1 240	1 158	1 068	1 001	912	835
ix)	Horizontal	Summer	8 107	8 139	8 379	8 553	8 817	8 863
		Winter	6 409	6 040	5 615	5 231	4 748	4 281

3.5 Relative Humidity and Prevailing Winds

3.5.1 The discomfort due to high relative humidity in air when temperatures are also high can be counteracted, to a great extent, by circulation of air with electric fans or by ventilation. In the past, simultaneously with heavy construction and surrounding *Verandahs* to counter the effect of sun's radiation, there was also an over emphasis on prevailing winds to minimise the adverse effects of high humidity with high temperatures. With the introduction of electric fan to effectively circulate air and owing to taking into account the rise in cost of construction of buildings, emphasis should be on protection from solar radiation where temperatures are very high. When, however, there is less diurnal variation between morning and mean maximum temperatures along with high humidity, as in coastal areas, the emphasis should be on prevailing winds.

3.5.1.1 For the purpose of orientation, it is necessary to study the velocity and direction of the wind at each hour and in each month instead of relying on generalizations of a month or a period or for the year as a whole. This helps to spot the right winds for a particular period of day or night.

3.5.1.2 It is generally found that variation up to 30° with respect to the prevalent wind direction does not materially affect indoor ventilation (average indoor air speed) inside the building.

3.5.2 In hot-dry climate, advantage can be taken of evaporative cooling in summer to cool the air before introducing it into the building. But in warm humid climate, it is desirable either to regulate the rate of air movement with the aid of electric fans or to take advantage of prevailing winds.

3.6 Aspects of Daylighting

The clear design sky concept accounts for the worst-case scenario, making building orientation less critical, except for the need to avoid direct sunlight and glare. However, mutual shading effects from opposite facades and significant vegetation elements shall be considered to maintain effective daylighting. For glare control reference may be made from relevant guidelines/best practices ('Handbook on Sustainability in Buildings'). Daylighting design is supported by three key pillars: daylight availability, sun control, and glare control, all of which are essential to ensure optimal visual comfort and energy efficiency within buildings.

3.7 Spatial and Environmental Considerations in Building Design

Sustainable building design focuses on optimizing the use of natural resources, improving energy efficiency and ensuring occupant well-being. Integrating natural elements such as vegetation and considering the spatial relationships between buildings play a crucial role in enhancing daylight access, ventilation, and thermal comfort, while promoting ecological balance.

The following considerations should guide the integration of these elements into building design:

a) It is suggested to plant tall trees or plants at least as tall as the building around new buildings. This can make the area look aesthetic and help the environment by giving shade, cleaning the air and making the place cooler. It is also better to use plants that naturally grow in the area;

b) Adequate spacing between a building and neighbouring structures is essential for ensuring access to natural light, ventilation, and privacy. The distance between buildings should be planned to minimize overshadowing, reduce light trespass and promote natural airflow, enhancing the overall livability of the area;

c) The orientation of building facades relative to cardinal directions should be planned to optimize solar gain, energy efficiency, and occupant comfort. Facades should maximize natural light while minimizing glare and overheating, contributing to overall energy efficiency and improving thermal performance; and

d) Tree planting in open spaces and streets should be carefully planned to provide shade during the summer season, allow intermittent or seasonal sunlight access, without obstructing natural winds or compromising daylight access. The selected trees should reduce glare, create cool microclimates, and improve air quality. Deciduous trees that shed leaves in winter and retain thick foliage in summer are especially advantageous, particularly for southern and western exposures, allowing maximum sunlight in winter and providing effective shading in summer. Trees with high-density foliage and low gap percentages (for example, *Ashoka*, *Asopalav*) should be placed at a distance proportional to their mature height to avoid obstructing light and airflow. Less dense or deciduous trees (for example, *Gulmohar*, *Amaltas*, *Neem*) may be planted with considerations beyond daylight access, including aesthetics and ecological benefits. In addition, it is recommended that native species of trees be preferred, as identified by the respective state environmental departments, to support region-specific environmental planning.

3.8 Operable Windows and UV Exposure

Operable windows should be provided in habitable spaces to allow for natural ventilation and daylighting. Most glazing types (single pane or double pane) block the UV part of the solar radiation to avoid over-exposure of interiors and occupants to damaging effects of UV radiation. However, some UV exposure has health benefits (UV-B for vitamin D3 production) that occupants can only access if the glass windows are operable. Operable windows should be designed for maximum accessibility to building occupants and direct sun access on facades that receive direct sun, operable windows should be preferred from healthy daylight access point-of-view.

3.9 For detailed information regarding orientation of buildings and recommendations for various climatic zones of country, reference may be made to good practice [D-1(1)].

4 LIGHTING

4.1 Principles of Lighting

4.1.1 *Aims of Good Lighting*

Good lighting is an essential element of building design, serving both visual and non-visual functions to promote occupant comfort, safety and well-being. It should ensure a visually comfortable and functional environment that enhances task performance, supports safe movement and complements the architectural and interior design of spaces. Beyond meeting visual requirements, lighting should also address non-visual impacts by supporting healthy circadian rhythms and aiding in proper eye development, particularly in children. Effective control of glare is critical, as poorly managed glare can lead to visual discomfort, eye strain and headaches. Proper glare management not only improves visual comfort and productivity but also contributes significantly to occupant satisfaction and overall quality of life in buildings.

4.1.1.1 Realization of these aims involves the following:

a) Careful planning of the brightness and colour pattern within both the working areas and the surroundings so that attention is drawn naturally to the important areas, detail is seen quickly and accurately and the room is free from any sense of gloom or monotony (*see* **4.1.4**);

b) Using directional lighting where appropriate to assist perception of task detail and to give good modelling;

c) Controlling direct and reflected glare from light sources to eliminate visual discomfort;

d) In artificial lighting installations, minimizing flicker from certain types of lamps and paying attention to the colour rendering properties of the light;

e) Correlating lighting throughout the building to prevent excessive differences between adjacent areas so as to reduce the risk of accidents; and

f) Installing emergency lighting systems, where necessary.

4.1.2 *Planning the Brightness Pattern*

The brightness pattern seen within an interior may be considered as composed of three main parts – the task itself, immediate background of the task and the general surroundings of walls, ceiling, floor, equipment and furnishings.

The illuminance requirements given in good practice [D-1(2)] for elders and persons with disabilities, shall be complied with in addition to the requirements specified in this Section.

4.1.2.1 In occupations where the visual demands are small, the levels of illumination derived from a criterion of visual performance alone may be too low to satisfy the other requirements. For such situations, therefore, illuminance recommendations are based on standards of welfare, safety and amenity judged appropriate to the occupations; they are also sufficient to give these tasks brightness which ensures that the visual performance exceeds the specified minimum.

4.1.2.2 Where work takes place over the whole utilizable area of room, the illumination over that area should be reasonably uniform and it is recommended that the uniformity ratio (minimum illuminance divided by average illuminance levels) should be not less than 0.7 for the working area.

4.1.2.3 To ensure visual comfort and minimize strain, the illuminance levels within a space should be carefully balanced. Large spatial variations in illuminance around the task or activity area shall be avoided, as they can lead to visual stress and discomfort. The illuminance of the immediate surrounding area shall be related to that of the task area or activity area, ensuring a well-balanced luminance distribution within the visual field. This immediate surrounding area shall be defined as a band with a minimum width of 0.5 m around the task area. While the illuminance of this surrounding area may be lower than that of the task area, it shall not fall below the minimum values specified in Table 4. Additionally, the size and position of the immediate surrounding area shall be clearly stated and documented in the lighting design specifications. Proper planning of these illuminance levels contributes to a visually comfortable and efficient built environment.

Table 4 Relationship of Average Illuminances on Immediate Surrounding to the Average Illuminance on the Task Area or Activity Area

(*Clause* 4.1.2.3)

Sl No. (1)	Average Illuminance on the Task Area or Activity Area lx (2)	Average Illuminance on Immediate Surrounding Areas lx (3)
i)	≥750	500
ii)	500	300
iii)	300	200
iv)	200	150
v)	≤150	equal to task area

4.1.2.4 In indoor workplaces, particularly those devoid of daylight, ensuring adequate illumination beyond the immediate task surroundings is essential for visual comfort and spatial perception. A large area outside the immediate surrounding area, referred to as the background area, shall be illuminated to maintain a well-balanced visual environment. The background area is a horizontal surface at floor level, adjacent to the immediate surrounding area within the limits of the space. It shall have a maintained average illuminance of at least one-third of the illuminance value of the immediate surrounding area. In larger rooms, this background area shall have a minimum width of 3 m to ensure uniformity in lighting. Proper illumination of the background area may help in reducing visual fatigue and enhancing overall workplace efficiency.

4.1.2.5 In case of all buildings and facilities open to and used by the public, including all forms of public housing by the government/civic bodies and private developers, the requirements for visual contrast as given in good practice [D-1(2)] shall also be complied with for ensuring visual comfort for elders and persons with disabilities.

4.1.3 *Glare*

Excessive contrast or abrupt and large changes in brightness produce the effect of glare. When glare is present, the efficiency of vision is reduced and small details or subtle changes in scene cannot be perceived. It may be,

a) direct glare due to light sources within the field of vision;

b) reflected glare due to reflections from light sources or surfaces of excessive brightness; and

c) veiling glare where the peripheral field is comparatively very bright.

4.1.3.1 An example of glare sources in daylighting is the view of the bright sky through a window or skylight, especially when the surrounding wall or ceiling is comparatively dark or weakly illuminated. Glare can be minimized in this case either by shielding the open sky from direct sight by louvers, external hoods or deep reveals, curtains or other shading devices or by cross lighting the surroundings to a comparable level. A gradual transition of brightness from one portion to the other within the field of vision always avoids or minimizes the discomfort from glare.

For electric lamps the minimum shielding angles for lamp luminance shall not be less than the values given in the table below:

Sl No. (1)	*Lamp Luminance* kcd/m^2 (2)	*Minimum Shielding Angle* Degrees (3)
i)	1 to 20	10
ii)	20 to 50	15
iii)	50 to 500	20
iv)	≥500	30

The above mentioned shielding angle should not be applied to luminaries who do not appear in the field of view of a worker during usual work and/or do not give the worker any noticeable disability glare

Table 6 also gives recommended value of quality class of direct glare limitation for different tasks. These are numbers assigned to qualitative limits of direct glare; high, medium and low quality as 1, 2 and 3, respectively. For more details, reference may be made to good practice [D–1(3)].

4.1.4 *Recommended Values of Illuminance*

Table 6 gives the illuminance and lighting performance parameters commensurate with the general standards of lighting described in this Section and related to many occupations and buildings. These are valid under most of the conditions whether the illumination is by daylighting, artificial lighting or a combination of the two. The great variety of visual tasks makes it impossible to list them all and those given should be regarded as representing types of tasks.

The illuminance shall comply with the requirements given in good practice [D-1(2)] for persons with disabilities, in addition to the requirements specified in Table 6.

For comprehending and applying Table 6, reference may be made to **4.1.4.1** to **4.1.7**.

4.1.4.1 *Composition of Table* 6

a) Column (2) lists the reference number for each task area or activity area;

b) Column (3) lists those tasks areas or activities areas, for which specific requirements are given. If the particular task or activity is not listed, the values given for a similar, comparable situation should be adopted. Task areas or activity areas can also be a room, for example, a corridor or resting room;

c) Column (4) gives the required maintained average illuminance $\bar{E}_m$ on the reference surface (*see* **4.1.7**) for the interior (area) in which the task or activity from column (3) is performed;

d) Column (5) gives the minimum illuminance uniformity U_o on the reference surface for the maintained average illuminance $\bar{E}_m$ chosen according to **5**;

e) Column (6) gives the minimum colour rendering indices (R_a) (*see* **4.1.8**) for the situation listed in col (3);

f) Column (7) gives the unified glare rating limits (UGR limits, R_{UGL}) that are applicable to the situation listed in col (3) (*see* **4.1.3**);

g) Column (8) gives the maintained cylindrical illuminance $\bar{E}_{m,z}$ for the recognition of object and people;

h) Column (9) gives the maintained average illuminance on walls $\bar{E}_{m,wall}$; and

j) Column (10) gives the maintained average illuminance on ceilings $\bar{E}_{m,ceiling}$.

4.1.4.2 Indicative list detailing the different locations and tasks are grouped as per the following:

Sl No. (1)	*Location* (2)	*Tasks/Specific Location* (3)
i)	Traffic zones inside buildings	–
ii)	General areas inside buildings	Rest, sanitation and first aid rooms Control rooms Store rooms, cold stores
iii)	Logistics and warehouses	–

Table (*Concluded*)

Sl No. (1)	*Location* (2)	*Tasks/Specific Location* (3)
iv)	Industrial activities and crafts	Agriculture Bakeries Cement, cement goods, concrete, bricks Ceramics, tiles, glass, glassware Chemical, plastics and rubber industry Electrical and electronic industry Food stuffs and luxury food industry Foundries and metal casting Hair dressers Jewellery manufacturing Laundries and dry cleaning Leather and leather goods Metal working and processing Paper and paper goods Power stations Printers Rolling mills, iron and steel works Textile manufacture and processing Vehicle construction and repair Wood working and processing
v)	Offices	–
vi)	Retail premises	–
vii)	Places of public assembly	General areas Restaurants and hotels Theatres, concert halls, cinemas, places for entertainment Trade fairs, exhibition halls Museums Libraries Car parks (indoor)
viii)	Educational premises	Nursery school, play school Educational buildings
ix)	Health care premises	Rooms for general use Staff rooms Wards, maternity wards Examination rooms (general) Eye examination rooms Ear examination rooms Scanner rooms Delivery rooms Treatment rooms (general) Operating areas Intensive care unit Dental clinics/units Laboratories and pharmacies Decontamination rooms Autopsy rooms and mortuaries
x)	Transportation areas	Airports Railway installations

4.1.4.3 The illumination levels recommended in Table 6 are those to be maintained at all time on the task. As circumstances may be significantly different for different interiors used for the same application or for different conditions for the same kind of activity, a range of illuminances is recommended for each type of interior or activity instead of a single value of illuminance. Each range consists of three successive steps of the recommended scale of illuminances. They represent good practice and should be regarded as giving order of illumination commonly required rather than as having some absolute significance. For working interiors, the middle value of each range represents the recommended service illuminance that would be used unless one or more of the factors mentioned below apply.

4.1.4.3.1 The higher value of the range should be used when,

a) unusually low reflectances or contrasts are present in the task;

b) errors are costly to rectify;

c) visual work is critical;

d) accuracy or higher productivity is of great importance; and

e) visual capacity of the worker makes it necessary.

4.1.4.3.2 The lower value of the range may be used when,

a) reflectances or contrast are unusually high;

b) speed and accuracy is not important; and

c) the task is executed only occasionally.

4.1.4.4 Where a visual task is required to be carried out throughout an interior, general illumination level to the recommended value on the working plane is necessary; where the precise height and location of the task are not known or cannot be easily specified, the recommended value is that on horizontal plane 850 mm above floor level.

NOTE — For an industrial task, working plane for the purpose of general illumination levels is that on a work place which is generally 750 mm above the floor level. For certain purposes, such as viewing the objects of arts, the illumination levels recommended are for the vertical plane at which the art pieces are placed.

4.1.4.5 Where the task is localized, the recommended value is that for the task only; it need not, and sometimes should not, be the general level of illumination used throughout the interior. Some processes, such as industrial inspection process, call for lighting of specialized design, in which case the level of illumination is only one of the several factors to be taken into account.

4.1.4.6 In case of all buildings and facilities open to and used by the public, including all forms of public housing by the government/civic bodies and private developers, the minimum illuminance level as given in good practice [D-1(2)] shall also be complied with for ensuring sufficient lighting for accessibility by elders and persons with disabilities.

4.1.5 *Lighting for Movement about a Building*

Most buildings are complexes of working areas and other areas, such as passages, corridors, stairways, lobbies and entrances. The lighting of all these areas shall be properly correlated to give safe movement within the building at all times. In case of all buildings and facilities open to and used by the public, including all forms of public housing by the government/civic bodies and private developers, the illuminance in these areas shall comply with the requirements given in good practice [D-1(2)].

4.1.5.1 *Corridors, passages and stairways*

Transitions from brightly lit work areas to dimly lit corridors, passages, or stairways can pose safety risks, as the human eye requires time to adapt to significant changes in luminance. To mitigate these risks, such transitional spaces should be illuminated uniformly and adequately to ensure clear visibility and safe movement. In areas that are used intermittently, occupancy or motion-sensing lighting controls may be used to conserve energy while ensuring illumination is provided when the space is occupied. Stairways should be designed to prevent direct glare from luminaires and to eliminate harsh shadows that can obscure steps. Tread lighting or integrated step-strip lighting can be used to delineate step edges, especially in low-light environments or emergency egress paths. For outdoor applications, such as industrial catwalks and stairways, lighting should be robust, weather-resistant, and positioned to provide uniform coverage without creating glare. These strategies collectively enhance visual guidance, reduce fall hazards, and improve overall safety in circulation spaces.

4.1.5.2 *Entrances*

The problems of correctly grading the lighting within a building to allow adequate time for adaptation when passing from one area to another area are particularly acute at building entrances. These are given below:

a) By day, people entering a building will be adapted to the very high levels of brightness usually present outdoors and there is risk of accident if entrance areas, particularly any steps, are poorly lighted. This problem may often be overcome by arranging windows to give adequate natural lighting at the immediate entrance, grading to lower levels further inside the entrance area. Where this cannot be done, supplementary artificial lighting should be installed to raise the level of illumination to an appropriate value; and

b) At night it is desirable to light entrance halls and lobbies so that the illumination level reduces towards the exit and so that no bright fittings are in the line of sight of people leaving the building. Any entrance steps to the building should be well-lighted by correctly screened fittings.

4.1.6 *Brightness Appearance of Rooms*

To enhance the brightness appearance and visual comfort of rooms, it is important to define the task or activity areas within the space and assess the type of visual tasks performed. Appropriate lighting criteria, such as maintained average illuminance ($\bar{E}_m$), uniformity ratio (U_o), colour rendering index (R_a) and unified glare rating limit (R_{UGL}), should be selected based on the most demanding tasks. Key room surfaces, including walls and ceilings, should be illuminated to contribute to the perception of brightness. Higher illuminance levels in task areas may be considered to support better visual performance, while the illumination of objects and room surfaces, such as walls ($\bar{E}_{m,wall}$) and ceilings ($\bar{E}_{m,ceiling}$), should be optimized. In spaces with high ceilings or in industrial settings where ceiling lighting is less critical, a lower ceiling illuminance may be acceptable. Table 5 shows the assignment of columns to requirements, as given in **4.1.4.1**.

4.1.7 *Lighting Requirements for Task Areas*, *Activity Areas*, *Room and Space Brightness*

The requirements for task areas and activity areas are given in Table 5. The requirements for the specific tasks and activities are given by $\bar{E}_m$, U_o, R_a and R_{UGL}. The requirements for the space in which the task(s) or activities are carried out are given by $\bar{E}_{m,z}$ for the perception of objects and people within this space and $\bar{E}_{m,wall}$ and $\bar{E}_{m,ceiling}$ for room brightness. The latter are used for designing the room and the space including R_{UGL}. Glare (by R_{UGL}) is dedicated to the space in which a task is carried out.

The first four columns are used for of task area or activity area design and more than one of these areas can occur within one space.

Table 5 Assignment of Columns in Table 6 to Requirements

(*Clauses* 4.1.6 *and* 4.1.7)

Sl No. (1)	Task Area or Activity Area Design (2)				Room or Space Design Requirements (3)		
i)	Task or activity related requirements				Brightness appearance of rooms (**4.1.6**)		
ii)	$\bar{E}_m$ lux	U_o	R_a	R_{UGL}	$\bar{E}_{m,z}$ lux	$\bar{E}_{m,wall}$ lux	$\bar{E}_{m,ceiling}$ lux

where

$\bar{E}_m$ = minimum average illuminance level at defined area;
U_o = uniformity ratio (minimum illuminance/average illuminance);
R_a = colour rendering properties of a light source;
R_{UGL} = unified glare rating limit value;
$\bar{E}_{m,z}$ = maintained average cylindrical illuminance;
$\bar{E}_{m,wall}$ = average illuminance level at wall(s); and
$\bar{E}_{m,ceiling}$ = average illuminance level at ceiling.

In all enclosed places the maintained illuminances on the major surfaces shall have the values specified in Table 6.

Table 6 Illuminance and Lighting Performance Parameters

(*Foreword*, *Clauses* 4.1.3.1, 4.1.4, 4.1.4.1, 4.1.4.3, 4.1.7, 4.3.2, 4.3.2.1 *and* 4.4.8)

Sl No.	Ref No.	Type of Task/Activity Area	$\bar{E}_m$	U_o	R_a	R_{UGL}	$\bar{E}_{m,z}$	$\bar{E}_{m,wall}$	$\bar{E}_{m,ceiling}$
			lx				lx	lx	lx
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
i)	**1**	**Areas Inside Buildings**							
	1.1	Corridors and circulation areas	75-100-150	0.40	70	28	–	–	–
	1.2	Stairs, escalators, moving walks	75-100-150	0.40	70	25	–	–	–
	1.3	Lifts	75-100-150	0.40	70	25	–	–	–
	1.4	Area in front of lifts and escalators	150-200-300	0.40	70	25	–	–	–
	1.5	Loading ramps/bays	100-150-200	0.40	70	25	–	–	–
	1.6	Building entrance with canopy	20-30-50	0.40	–	–	–	–	–
	1.7	Gangways: manned	100-150-200	0.40	70	25	–	–	–
ii)	**2**	**General Areas Inside Buildings-Rest, Sanitation and First Aid Rooms**							
	2.1	Canteens and break areas	150-200-300	0.40	80	22	–	–	–
	2.2	Resting rooms	75-100-150	0.40	80	22	–	–	–
	2.3	Rooms for physical exercise	200-300-500	0.40	80	22	–	–	–
	2.4	Cloakroom (area), washrooms, bathrooms, dressing, lockers, shower, sink and toilet areas	150-200-300	0.40	80	25	–	–	–
	2.5	Facial lighting in front of mirrors	150-200-300	0.40	80	–	–	–	–
	2.6	Sick bay	300-500-750	0.60	80	19	–	–	–
	2.7	Rooms for medical attention	300-500-750	0.60	90	19	–	–	–
	2.8	General cleaning	75-100-150	0.40	–	–	–	–	–

Table 6 (*Continued*)

Sl No.	Ref No.	Type of Task/Activity Area	$\bar{E}_m$	U_o	R_a	R_{UGL}	$\bar{E}_{m,z}$	$\bar{E}_{m,wall}$	$\bar{E}_{m,ceiling}$
			lx				lx	lx	lx
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
iii)	**3**	**General Areas Inside Buildings-Control Rooms**							
	3.1	Plant rooms, switch gear rooms	150-200-300	0.40	80	25	50	50	–
	3.2	Post sorting, switchboard	300-500-750	0.60	80	19	150	150	–
	3.3	Surveillance station	200-300-500	0.60	80	19	100	100	–
iv)	**4**	**General Areas Inside Buildings-Store Rooms, Cold Stores**							
	4.1	Store and stockrooms	75-100-150	0.40	80	25	–	–	–
	4.2	Dispatch packing handling areas	200-300-500	0.60	80	25	–	–	–
	4.3	Larder (large storage space for food)	150-200-300	0.40	80	25	–	–	–
v)	**5**	**Logistics and Warehouses**							
	5.1	Unloading/loading area	150-200-300	0.40	80	25	50	–	–
	5.2	Packing/grouping area	200-300-500	0.50	80	25	100	–	–
	5.3	Configuration and rehandling	500-750-1 000	0.60	80	22	150	–	–
	5.4	Open goods storage	150-200-300	0.40	80	25	50	–	–
	5.5	Rack storage floor	100-150-200	0.50	80	25	–	–	–
	5.6	Rack storage rack face	50-75-100	0.40	80	–	–	–	–
	5.7	Central logistics corridor (heavy traffic)	200-300-500	0.60	80	25	100	–	–
	5.8	Automated zones (unmanned)	50-75-100	0.40	80	25	–	–	–
vi)	**6**	**Industrial Activities and Crafts-Agriculture**							
	6.1	Loading and operating of goods, handling equipment and machinery	150-200-300	0.40	80	25	–	–	–
	6.2	Buildings for livestock	30-50-75	0.40	70	-	–	–	–
	6.3	Sick animal pens; calving stalls	150-200-300	0.60	80	25	–	–	–
	6.4	Feed preparation; dairy; utensil washing	150-200-300	0.60	80	25	–	–	–

Table 6 (*Continued*)

Sl No.	Ref No.	Type of Task/Activity Area	$\bar{E}_m$ lx	U_o	R_a	R_{UGL}	$\bar{E}_{m,z}$ lx	$\bar{E}_{m,wall}$ lx	$\bar{E}_{m,ceiling}$ lx
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
vii)	**7**	**Industrial Activities and Crafts–Bakeries**							
	7.1	Preparation and baking	200-300-500	0.60	80	22	75	–	–
	7.2	Finishing, glazing, decorating	300-500-750	0.70	80	22	100	–	–
viii)	**8**	**Industrial Activities and Crafts-Cement, Cement Goods, Concrete, Bricks**							
	8.1	Drying	30-50-75	0.40	70	28	–	–	–
	8.2	Preparation of materials; work on kilns and mixers	150-200-300	0.40	70	28	50	–	–
	8.3	General machine work	200-300-500	0.60	80	25	100	–	–
	8.4	Rough forms	200-300-500	0.60	80	25	100	–	–
ix)	**9**	**Industrial Activities and Crafts-Ceramics, Tiles, Glass, Glassware**							
	9.1	Drying	30-50-75	0.40	70	28	–	–	–
	9.2	Preparation, general machine work	200-300-500	0.60	80	25	100	–	–
	9.3	Enamelling, rolling, pressing, shaping simple parts, glazing, glass blowing	200-300-500	0.60	80	25	100	–	–
	9.4	Grinding, engraving, glass polishing, shaping precision parts, manufacture of glass instruments	500-750-1 000	0.70	80	19	150	75	50
	9.5	Grinding of optical glass, crystal, hand grinding and engraving	500-750-1 000	0.70	80	19	150	75	50
	9.6	Precision work, for example, decorative grinding, hand painting	750-1 000-1 000	0.70	90	19	150	75	50
	9.7	Manufacture of synthetic precious stones	1 000-1 500-2 000	0.70	90	19	150	75	50

Table 6 (*Continued*)

Sl No.	Ref No.	Type of Task/Activity Area	$\bar{E}_m$	U_o	R_a	R_{UGL}	$\bar{E}_{m,z}$	$\bar{E}_{m,wall}$	$\bar{E}_{m,ceiling}$
			lx				lx	lx	lx
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
x)	**10**	**Industrial Activities and Crafts-Chemical, Plastics and Rubber Industry**							
	10.1	Remote operated processing installations	30-50-75	0.40	70	–	–	–	–
	10.2	Processing installations with limited manual intervention	100-150-200	0.40	70	28	50	–	–
	10.3	Constantly manned work stations in processing installations	200-300-500	0.60	80	25	100	–	–
	10.4	Precision measuring rooms, laboratories	300-500-750	0.60	80	19	150	75	50
	10.5	Pharmaceutical production	300-500-750	0.60	80	22	150	–	–
	10.6	Tyre production	300-500-750	0.60	80	22	150	–	–
	10.7	Colour inspection	750-1 000-1 500	0.70	90	19	150	75	50
	10.8	Cutting, finishing, inspection	500-750-1 000	0.70	80	19	150	75	50
xi)	**11**	**Industrial Activities and Crafts-Electrical and Electronic Industry**							
	11.1	Cable and wire manufacture	200-300-500	0.60	80	25	100	–	–
	11.2	Winding-large coils	200-300-500	0.60	80	25	100	–	–
	11.3	Winding-medium-sized coils	300-500-750	0.60	80	22	150	–	–
	11.4	Winding-small coils	500-750-1000	0.70	80	19	150	75	50
	11.5	Coil impregnating	200-300-500	0.60	80	25	100	–	–
	11.6	Galvanizing	200-300-500	0.60	80	25	100	–	–
	11.7	Assembly work:- rough, for example, large transformers	200-300-500	0.60	80	25	100	–	–
	11.8	Assembly work: Medium, for example, switchboards	300-500-750	0.60	80	22	150	–	–

Table 6 (*Continued*)

Sl No.	Ref No.	Type of Task/Activity Area	$\bar{E}_m$	U_o	R_a	R_{UGL}	$\bar{E}_{m,z}$	$\bar{E}_{m,wall}$	$\bar{E}_{m,ceiling}$
			lx				lx	lx	lx
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	11.9	Assembly work: Fine, for example, telephones, radios, IT equipment (computers)	500-750-1 000	0.70	80	19	150	75	50
	11.10	Assembly work: Precision, for example, measuring equipment, printed circuit boards	750-1 000-1 500	0.70	80	19	150	75	50
	11.11	Electronic workshops, testing, adjusting	1 000-1 500-2 000	0.70	80	19	150	75	50
xii)	**12**	**Industrial Activities and Crafts-Food Stuffs and Luxury Food Industry**							
	12.1	Work stations	150-200-300	0.40	80	25	50	–	–
	12.2	Sorting and washing of products, milling, mixing, packing	200-300-500	0.60	80	25	100	–	–
	12.3	Work stations and critical zones in slaughter houses, butchers, dairies, mills, on filtering floor in sugar refineries	300-500-750	0.60	80	25	150	–	–
	12.4	Cutting and sorting of fruit and vegetables	200-300-500	0.60	80	25	100	–	–
	12.5	Manufacture of delicatessen foods,	300-500-750	0.60	80	22	150	–	–
	12.6	Inspection of glasses and bottles, product control, trimming, sorting, decoration	300-500-750	0.60	80	22	150	–	–
	12.7	Laboratories	300-500-750	0.60	80	19	150	75	50
	12.8	Colour inspection	750-1 000-1 500	0.70	90	19	150	75	50

Table 6 (*Continued*)

Sl No.	Ref No.	Type of Task/Activity Area	$\bar{E}_m$	U_o	R_a	R_{UGL}	$\bar{E}_{m,z}$	$\bar{E}_{m,wall}$	$\bar{E}_{m,ceiling}$
			lx				lx	lx	lx
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
xiii)	**13**	**Industrial Activities and Crafts-Foundries and Metal Casting**							
	13.1	Man-size underfloor tunnels, cellars, etc	30-50-75	0.40	70	–	–	–	–
	13.2	Platforms	75-100-150	0.40	70	25	50	–	–
	13.3	Sand preparation	150-200-300	0.40	80	25	50	–	–
	13.4	Dressing	150-200-300	0.40	80	25	50	–	–
	13.5	Work stations at cupola and mixer	150-200-300	0.40	80	25	50	–	–
	13.6	Casting bay	150-200-300	0.40	80	25	50	–	–
	13.7	Shake out areas	150-200-300	0.40	80	25	50	–	–
	13.8	Machine moulding	150-200-300	0.40	80	25	50	–	–
	13.9	Hand and core moulding	200-300-500	0.60	80	25	100	–	–
	13.10	Die casting	200- 300-500	0.60	80	25	100	–	–
	13.11	Model building	300-500-750	0.60	80	22	150	–	–
xiv)	**14**	**Industrial Activities and Crafts-Hairdressers**							
	14.1	Hairdressing	300-500-750	0.60	90	19	150	75	50
xv)	**15**	**Industrial Activities and Crafts-Jewellery Manufacturing**							
	15.1	Working with precious stones	1 000-1 500-2 000	0.70	90	19	150	75	50
	15.2	Manufacture of jewellery	750-1 000-1 500	0.70	90	19	150	75	50
	15.3	Watch making (manual)	1 000-1 500-2 000	0.70	80	19	150	75	50
	15.4	Watch making (automatic)	300-500-750	0.60	80	19	150	75	50
xvi)	**16**	**Industrial Activities and Crafts-Laundries and Dry Cleaning**							
	16.1	Goods in, marking and sorting	200-300-500	0.60	80	25	100	–	–
	16.2	Washing and dry cleaning	200-300-500	0.60	80	25	100	–	–

Table 6 (*Continued*)

Sl No.	Ref No.	Type of Task/Activity Area	$\bar{E}_m$	U_o	R_a	R_{UGL}	$\bar{E}_{m,z}$	$\bar{E}_{m,wall}$	$\bar{E}_{m,ceiling}$
			lx				lx	lx	lx
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	16.3	Ironing, pressing	200-300-500	0.60	80	25	100	–	–
	16.4	Inspection and repairs	500-750–1 000	0.70	80	19	150	75	50
xvii)	**17**	**Industrial Activities and Crafts-Leather and Leather Goods**							
	17.1	Work on vats, barrels, pits	150-200-300	0.40	80	25	75	–	–
	17.2	Fleshing, skiving, rubbing, tumbling of skins	200-300-500	0.40	80	25	100	–	–
	17.3	Saddlery work, shoe manufacture: stitching, sewing, polishing, shaping, cutting, punching	300-500-750	0.60	80	22	150	–	–
	17.4	Sorting	300-500-750	0.60	90	22	150	–	–
	17.5	Leather dyeing (machine)	300-500-750	0.60	80	22	150	–	–
	17.6	Quality control	750-1 000-1 500	0.70	80	19	150	75	50
	17.7	Colour inspection	750-1 000-1 500	0.70	90	19	150	75	50
	17.8	Shoe making	300-500-750	0.60	80	22	150	–	–
	17.9	Glove making	300-500-750	0.60	80	22	150	–	–
xviii)	**18**	**Industrial Activities and Crafts-Metal Working and Processing**							
	18.1	Open die forging	150-200-300	0.60	80	25	50	–	–
	18.2	Drop forging	200-300-500	0.60	80	25	75	–	–
	18.3	Welding	200-300-500	0.60	80	25	75	–	–
	18.4	Rough and average machining: Tolerances ≥ 0.1 mm	200-300-500	0.60	80	22	75	–	–
	18.5	Precision machining; grinding: Tolerances < 0.1 mm	300-500-750	0.70	80	19	150	75	50
	18.6	Scribing; inspection	500-750-1 000	0.70	80	19	150	75	50

Table 6 (*Continued*)

Sl No.	Ref No.	Type of Task/Activity Area	$\bar{E}_m$	U_o	R_a	R_{UGL}	$\bar{E}_{m,z}$	$\bar{E}_{m,wall}$	$\bar{E}_{m,ceiling}$
			lx				lx	lx	lx
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	18.7	Wire and pipe drawing shops; cold forming	200-300-500	0.60	80	25	75	–	–
	18.8	Plate machining: Thickness ≥ 5 mm	150-200-300	0.60	80	25	50	–	–
	18.9	Sheet metalwork: Thickness < 5 mm	200-300-500	0.60	80	22	75	–	–
	18.10	Tool making, cutting equipment manufacture	500-750-1 000	0.70	80	19	150	–	–
	18.11	Assembly:						–	–
		1) Rough	150-200-300	0.60	60	25	50	–	–
		2) Medium	200-300-500	0.60	80	25	75	–	–
		3) Fine	300-500-750	0.60	80	22	150	–	–
		4) Precision	500-750-1 000	0.70	80	19	150	75	50
	18.12	Galvanizing	200-300-500	0.60	80	25	75	–	–
	18.13	Surface preparation and painting	500-750-1 000	0.70	80	25	150	–	–
	18.14	Tool, template and jig making, precision mechanics, micro- mechanics	750-1 000-1 500	0.70	80	19	150	75	50
xix)	**19**	**Industrial Activities and Crafts-Paper and Paper Goods**							
	19.1	Edge runners, pulp mills	150-200-300	0.40	80	25	50	–	–
	19.2	Paper manufacture and processing, paper and corrugating machines, cardboard manufacture	200-300-500	0.60	80	25	75	–	–
	19.3	Standard bookbinding work, for example, folding, sorting, gluing, cutting, embossing, sewing	300-500-750	0.60	80	22	150	–	–
xx)	**20**	**Industrial Activities and Crafts-Power Stations**							
	a) 20.1	Fuel supply plant	30-50-75	0.40	70	–	–	–	–

Table 6 (*Continued*)

Sl No.	Ref No.	Type of Task/Activity Area	$\bar{E}_m$	U_o	R_a	R_{UGL}	$\bar{E}_{m,z}$	$\bar{E}_{m,wall}$	$\bar{E}_{m,ceiling}$
			lx				lx	lx	lx
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	20.2	Boiler house	75-100-150	0.40	70	28	50	–	–
	20.3	Machine halls	150-200-300	0.40	80	25	50	–	–
	20.4	Side rooms, for example pump rooms, condenser rooms, etc; switchboards (inside buildings)	150-200-300	0.40	80	25	50	–	–
	20.5	Control rooms	300-500-750	0.70	80	19	150	75	50
xxi)	**21**	**Industrial Activities and Crafts-Printers**							
	21.1	Cutting, gilding, embossing, block engraving, work on	300-500-750	0.60	80	19	150	75	50
	21.2	Paper sorting and hand printing	300-500-750	0.60	80	19	150	75	50
	21.3	Type setting, retouching, lithography	750-1 000-1 500	0.70	80	19	150	75	50
	21.4	Colour inspection in multicoloured printing	1 000-1 500-2 000	0.70	90	19	150	75	50
	21.5	Steel and copper engraving	1 500-2 000-3 000	0.70	80	19	150	75	50
xxii)	**22**	**Industrial Activities and Crafts-Rolling Mills, Iron and Steel Works**							
	22.1	Production plants without manual operation	30-50-75	0.40	70	–	–	–	–
	22.2	Production plants with occasional manual operation	100-150-200	0.40	70	28	50	–	–
	22.3	Production plants with continuous manual operation	150-200-300	0.60	80	25	50	–	–
	22.4	Slab store	30-50-75	0.40	70	–	–	–	–
	22.8	Furnaces	150-200-300	0.40	70	25	50	–	–
	22.9	Mill train; coiler; shear line	200-300-500	0.60	70	25	75	–	–
	22.10	Control platforms; control panels	200-300-500	0.60	80	22	75	–	–

Table 6 (*Continued*)

Sl No.	Ref No.	Type of Task/Activity Area	$\bar{E}_m$	U_o	R_a	R_{UGL}	$\bar{E}_{m,z}$	$\bar{E}_{m,wall}$	$\bar{E}_{m,ceiling}$
			lx				lx	lx	lx
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	22.11	Test, measurement and inspection	300-500-750	0.60	80	22	150	–	–
	22.12	Underfloor man-sized tunnels; belt sections, cellars, etc	30-50-75	0.40	70	–	–	–	–
xxiii)	**23**	**Industrial Activities and Crafts-Textile Manufacture and Processing**							
	23.1	Work stations and zones in baths, bale opening	150-200-300	0.60	70	25	50	–	–
	23.2	Carding, washing, ironing, devilling machine work, drawing, combing, sizing, card cutting, pre-spinning, jute and hemp spinning	200-300-500	0.60	70	22	100	–	–
	23.3	Spinning, plying, reeling, winding	300-500-750	0.60	70	22	150	–	–
	23.4	Warping, weaving, braiding, knitting	300-500-750	0.60	70	22	150	–	–
	23.5	Sewing, fine knitting, taking up stitches	500-750-1 000	0.70	80	22	150	–	–
	23.6	Manual design, drawing patterns	500-750-1 000	0.70	90	22	150	–	–
	23.7	Finishing, dyeing	300-500-750	0.60	80	22	150	–	–
	23.8	Drying room	75-100-150	0.40	60	28	50	–	–
	23.9	Automatic fabric printing	300-500-750	0.60	90	25	100	–	–
	23.10	Burling, picking, trimming	750-1 000-1 500	0.70	80	19	150	75	50
	23.11	Colour inspection; fabric control	750-1 000-1 500	0.70	90	19	150	75	50
	23.12	Invisible mending	1 250-1 500-2 000	0.70	90	19	150	75	50
	23.13	Hat manufacturing	300-500-750	0.60	80	22	150	–	–
xxiv)	**24**	**Industrial Activities and Crafts-Vehicle Construction and Repair**							
	24.1	Press shop - Large parts	200-300-500	0.60	80	25	100	–	–
	24.2	Press shop - Visual inspection	300-500-750	0.60	80	22	150	–	–

Table 6 (*Continued*)

Sl No.	Ref No.	Type of Task/Activity Area	$\bar{E}_m$	U_o	R_a	R_{UGL}	$\bar{E}_{m,z}$	$\bar{E}_{m,wall}$	$\bar{E}_{m,ceiling}$
			lx				lx	lx	lx
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	24.3	Body work and assembly-Automatic line	200-300-500	0.60	80	25	100	–	–
	24.4	Body work and assembly- Manual welding	300-500-750	0.60	80	22	150	–	–
	24.5	Painting, spraying chamber, polishing chamber	500-750-1 000	0.70	80	22	150	–	–
	24.6	Painting, inspection, touch- up and polishing	750-1 000-1 500	0.70	90	19	150	75	50
	24.7	Upholstery manufacture (manual)	750-1 000-1 500	0.70	80	19	150	75	50
	24.8	Detailing: Subparts assembly (doors, dashboard, upholstery), under chassis assembly, motor and mechanical assembly, final assembly conveyor line	500-750-1 000	0.70	80	22	150	–	–
	24.9	Detailing - Work with electronics	500-750-1 000	0.60	90	22	150	–	–
	24.10	Final inspection	750-1 000-1 500	0.70	90	19	150	75	50
	24.11	General vehicle services, repair and testing	300-500-750	0.60	80	22	100	–	–
xxv)	**25**	**Industrial Activities and Crafts-Wood Working and Processing**							
	25.1	Automatic processing, for example, drying, plywood manufacturing	30-50-75	0.40	70	28	–	–	–
	25.2	Steam pits	100-150-200	0,40	70	28	50	–	–
	25.3	Saw frame	200-300-500	0.60	70	25	100	–	–
	25.4	Work at joiner’s bench, gluing, assembly	200-300-500	0.60	80	25	100	–	–
	25.5	Polishing, painting, fancy joinery	500-750-1 000	0.70	80	22	150	–	–
	25.6	Work on wood working machines, for example, turning, fluting, dressing,	300-500-750	0.60	80	19	150	75	50

Table 6 (*Continued*)

Sl No.	Ref No.	Type of Task/Activity Area	$\bar{E}_m$ lx	U_o	R_a	R_{UGL}	$\bar{E}_{m,z}$ lx	$\bar{E}_{m,wall}$ lx	$\bar{E}_{m,ceiling}$ lx
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
		rebating, grooving, cutting, sawing, sinking							
	25.7	Selection of veneer woods	500-750-1 000	0.90	70	22	150	–	–
	25.8	Marquetry, inlay work	500-750-1 000	0.90	70	22	150	–	–
	25.9	Quality control, inspection	750-1 000-1 500	0.90	70	19	150	75	50
xxvi)	**26**	**Offices**							
	26.1	Filing, copying, etc	200-300-500	0.40	80	19	100	75	50
	26.2	General office area - Writing, typing, reading, data processing	300-500-750	0.60	80	19	150	75	50
	26.3	Private cabins	300-500-750	0.70	80	19	150	75	50
	26.4	CAD work stations	300-500-750	0.60	80	19	150	75	50
	26.5	Huddle/breakout area	200-300-500	0.60	80	19	150	75	50
	26.6	Conference and meeting rooms	300-500-750	0.60	80	19	150	75	50
	26.7	Light on presenter	150-200-300		80	19			
	26.8	Reception desk	200-300 -500	0.60	80	22	100	75	50
	26.9	Archiving	150-200-300	0.40	80	25	75	–	–
	26.10	Canteens and break out areas	150-200-300	0.60	80	22	–	–	–
	26.11	Resting rooms	75-100-200	0.40	80	22	–	–	–
	26.12	Rooms for physical exercise	200-300-500	0.40	80	22	–	–	–
	26.13	Cloakroom (area), wash room	150-200-300	0.40	80	25	100	75	50
	26.14	Facial lighting in front of mirrors	200-300-500	0.40	80	–	–	–	–
	26.15	Sick bay	300-500-750	0.60	80	19	100	75	50
	26.16	Rooms for medical attention	300-500-750	0.40	90	19	100	75	50
	26.17	General cleaning	75-100-150	0.40	80	–	–	–	–

Table 6 (*Continued*)

Sl No.	Ref No.	Type of Task/Activity Area	$\bar{E}_m$ lx	U_o	R_a	R_{UGL}	$\bar{E}_{m,z}$ lx	$\bar{E}_{m,wall}$ lx	$\bar{E}_{m,ceiling}$ lx
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	26.18	Corridors and circulation areas	75 -100-150	0.40	70	28	–	–	–
	26.19	Stairs, escalators, travelators	75-100-150	0.40	70	25	–	–	–
	26.20	Lifts	75-100-150	0.40	70	25	–	–	–
	26.21	Area in front of lifts and escalators	150-200-300	0.40	70	25	–	75	50
	26.22	Auditorium, training hall, town hall, amphitheater	300-500-750	0.60	80	19	75	50	–
xxvii)	**27**	**Retail Premises**							
	27.1	General sales area	200-300-500	0.40	80	22	75	–	–
	27.2	Till area	300-500 -750	0.60	80	19	100	75	50
	27.3	Wrapper table	300-500-750	0.60	80	22	100	–	–
	27.4	Storage area	200-300-500	0.40	80	25	50	–	–
	27.5	Dressing/fitting room	200-300-500	0.4	90	–	–	–	–
xxviii)	**28**	**Places of Public Assembly General Areas**							
	28.1	Entrance halls	75-100-150	0.40	80	22	50	–	–
	28.2	Cloakrooms	150-200-300	0.40	80	25	75	–	–
	28.3	Lounges	150-200-300	0.40	80	22	75	–	–
	28.4	Ticket offices	200-300-500	0.60	80	22	75	–	–
xxix)	**29**	**Places of Public Assembly- Restaurants and Hotels**							
	29.1	Reception/cashier desk, porters desk	200-300-500	0.60	80	22	100	–	–
	29.2	Kitchen	300-500-750	0.60	80	22	100	–	–
	29.3	Restaurant, dining room, function room	–	–	80	–	–	–	–
	29.4	Self-service restaurant	150-200-300	0.40	80	22	75	–	–
	29.5	Buffet	200-300-500	0.60	80	22	75	–	–

Table 6 (*Continued*)

Sl No.	Ref No.	Type of Task/Activity Area	$\bar{E}_m$ lx	U_o	R_a	R_{UGL}	$\bar{E}_{m,z}$ lx	$\bar{E}_{m,wall}$ lx	$\bar{E}_{m,ceiling}$ lx
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	29.6	Conference rooms	300-500-750	0.60	80	19	150	75	50
	29.7	Corridors	75-100-150	0.40	80	25	50		
xxx)	**30**	**Places of Public Assembly-Theatres, Concert Halls, Cinemas, Places for Entertainment**							
	30.1	Practice rooms	200-300-500	0.60	80	22	100	–	–
	30.2	Dressing rooms	200-300-500	0.60	90	22	100	–	–
	30.3	Seating areas-maintenance, cleaning	150-200-300	0.40	80	22	50	–	–
	30.4	Stage area rigging	200-300-500	0.40	80	25	75	–	–
xxxi)	**31**	**Places of Public Assembly-Trade Fairs, Exhibition Halls**							
	31.1	General lighting	200-300-500	0.40	80	22	50	–	–
xxxii)	**32**	**Places of Public Assembly-Museums**							
	32.1	Exhibits, insensitive to light	–	–	80	–	–	–	–
	32.2	Exhibits sensitive to light	–	–	80	–	–	–	–
xxxiii)	**33**	**Places of Public Assembly-Libraries**							
	33.1	Bookshelves	150-200-300	0.40	80	19	–	–	–
	33.2	Reading area	300-500-750	0.60	80	19	100	75	50
	33.3	Counters	300-500-750	0.60	80	19	150	75	50
	33.4	General lighting	200-300-500	0.40	80	22	75	–	–
xxxiv)	**34**	**Places of Public Assembly-Car Parks (Indoor)**							
	34.1	Entry/exit ramps (during daylight hours)	200-300-500	0.40	70	25	75	–	–
	34.2	Entry/exit ramps (at night)	50-75-100	0.40	70	25	50	–	–

Table 6 (*Continued*)

Sl No.	Ref No.	Type of Task/Activity Area	$\bar{E}_m$	U_o	R_a	R_{UGL}	$\bar{E}_{m,z}$	$\bar{E}_{m,wall}$	$\bar{E}_{m,ceiling}$
			lx				lx	lx	lx
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	34.3	Traffic lanes, internal ramps and pedestrian paths	50-75-100	0.40	70	25	50	–	–
	34.4	Parking areas - Not open to public	50-75-100	0.25	70	–	50	–	–
	34.5	Parking areas - Open to public with a large number of users for example, shopping centres, arenas	100-150-200	0.40	70	–	50	–	–
	34.6	Ticket office	200-300-500	0.60	80	19	75	75	50
xxxv)	**35**	**Educational Premises-Nursery School, Play School**							
	35.1	Play room	200-300-500	0.40	80	22	100	75	50
	35.2	Nursery	200-300-500	0.40	80	22	100	75	50
	35.3	Handicraft room	200-300-500	0.60	80	19	100	75	50
xxxvi)	**36**	**Educational Premises-Educational Buildings**							
	36.1	Classroom-General activities	300-500-750	0.60	80	19	150	75	50
	36.2	Auditorium, lecture halls	300-500-750	0.60	80	19	150	75	50
	36.3	Attending lecture in seating areas in auditoriums and lecture halls	150-200-300	0.60	80	19	75	75	50
	36.4	Black, green and white boards	300-500-750	0.70	80	19	–	–	–
	36.5	Black, green and white boards in auditorium and lecture halls	300-500-750	0.60	80	19	–	–	–
	36.6	Projector and smartboard presentation	–	–	–	–	–	–	–
	36.7	Display board	150-200-300	0.60	80	19	–	–	–
	36.8	Demonstration table in auditoriums and lecture halls	500-750-1 000	0.70	80	19	–	–	–
	36.9	Light on teacher/presenter	–	–	80	–	150	–	–
	36.10	Light on podium area	200-300-500	0.70	80	–	–	–	–

Table 6 (*Continued*)

Sl No.	**Ref No.**	**Type of Task/Activity Area**	$\bar{E}_m$	U_o	R_a	R_{UGL}	$\bar{E}_{m,z}$	$\bar{E}_{m,wall}$	$\bar{E}_{m,ceiling}$
			lx				lx	lx	lx
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	36.11	Computer work only	200-300-500	0.60	80	19	100	75	50
	36.12	Art rooms in art schools	500-750-1 000	0.70	90	19	150	75	50
	36.13	Technical drawing rooms	500-750-1 000	0.60	80	19	150	75	50
	36.14	Practical rooms and laboratories	300-500-750	0.60	80	19	150	75	50
	36.15	Handcraft rooms	300-500-750	0.60	80	19	150	75	50
	36.16	Teaching workshop	300-500-750	0.60	80	19	150	75	50
	36.17	Preparation rooms and workshops	300-500-750	0.60	80	22	150	–	–
	36.18	Entrance halls	150-200-300	0.40	80	22	75	–	–
	36.19	Circulation areas, corridors	75-100-150	0.40	80	25	50	–	–
	36.20	Stairs	100-150-200	0.40	80	25	50	–	–
	36.21	Student common rooms and assembly halls	150-200-300	0.40	80	22	75	–	–
	36.22	Teachers rooms	200-300-500	0.60	80	19	100	75	50
	36.23	Library – Bookshelves	150-200-300	0.60	80	19	75	75	50
	36.24	Library - Reading areas	300-500-750	0.60	80	19	100	75	50
	36.25	Stock rooms for teaching materials	75–100-150	0.40	80	25	50	–	–
	36.26	Sports halls, gymnasiums, swimming pools	200–300–500	0.60	80	22	100	–	–
	36.27	School canteens	150-200-300	0.40	80	22	75	–	–
	36.28	Kitchen	300–500-750	0.60	80	22	100	–	–
xxxvii)	**37**	**Health Care Premises-Rooms for General Use**							
	37.1	Waiting rooms	150-200-300	0.40	80	22	75	75	30
	37.2	Corridors: During the day	75-100-150	0.40	80	22	50	50	30
	37.3	Corridors: Cleaning	75-100-150	0.40	80	22	50	50	30

Table 6 (*Continued*)

Sl No.	Ref No.	Type of Task/Activity Area	$\bar{E}_{m}$	U_{o}	R_{a}	R_{UGL}	$\bar{E}_{m,z}$	$\bar{E}_{m,wall}$	$\bar{E}_{m,ceiling}$
			lx				lx	lx	lx
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	37.4	Corridors: During the night	30-50-75	0.40	80	22	–	–	–
	37.5	Corridors with multi-purpose use (for example, pre-examination of patients)	150-200-300	0.60	80	22	75	75	50
	37.6	Day rooms	200-300-500	0.60	80	22	75	75	50
	37.7	Lifts for persons and visitors	75-100-150	0.60	80	22	50	50	30
	37.8	Service lifts	150-200-300	0.60	80	22	75	75	50
xxxviii)	**38**	**Health Care Premises-Staff Rooms**							
	38.1	Staff office	300-500-750	0.60	80	19	150	75	50
	38.2	Staff rooms	200-300-500	0.60	80	19	100	75	50
xxxix)	**39**	**Health Care Premises-Wards, Maternity Wards**							
	39.1	General lighting	75-100-150	0.70	80	19	50	50	30
	39.2	Reading lighting	200-300-500	0.70	80	19	100	75	50
	39.3	Wards-simple examinations	200-300-500	0.70	80	19	100	75	50
	39.4	Examination and treatment	750-1 000-1 500	0.70	90	19	150	75	50
	39.5	Night lighting, observation lighting	5	–	80	–	–	–	–
	39.6	Bathrooms and toilets for patients	150-200-300	0.70	90	22	75	75	50
xl)	**40**	**Health Care Premises-Examination Rooms (General)**							
	40.1	General lighting	300-500-750	0.60	90	19	150	75	50
	40.2	Examination and treatment	750-1 000-1 500	0.70	90	19	150	75	50
xli)	**41**	**Health Care Premises-Eye Examination Rooms**							
	41.1	General lighting	300-500-750	0.60	90	19	150	75	50
	41.2	Examination of the outer eye	750-1 000-1 500	–	90	–	150	75	50

Table 6 (*Continued*)

Sl No.	Ref No.	Type of Task/Activity Area	$\bar{E}_m$	U_o	R_a	R_{UGL}	$\bar{E}_{m,z}$	$\bar{E}_{m,wall}$	$\bar{E}_{m,ceiling}$
			lx				lx	lx	lx
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	41.3	Reading and colour vision tests with vision charts	300-500-750	0.70	90	19	150	75	50
xlii)	**42**	**Health Care Premises-Ear Examination Rooms**							
	42.1	General lighting	300-500-750	0.60	90	19	150	75	50
	42.2	Ear examination	750-1 000-1 500	–	90	–	150	75	50
xliii)	**43**	**Health Care Premises-Scanner Rooms**							
	43.1	General lighting	200-300-500	0.60	80	19	100	75	50
	43.2	Scanners with image enhancers and television systems	30-50-75	–	80	19	–	–	–
xliv)	**44**	**Health Care Premises-Delivery Rooms**							
	44.1	General lighting	200-300-500	0.60	90	19	100	75	50
	44.2	Examination and treatment	750-1 000-1 500	0.70	90	19	150	75	50
xlv)	**45**	**Health Care Premises-Treatment Rooms (General)**							
	45.1	Dialysis	300-500-750	0.60	80	19	150	75	50
	45.2	Dermatology	300-500-750	0.60	90	19	150	75	50
	45.3	Endoscopy	200-300-500	0.60	80	19	100	75	50
	45.4	Plastering	300-500-750	0.60	80	19	150	75	50
	45.5	Medical baths	200-300-500	0.60	80	19	100	75	50
	45.6	Massage and radiotherapy	200-300-500	0.60	80	19	100	75	50
xlvi)	**46**	**Health Care Premises-Operating Areas**							
	46.1	Pre-op and recovery rooms	500-750-1 000	0.60	90	19	150	75	50
	46.2	Operating cavity surround	750-1 000-1 500	0.60	90	19	150	75	50
	46.3	Operating theatre	750-100-1 500	0.60	90	19	–	–	–

Table 6 (*Continued*)

Sl No.	Ref No.	Type of Task/Activity Area	$\bar{E}_m$	U_o	R_a	R_{UGL}	$\bar{E}_{m,z}$	$\bar{E}_{m,wall}$	$\bar{E}_{m,ceiling}$
			lx				lx	lx	lx
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	46.4	Operating cavity	–	–	90	–	–	–	–
xlvii)	**47**	**Health Care Premises-Intensive Care Unit**							
	47.1	General lighting	200-300-500	0.60	90	19	50	50	30
	47.2	Simple examinations	300-500-750	0.60	90	19	100	75	50
	47.3	Examination and treatment	1 000-1 250 -1 500	0.70	90	19	150	75	50
	47.4	Night watch	20	–	90	19	–	–	–
xlviii)	**48**	**Health Care Premises-Dental Clinics/Units**							
	48.1	General lighting	300-500-750	0.60	90	19	150	75	50
	48.2	At the patient	750-1 000-1 500	0.70	90	–	150	75	50
	48.3	Operating cavity	–	–	–	–	–	–	–
	48.4	White teeth matching	–	–	–	–	–	–	–
xlix)	**49**	**Health Care Premises-Laboratories and Pharmacies**							
	49.1	General lighting	300-500-750	0.60	80	19	150	75	50
	49.2	Colour inspection	750-1 000- 1 500	0.70	90	19	150	75	50
l)	**50**	**Health Care Premises-Decontamination Rooms**							
	50.1	Sterilization	300-500-750	0.60	80	22	100	75	50
	50.2	Disinfection	300-500-750	0.60	80	22	100	75	50
li)	**51**	**Health Care Premises-Autopsy Rooms and Mortuaries**							
	51.1	General lighting	300-500-750	0.60	90	19	150	75	50
	51.2	Autopsy table and dissecting table	500-7500	0.70	90	–	150	75	50

Table 6 (*Continued*)

Sl No.	Ref No.	Type of Task/Activity Area	$\bar{E}_m$	U_o	R_a	R_{UGL}	$\bar{E}_{m,z}$	$\bar{E}_{m,wall}$	$\bar{E}_{m,ceiling}$
			lx				lx	lx	lx
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
lii)	**52**	**Transportation Areas-Airports**							
	52.1	Arrival and departure halls, baggage claim areas	150-200-300	0.40	80	22	75	–	–
	52.2	Connecting areas	100-150-200	0.40	80	22	50	–	–
	52.3	Information desks, check-in desks	300-500-750	0.70	80	19	150	–	–
	52.4	Customs and passport control desks	300-500-750	0.70	80	19	150	–	–
	52.5	Waiting areas	150-200-300	0.40	80	22	50	–	–
	52.6	Luggage storage rooms	150-200-300	0.40	80	25	50	–	–
	52.7	Security check areas	200-300-500	0.60	80	19	100	–	–
	52.8	Air traffic control tower	300-500-750	0.60	80	19	50	75	50
	52.9	Tasks in hangars: Testing and repair areas, engine test areas, measuring areas	300-500-750	0.60	80	22	50	–	–
liii)	**53**	**Transportation Areas-Railway Installations**							
	53.1	Fully enclosed platforms: Small number of passengers	30-50-75	0.30	80	–	–	–	–
	53.2	Fully enclosed platforms: Medium number of passengers	75-100-150	0.40	80	–	–	–	–
	53.3	Fully enclosed platforms: Large number of passengers	150-200-300	0.50	80	–	–	–	–
	53.4	Fully enclosed passenger subways (underpasses): Small number of passengers	30-50-75	0.30	80	–	–	–	–
	53.5	Fully enclosed passenger subways (underpasses): Medium number of passengers	75-100-150	0.40	80	–	–	–	–

Table 6 (*Continued*)

Sl No.	**Ref No.**	**Type of Task/Activity Area**	$\bar{E}_{m}$ lx	U_{o}	R_{a}	R_{UGL}	$\bar{E}_{m,z}$ lx	$\bar{E}_{m,wall}$ lx	$\bar{E}_{m,ceiling}$ lx
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	53.6	Fully enclosed passenger subways (underpasses): Large number of passengers	150-200-300	0.50	80	–	–	–	–
	53.7	Stairs, escalators: Small number of passengers	30-50-75	0.30	80	–	–	–	–
	53.8	Stairs, escalators: Medium number of passengers	75-100-150	0.40	80	–	–	–	–
	53.9	Stairs, escalators: Large number of passengers	150-200-300	0.50	80	–	–	–	–
	53.10	Ticket hall and concourse	150-200-300	0.50	80	28	75	–	–
	53.11	Ticket counters and luggage offices	200-300-500	0.50	80	19	100	75	50
	53.12	Waiting rooms	150-200-300	0.40	80	22	75	–	–
	53.13	Entrance halls, station halls	150-200-300	0.40	80	–	75	–	–
	53.14	Switch and plant rooms	150-200-300	0.50	80	28	50	–	–
	53.15	Railway control centre (area of dispatcher)	150-200-300	0.50	80	19	–	–	–
	53.16	Access tunnels	30-50-75	0.40	20	–	–	–	–
	53.17	Assembly work in maintenance sheds - Rough	150-200-300	0.40	80	–	–	–	–
	53.18	Assembly work in maintenance sheds - Medium	200-300-500	0.50	80	–	–	–	–
	53.19	Assembly work in maintenance sheds - Fine	300-500 -750	0.60	80	–	–	–	–
	53.20	Assembly work in maintenance sheds precision	500-750-1 000	0.70	80	–	–	–	–

Table 6 (*Concluded*)

Sl No.	Ref No.	Type of Task/Activity Area	$\bar{E}_m$ lx	U_o	R_a	R_{UGL}	$\bar{E}_{m,z}$ lx	$\bar{E}_{m,wall}$ lx	$\bar{E}_{m,ceiling}$ lx
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	53.21	Circulation areas for maintenance halls for railway vehicles (without additional vehicular traffic)	75-100-150	0.25	80	–	–	–	–
	53.22	Circulation areas for maintenance halls for railway vehicles (with additional vehicular traffic)	100-150-200	0.40	80	–	–	–	–

NOTES

1 For 33.1, illuminance level mentioned is vertical at bookshelves.

2 For 36.4, 36.7 and 36.23, illuminance level mentioned is vertical illuminance.

3 For 40.1 and 40.2, preferred colour temperature should be 4 000 K to 5 000 K.

4 For 41.1, preferred colour temperature should be 4 000 K to 5 000 K.

5 For 41.2 and 41.3, preferred colour temperature should be 4 000 K to 6 500 K.

6 For 46.1, 46.2, 46.3 and 46.4, additional local lighting to be provided to achieve 10 000 lux to 50 000 lux.

4.1.8 *Colour Rendering*

The colour appearance of light and its colour rendering capability are different aspects of the light sources. A faithful reproduction of an object colour depends on the colour rendering capability of the light source. In 1965, International Commission on Illumination (CIE) developed a quantitative method of assignment of colour rendering property and is denoted as Colour Rendering Index (CRI).

CRI is arrived at by a test by which a number of specified samples are tested under a standard or reference light source and the chromaticity coordinate are plotted on the IE triangle as given in Fig. 7 of Part 2 'Physics of Light, Section 3 Colour' of good practice [D-1(3)]. The same test is repeated under the source under test and corresponding chromaticity coordinate are plotted on the same plot. The difference between the position of each sample for test and standard source is measured to scale. The general colour rendering index (R_a) is obtained by the average value for eight samples {*see* Fig. 8 of Part 2 'Physics of Light, Section 3 Colour' of good practice [D-1(3)]}. For perfect agreement of colour, the R1 value should be 100. In general:

$$R_a = 1/(R1 + R2 + R3 + R4 + \ldots\ldots + R8)$$

The specific colour rendering index for an individual sample is given by:

$$R_i = 100 - 4.6\Delta E_i$$

where

ΔE_i = chromaticity shift on the CIE chromaticity diagram for each sample.

From the obtained value of R_a, as calculated above, the colour rendering shall be evaluated as mentioned in the following table:

Sl No. (1)	*Colour Rendering Evaluated* (2)	R_a (*General Colour Rendering Index*) (3)
i)	Excellent	$90 \leq R_a < 100$
ii)	Good	$80 \leq R_a < 90$
iii)	Moderate	$70 \leq R_a < 80$

4.1.9 For detailed information regarding principles of good lighting, reference may be made to good practice [D-1(4)].

4.2 Daylighting

While the sun is the primary source of natural light, the daylight received at the Earth's surface comprises two components: direct solar illuminance and sky illuminance (diffused light from the sky dome). For effective daylighting design in buildings, direct solar illuminance is typically excluded due to the potential for glare, excessive contrast and thermal discomfort (overheating). Glare from direct sun exposure in occupied zones should be mitigated through appropriate window orientation, sizing and external/internal shading strategies. Accordingly, daylighting strategies should emphasize sky illuminance, which provides diffused uniform light conducive to visual comfort and energy efficiency. By relying on sky illuminance, daylighting design achieves balanced illumination, reduces glare and cooling loads, and supports both visual comfort and sustainable building performance.

4.2.1 The relative amount of sky illuminance at a given point-in-time depends on the position of the sun defined by its altitude, which in turn, varies with the latitude of the locality, the day of the year and the time of the day, as indicated in Table 7.

4.2.2 The external available horizontal sky illuminance (diffuse illuminance) values which are exceeded for about 90 percent of the daytime working hours may be taken as outdoor design illuminance values for ensuring adequacy of daylighting design. The outdoor design sky illuminance varies for different climatic regions of the country. The recommended design sky illuminance values are 6 800 lux for cold climate, 8 000 lux for composite climate, 9 000 lux for warm humid climate, 9 000 lux for temperate climate and 10 500 lux for hot-dry climate. For integration with the artificial lighting during daytime working hours an increase of 500 lux in the recommended sky design illuminance for daylighting is suggested.

4.2.3 The daylight factor is dependent on the sky luminance distribution, which varies with atmospheric conditions. A clear design sky with its non-uniform distribution of luminance is adopted for the purposes of design in this section.

4.2.4 *Components of Daylight Factor*

Daylight factor is the sum of all the daylight reaching on an indoor reference point from the following sources:

a) Direct sky visible from the point;

b) External surfaces reflecting light directly (*see* Note 1) to the point; and

c) Internal surfaces reflecting and inter-reflecting light to the point.

NOTES

1 External surface reflection may be computed approximately only for points at the centre of the room, and for detailed analysis the procedures are complicated and these may be ignored for actual calculations.

2 Each of the three components, when expressed as a ratio or percent of the simultaneous external illuminance on the horizontal plane, defines respectively the sky component (SC), the external reflected component (ERC) and the internal reflected component (IRC) of the daylight factor.

4.2.4.1 The daylight factors on the horizontal plane only are usually taken, as the working plane in a room is generally horizontal; however, the factors in vertical planes should also be considered when specifying daylighting values for special cases, such as daylighting on classrooms, blackboards, pictures and paintings hung on walls.

4.2.5 *Sky Component* (*SC*)

Sky component for a window of any size is computed by the use of the appropriate Table 20, Table 21 and Table 22 of Annex B.

The recommended sky component level should be ensured generally on the working plane at the following positions:

a) At a distance of 3 m to 3.75 m from the window along the central line perpendicular to the window;

b) At the centre of the room if more appropriate; and

c) At fixed locations, such as school desks, black-boards and office tables.

The daylight area of the prescribed sky component should not normally be less than half the total area of the room.

4.2.5.1 The values obtainable from the tables are for rectangular, open unglazed windows, with no external obstructions. The values shall be corrected for the presence of window bars, glazing and external obstructions, if any. This assumes the maintenance of a regular cleaning schedule.

4.2.5.2 *Corrections for window bars*

The corrections for window bars shall be made by multiplying the values read from tables in Annex B by a factor equal to the ratio of the clear opening to the overall opening.

Table 7 Solar Altitudes (to the Nearest Degree) for Indian Latitudes

(*Clause* 4.2.1)

Sl No.	**Period of Year**	**22 June**						**21 March and 23 September**						**22 December**					
	Hours of Day (Sun or Solar) → Latitude ↓	07 00 17 00	08 00 16 00	09 00 15 00	10 00 14 00	11 00 13 00	12 00 -	07 00 17 00	08 00 16 00	09 00 15 00	10 00 14 00	11 00 13 00	12 00 -	07 00 17 00	08 00 16 00	09 00 15 00	10 00 14 00	11 00 13 00	12 00 -
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
i)	10ÁN	18	31	45	58	70	77	15	30	44	59	72	80	9	23	35	46	53	57
ii)	13ÁN	19	32	46	60	72	80	15	29	44	58	70	77	8	21	33	43	51	54
iii)	16ÁN	20	33	47	61	74	83	14	29	43	56	68	74	7	19	31	41	48	51
iv)	19ÁN	21	34	48	62	75	86	14	28	42	55	66	71	5	18	29	48	45	48
v)	22ÁN	22	35	49	62	75	89	14	28	41	53	64	68	4	16	27	36	42	45
vi)	25ÁN	23	36	49	63	76	88	13	27	40	52	61	65	3	14	25	34	39	42
vii)	28ÁN	23	36	49	63	76	86	13	26	39	50	59	62	1	13	23	31	37	39
viii)	31ÁN	24	37	50	62	75	82	13	25	37	48	56	56	–	11	21	28	34	36
ix)	34ÁN	25	37	49	62	73	79	12	25	36	46	53	56	–	9	18	26	31	33

4.2.5.3 *Correction for glazing*

Where windows are glazed, the sky components obtained from Annex B shall be reduced by 10 percent to 20 percent, provided the panes are of clear and clean glass. Where glass is of the frosted (ground) type, the sky components read from Annex A may be reduced by 15 percent to 30 percent. In case of tinted or reflective glass the reduction is about 50 percent. Higher indicated correction corresponds to larger windows and/or near reference points. In the case of openings and glazings which are not vertical, suitable correction shall be taken into account.

4.2.5.4 *Correction for external obstructions*

There is no separate correction, except that the values from tables in Annex B shall be read only for the unobstructed portions of the window.

4.2.6 *External Reflected Component* (*ERC*)

The value of the sky component corresponding to the portion of the window obstructed by the external obstructions may be found by the use of methods described in Annex C of good practice [D-1(5)].

These values when multiplied by the correction factors, corresponding to the mean elevation of obstruction from the point in question as given in Table 8, can be taken as the external reflected components for that point.

For method of calculating ERC, reference may be made to accepted standard {*see* examples given in Annex B of good practice [D-1(5)]}.

Table 8 Correction Factor for ERC

(*Clause* 4.2.6)

Sl No. (1)	Mean Angle of Elevation (2)	Correction Factor (3)
i)	5°	0.086
ii)	15°	0.086
iii)	25°	0.142
iv)	35°	0.192
v)	45°	0.226
vi)	55°	0.274
vii)	65°	0.304
viii)	75°	0.324
ix)	85°	0.334

4.2.7 *Internal Reflected Component* (*IRC*)

The component of daylight factor contributed by reflection from the inside surfaces varies directly as the window area and inversely as the total area of internal surfaces and depends on the reflection factor of the floor, wall and roof surfaces inside and of the ground outside. For rooms white-washed on walls and ceiling and windows of normal sizes, the IRC will have sizeable value even at points far away from the window. External obstructions, when present, will proportionately reduce IRC. Where accurate values of IRC are desired, the same may be done in accordance with the good practice [D-1(5)].

4.2.8 *General Principles of Openings to Afford Good Lighting*

4.2.8.1 Generally, while taller openings give greater penetrations, broader openings give better distribution of light. It is preferable that some area of the sky at an altitude of 20º to 25º should light up the working plane.

4.2.8.2 Broader openings may also be equally or more efficient, provided their sills are raised by 300 mm to 600 mm above the working plane.

NOTE — It is to be noted that while placing window with a high sill level might help natural lighting, this is likely to reduce ventilation at work levels. While designing the opening for ventilation also, a compromise may be made by providing the sill level about 150 mm below the head level of workers.

4.2.8.3 For a given penetration, a number of small openings properly positioned along the same, adjacent or opposite walls will give better distribution of illumination than a single large opening. The sky component at any point, due to a number of openings may be easily determined from the corresponding sky component contour charts appropriately superposed. The sum of the individual sky component for each opening at the point gives the overall component due to all the openings. The same charts may also facilitate easy drawing of sky component contours due to multiple openings.

4.2.8.4 Unilateral lighting from side openings will, in general, be unsatisfactory if the effective width of the room is more than 2 to 2.5 times the distance from the floor to the top of the opening. In such cases provision of light shelves is always advantageous.

4.2.8.5 Openings on two opposite sides will give greater uniformity of internal daylight illumination, especially when the room is 7 m or more across. They also minimize glare by illuminating the wall surrounding each of the opposing openings. Side openings on one side and clerestory openings on the opposite side may be provided where the situation so requires.

4.2.8.6 Cross-lighting with openings on adjacent walls tends to increase the diffused lighting within a room.

4.2.8.7 Openings in deep reveals tend to minimize glare effects.

4.2.8.8 Openings shall be provided with *Chajjahs*, louvers, baffles or other shading devices to exclude, as far as possible, direct sunlight entering the room. *Chajjahs*, louvers, etc, reduce the effective height of the opening for which due allowance shall be made. Broad and low openings are, in general, much easier to shade against sunlight entry. Direct sunlight, when it enters, increases the inside illuminance very considerably. Glare will result if it falls on walls at low angles, more so than when it falls on floors, especially when the floors are dark coloured or less reflective.

4.2.8.9 Light control media, such as translucent glass panes (opal or matt) surfaced by grinding, etching or sandblasting, configurated or corrugated glass, certain types of prismatic glass, tinted glass and glass blasts are often used. They should be provided, either fixed or movable outside or inside, especially in the upper portions of the openings. The lower portions are usually left clear to afford desirable view. The chief purpose of such fixtures is to reflect part of the light on to the roof and thereby increase the diffuse lighting within, light up the farther areas in the room and thereby produce a more uniform illumination throughout. They will also prevent the opening causing serious glare discomfort to the occupants but will provide some glare when illuminated by direct sunlight.

4.2.9 *Availability of Daylight in Multistoreyed Block*

Proper planning and layout of building can add appreciably to daylighting illumination inside. Certain dispositions of building masses offer much less mutual obstruction to daylight than others and have a significant relevance, especially when intensive site planning is undertaken. As guidance, the relative availability of daylight in multi-storeyed blocks (up to 4 storeys) of different relative orientations may be taken as given in Table 9.

4.2.10 For specified requirements for daylighting of special occupancies and areas, reference may be made to good practice [D-1(6)]. For using annual climate-based daylight assessment of design, a reference may be made to specialist literature (*see* Note). It also presents a computer simulation-based approach for assessment of adequacy of daylight in indoor spaces.

NOTE — The specialist literature may be Chapter 5 of Energy Conservation and Sustainable Building Code 2024.

Table 9 Relative Availability of Daylight on the Window Plane at Ground Level in Four-Storeyed Building Blocks (Clear Design-Sky as Basis, Daylight Availability Taken as Unity on an Unobstructed Facade, Values are for the Centre of the Blocks)

(*Clause* 4.2.9)

Sl No.	Distance of Separation Between Blocks	Infinitely Long Parallel Blocks	Parallel Blocks Facing Each Other (Length = 2 × Height)	Parallel Blocks facing Gaps Between Opposite Blocks (Length = 2 × Height)
(1)	(2)	(3)	(4)	(5)
i)	0.5 Ht	0.15	0.15	0.25
ii)	1.0 Ht	0.30	0.32	0.38
iii)	1.5 Ht	0.40	0.50	0.55
iv)	2.0 Ht	0.50	0.60	0.68

NOTE — Ht = Height of the building.

4.3 Artificial Lighting

4.3.1 Artificial lighting may have to be provided,

a) Where the recommended illumination levels have to be obtained by artificial lighting only;

b) To supplement daylighting when the level of illumination falls below the recommended value; and

c) Where visual task may demand a higher level of illumination.

4.3.2 *Artificial Lighting Design for Interiors*

For general lighting purposes, the recommended practice is to design for a level of illumination on the working plane on the basis of the recommended levels for visual tasks given in Table 6 by a method called ‘Lumen method’. In order to make the necessary detailed calculations concerning the type and quantity of lighting equipment necessary, advance information on the surface reflectances of walls, ceilings and floors is required. Similarly, calculations concerning the brightness ratio in the interior call for details of the interior décor and furnishing. Stepwise guidance regarding designing the interior lighting systems for a building using the ‘Lumen method’ is given in **4.3.2.1** to **4.3.2.4**.

4.3.2.1 *Determination of the illumination level*

Recommended value of illumination shall be taken from Table 6, depending upon the type of work to be carried out in the location in question and the visual tasks involved.

4.3.2.2 *Selection of the light sources and luminaires*

The selection of light sources and luminaires depends on the choice of lighting system, namely, general lighting, directional lighting and localized or local lighting.

4.3.2.3 *Determination of the luminous flux*

a) The luminous flux (ϕ) reaching the working plane depends upon the following:

   1) Lumen output of the lamps;

   2) Type of luminaire;

   3) Proportion of the room (room index) (k_r);

   4) Reflectance of internal surfaces of the room;

   5) Depreciation in the lumen output of the lamps after burning their rated life; and

6) Depreciation due to dirt collection on luminaires and room surface.

b) Coefficient of utilization or utilization factor;

1) The compilation of tables for the utilization factor requires a considerable amount of calculations, especially if these tables have to cover a wide range of lighting practices. For every luminaire, the exact light distribution has to be measured in the laboratory and their efficiencies have to be calculated and measured exactly. These measurements comprise,

i) the luminous flux radiated by the luminaires directly to the measuring surface;

ii) the luminous flux reflected and re-reflected by the ceiling and the walls to the measuring surface; and

iii) the inter-reflections between the ceiling and wall which result in the measuring surface receiving additional luminous flux.

All these measurements have to be made for different reflection factors of the ceiling and the walls for all necessary room indices. These tables have also to indicate the maintenance factor to be taken for the luminous flux depreciation throughout the life of an installation due to ageing of the lamp and owing to the deposition of dirt on the lamps and luminaires and room surfaces.

2) The values of the reflection factor of the ceiling and of the wall are as follows:

White and very light colours	0.7
Light colours	0.5
Middle tints	0.3
Dark colours	0.1

For the walls this should be estimated, taking into account the influence of the windows without curtains, shelves, *Almirahs* and doors with different colours, etc.

c) Calculation for determining the luminous flux {see Table 22 of accepted standard [D-1(7)]}

$$E_{\mathrm{av}} = \frac{\mu . \phi}{A}$$

or, $\phi = \frac{E_{\mathrm{a}} A}{\mu}$, for new condition, and

$\phi = \frac{E\mathrm{av}.A}{\mu . d}$, for working condition.

where

E_{av} = average illumination level required on the working plane, in lux;

μ = utilization factor in new conditions;

ϕ = total luminous flux of the light sources installed in the room, in lumens;

A = area of the working plane, in m^2; and

d = maintenance factor.

In practice, it is easier to calculate straightaway the number of lamps or luminaires from:

$$N_{lamp} = \frac{E_{av} . A}{\mu . d . \phi_{lamp}}$$

$$N_{luminaries} = \frac{E_{av} . A}{\mu . d . \phi_{luminaries}}$$

where

N_{lamp} = total number of lamps;

ϕ_{lamp} = luminous flux of each lamp, in lumens;

$N_{\text{luminaires}}$ = total number of luminaires; and

$\phi_{\text{luminaries}}$ = luminous flux of each luminaire, in lumens.

4.3.2.4 *Arrangement of the luminaires*

This is done to achieve better uniformly distributed illumination. The location of the luminaires has an important effect on the utilization factor:

a) In general, luminaires are spaced 'x' metre apart in either direction, while the distance of the end luminaire from the wall is '0.5 x' metre. The distance 'x' is more or less equal to the mounting height 'H_m' between the luminaire and the working plane. The utilization factor tables are calculated for this arrangement of luminaires {*see* Table 22 of the accepted standard [D-1(7)]}.

b) For small rooms where the room index (k_r) is less than 1, the distance 'x' should always be less than H_m, since otherwise luminaires cannot be properly located. In most cases of such rooms, four or two luminaires are placed for good general lighting. If, however, in such rooms only one luminaire is installed in the middle, higher utilization factors are obtained, but the uniformity of distribution is poor. For such cases, references should be made to the additional tables for k_r = 0.6 to 1.25 for luminaires located centrally.

4.3.3 *Artificial Lighting to Supplement Daylighting*

4.3.3.1 The need for general supplementary artificial lighting arises due to diminution of daylighting beyond design hours, that is, for solar altitude below 15° or when dark cloudy conditions occur.

4.3.3.2 The need may also arise for providing artificial lighting during the day in the innermost parts of the building which cannot be adequately provided with daylighting, or when the outside windows are not of adequate size or when there are unavoidable external obstructions to the incoming daylighting.

4.3.3.3 The need for supplementary lighting during the day arises, particularly when the daylighting on the working plane falls below 100 lux and the surrounding luminance drops below 19 cd/m^2.

4.3.3.4 The requirement of supplementary artificial lighting increases with the decrease in daylighting availability. Therefore, conditions near sunset or sunrise or equivalent conditions due to clouds or obstructions, etc, represent the worst conditions when the supplementary lighting is most needed.

4.3.3.5 The requirement of supplementary artificial lighting when daylighting availability becomes poor may be determined from Fig. 3 for an assumed ceiling height of 3.0 m, depending upon floor area, fenestration percentage and room surface reflectance. Cool daylight fluorescent tubes are recommended with semi-direct luminaires. To ensure a good distribution of illumination, the mounting height should be between 1.5 m and 2.0 m above the work plane for a separation of 2.0 m to 3.0 m between the luminaires. Also, the number of lamps should preferably be more in the rear half of the room than in the vicinity of windows. The following steps may be followed for using Fig. 3 for determining the number of fluorescent tubes required for supplementary daylighting:

a) Determine fenestration percentage of the floor area, that is:

$$\frac{Window\ area}{Floor\ area} \times 100$$

b) In Fig. 3, refer to the curve corresponding to the percent fenestration determined above and the set of reflectances of ceiling, walls and floor actually provided; and

c) For the referred curve of Fig. 3 read, along the ordinate, the number of 40 W fluorescent tubes required, corresponding to the given floor area on the abscissa.

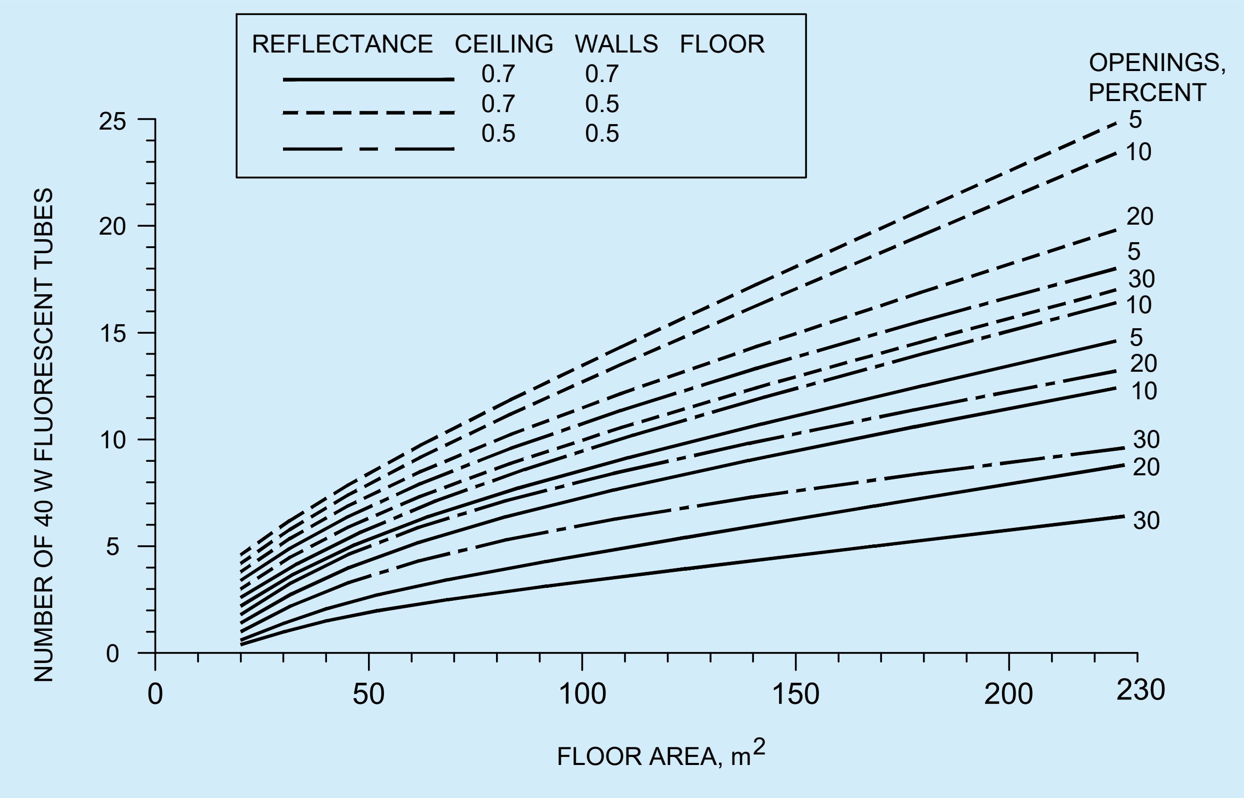

FIG. 3 SUPPLEMENTARY ARTIFICIAL LIGHTING FOR 40 W FLUORESCENT TUBES

4.3.4 For detailed information on the design aspects and principles of artificial lighting, reference may be made to good practice [D-1(4)].

4.3.5 For specific requirements for lighting of special occupancies and areas, reference may be made to good practice [D-1(8)].

4.3.6 Electrical installation aspect for artificial lighting should be in accordance with Part D 'Building Services, Section 2 Electrical and Allied Installations' of this NBCS.

4.4 Energy Conservation in Lighting

4.4.1 A substantial portion of the energy consumed on lighting may be saved by utilization of daylight and rational design of supplementary artificial lights.

4.4.2 Daytime use of artificial lights may be minimized by proper design of windows for adequate daylight indoors. Daylighting design should be according to 4.2.

4.4.3 Fenestration expressed as percentage of floor area required for satisfactory visual performance of a few tasks for different separation to height (*S*/*H*) ratio of external obstructions such as opposite buildings may be obtained from the design nomogram (*see* Fig. 4). The obstructions at a distance of three times their height or more (*S*/*H* > 3) from a window facade are not significant and a window facing such an obstruction may be regarded as a case of unobstructed window.

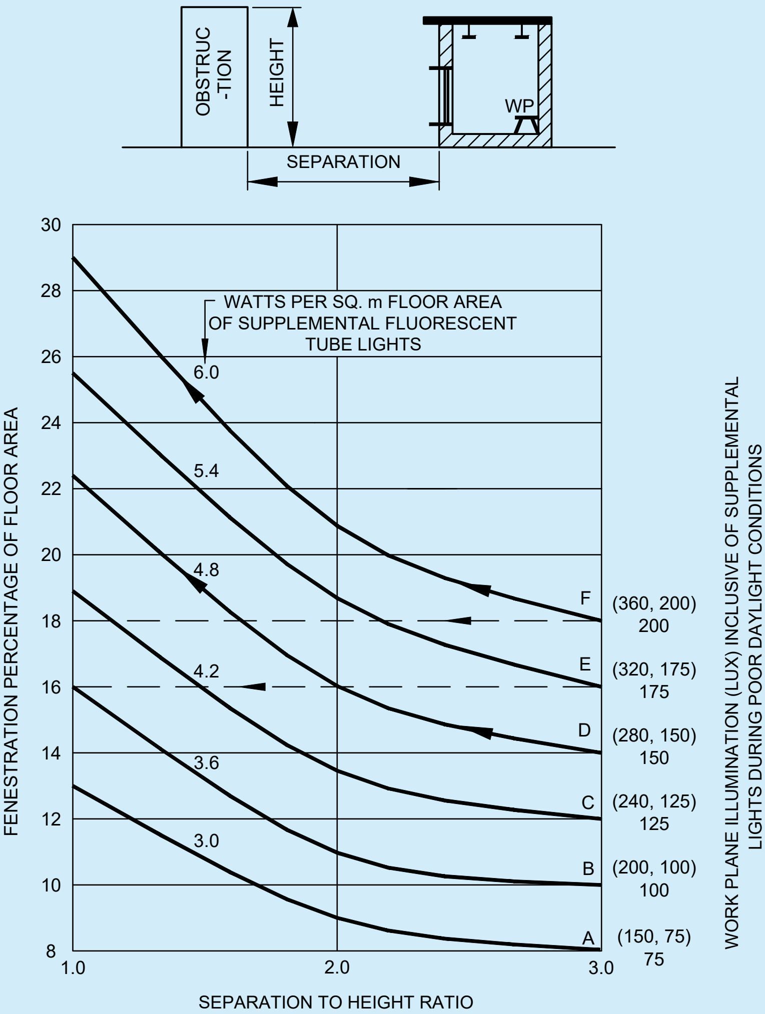

FIG. 4 NOMOGRAPH FOR DAYLIGHTING AND SUPPLEMENTAL LIGHTING DESIGN OF BUILDINGS

4.4.3.1 The nomogram consists of horizontal lines indicating fenestration percentage of floor area and vertical lines indicating the separation to height ratio of external obstructions such as opposite buildings. Any vertical line for separation to height ratio other than already shown in the nomogram (1.0, 2.0 and 3.0) may be drawn by designer, if required. For cases where there is no obstruction, the ordinate corresponding to the value 3.0 may be used. The value of percentage fenestration and separation to height ratio are marked on left hand ordinate and abscissa respectively. The illumination levels are marked on the right hand ordinate. The values given within brackets are the illumination levels on the work plane at centre and rear of the room. The wattage of fluorescent tubes required per square metre of the floor area for different illumination levels is shown on each curve.

4.4.3.2 Following assumptions have been made in the construction of the nomogram:

a) An average interior finish with ceiling white, walls off white and floor grey has been assumed;

b) Ceiling height of 3 m, room depths up to 10 m and floor area between 30 m^2 and 50 m^2 have been assumed. For floor area beyond 50 m^2 and less than 30 m^2, the values of percent fenestration as well as wattage/m^2 should be multiplied by a factor of 0.85 and 1.15, respectively;

c) It is assumed that windows are of metallic sashes with louvers of width up to 600 mm or a *Chhajja* (balcony projection) at ceiling level of width up to 2.0 m. For wooden sashes, the window area should be increased by a factor of about 1.1; and

d) Luminaires emanating more light in the downward direction than upward direction (such as reflectors with or without diffusing plastics) and mounted at a height of 1.5 m to 2.0 m above the work plane have been considered.

4.4.3.3 *Method of use*

The following steps shall be followed for the use of nomogram:

a) *Step* 1 — Decide the desired illumination level depending upon the task illumination requirement in the proposed room and read the value of watt per square metre on the curve corresponding to the required illumination level;

b) *Step* 2 — Fix the vertical line corresponding to the given separation to height ratio of opposite buildings on the abscissa. From the point of intersection of this vertical line and the above curve move along horizontal and read the value of fenestration percent on the left-hand ordinate; and

c) *Step* 3 — If the floor area is greater than 50 m^2 or if it is less than 30 m^2, the value of watt/m^2 as well as fenestration percent may be easily determined for adequate daylighting and supplemental artificial lighting for design purposes. However, if the fenestration provided is less than the required value, the wattage of supplementary artificial lights should be increased proportionately to make up for the deficiency of natural illumination.

4.4.4 For good distribution of day light on the working plane in a room, window height, window width and height of sill should be chosen in accordance with the following recommendations:

a) In office buildings windows of height 1.2 m or more in the centre of a bay with sill level at 1.0 to 1.2 m above floor and in residential buildings windows of height 1.0 m to 1.1 m with sill height as 0.9 m to 0.7 m above floor are recommended for good distribution of daylight indoors. Window width can accordingly be adjusted depending upon the required fenestration percentage of the floor area;

b) If the room depth is more than 10 m, windows should be provided on opposite sides for bilateral lighting; and

c) It is desirable to have a white finish for ceiling and off white (light colour) to white for walls. There is about 7 percent improvement in lighting levels in changing the finish of walls from moderate to white.

4.4.5 For good distribution and integration of daylight with artificial lights the following guidelines are recommended:

a) Employ cool daylight fluorescent tubes for supplementary artificial lighting;

b) Distribute luminaries with a separation of 2 m to 3 m in each bay of 3 m to 4 m width; and

c) Provide more supplementary lights such as twin tube luminaries in work areas where daylight is expected to be poor for example in the rear region of a room having single window and in the central region of a room having windows on opposite walls. In the vicinity of windows only single tube luminaries should be provided.

4.4.6 *Artificial Lighting*

Energy conservation in lighting is affected by reducing wastage and using energy effective lamps and luminaires without sacrificing lighting quality. Measures to be followed comprise utilization of daylight, energy effective artificial lighting design by providing required illumination where needed, turning off artificial lights when not needed, maintaining lighter finishes of ceiling, walls and furnishings, and implementing periodic schedule for cleaning of luminaires and group replacement of lamps at suitable intervals. Choice of light sources with higher luminous efficacy and luminaires with appropriate light distribution is the most effective means of energy saving in lighting. However, choice of light sources also depends on the other lighting quality parameters like colour rendering index and colour temperature or appearance. The choice of light sources type also depends on the desired mounting height in the interiors.

4.4.6.1 *Efficient artificial light sources and luminaires*

Luminous efficacies of some of the lamps used in lighting of buildings are given in Table 10 along with average life in burning hours, colour rendering index and colour temperature. Given the high luminous efficacy that can be achieved with most LED lighting, energy efficiency in lighting can be achieved via space appropriate zoning, identifying the application type (task versus ambient) and careful consideration of lighting quality requirements.

Table 10 Luminous Efficacy, Life, Lumen Maintenance and Colour Rendition of Light Sources

(*Clause* 4.4.6.1)

Sl No. (1)	**Light Source** (2)	**Wattage Range** W (3)	**Efficacy** Lm/W (4)	**Average Life** h (5)	**Lumen Maintenance** (6)	**Colour Rendition** (7)
i)	Incandescent lamps	15 to 200	12 to 20	500 to 1 000	Fair to good	Very good
ii)	Tungsten halogen	300 to 1 500	20 to 27	200 to 2 000	Good to very good	Very good
iii)	Slim line fluorescent	18 to 58	57 to 67	5 000	Fair to good	Good
iv)	High pressure mercury vapour lamps	60 to 1 000	50 to 65	5 000	Very low to fair	Federate
v)	Blended-light lamps	160 to 250	20 to 30	5 000	Low to fair	Federate
vi)	High pressure sodium vapour lamps	50 to 1 000	90 to 125	10 000 to 15 000	Fair to good	Low to good
vii)	Metal halide lamps	35 to 2 000	80 to 95	4 000 to 10 000	Very low	Very good
viii)	Low pressure sodium	10 to 180	100 to 200	10 000 to 20 000	Good to very good	Poor
ix)	LED	0.5 to 2.0	60 to 100	10 000	Very good	Good for white LED

NOTES

1 This includes lamps and wattages currently in use in buildings in India.

2 Luminous efficacy varies with the wattage of the lamp.

3 Average life values are from available Indian Standards. Where Indian Standard is not available, values given are only indicative.

4 For exact values, it is advisable to contact manufacturers.

4.4.6.2 For the same lumen output, it is possible to save 50 percent to 70 percent energy if CFL lamps are replaced with induction lighting, and 40 percent to 60 percent if replaced with LED lamps. Similar energy effective solutions are to be chosen for every application area.

Similarly, with white fluorescent tubes recommended for corridors and staircases, the electrical consumption reduces to 1/4.5 of the energy consumption with incandescent lamps.

4.4.6.3 Efficient luminaire also plays an important role in energy conservation in lighting. The choice of a luminaire should be such that it is efficient not only initially but also throughout its life. Following luminaries are recommended for different locations:

a) For offices semi-direct type of luminaries are recommended so that both the work plane illumination and surround luminance can be effectively enhanced;

b) For corridors and stair cases direct type of luminaries with wide spread of light distributions are recommended; and

c) In residential buildings, glare free wide spread of light distributions are recommended.

4.4.7 *Cleaning Schedule for Window Panes and Luminaires*

Adequate schedule for cleaning of window panes and luminaries will result in significant advantage of enhanced daylight and lumen output from luminaries. Frequent cleaning of windows will tend to reduce the duration over which artificial lights will be used and minimize the wastage of energy. Depending upon the location of the building a cleaning interval of three to six months is recommended for cleaning of luminaires.

4.4.8 *Photocontrols for Artificial Lights*

There is a considerable wastage of electrical energy in lighting of buildings due to carelessness in switching off lights even when sufficient daylight is available indoors. In offices and commercial buildings, occupants may switch on lights in the morning and keep them on throughout the day. When sufficient daylight is available inside, suitable photocontrols can be employed to switch off the artificial lights and thus prevent the wastage of energy.

The photocontrol should have the following features:

a) An integrated photocontrol system continually measures the amount of visible light under the lighting fixture and maintains the lux levels as referred in Table 6;

b) An integrated photocontrol system should maintain six daylighting scenarios that can be adjusted by the user namely; daytime occupied, daytime unoccupied, sunset occupied, sunset unoccupied, night time occupied and night time unoccupied;

c) The photocontrol sensor should have a 60° cone of reference to measure the amount of light on the work surface;

d) Photocontrol, along with supporting lighting based on influx of natural light, should have controls for intelligent 'occupancy based shut-off' system to control which areas need lighting at any moment; and

e) The controls should maintain a decent standard of 'ease of use' for occupants as well as building staff.

4.4.9 *Solar Photovoltaic Systems* (*SPV*)

Solar photovoltaic system enables direct conversion of sunlight into electricity and is viable option for lighting purpose in remote non grid areas. The common SPV lighting systems are:

a) Solar lantern;

b) Fixed type solar home lighting system; and

c) Street lighting system.

4.4.9.1 SPV lighting system should preferably be provided with CFL for energy efficiency.

4.4.9.2 Invertors used in buildings for supplying electricity during the power cut period should be charged through SPV system.

4.4.9.3 Regular maintenance of SPV system is necessary for its satisfactory functioning.

4.4.10 Lighting shelves and light pipes may be explored for utilization and integration in the lighting design.

4.5 Circadian Lighting

Light is fundamental to human health and well-being, extending beyond its role in vision. It is the principal regulator of our circadian rhythm, profoundly influencing visual experience, physiological processes and emotional state. Thus, human-centric lighting, designed for human health and well-being, is essential.

Human physiology is evolved under natural sunlight. Ideally, we would experience abundant daylight exposure, gradually decreasing in the evening, with minimal light at night. Modern indoor lifestyles disrupt this natural rhythm. Optimizing indoor environments to emulate this 24 h light-dark cycle can significantly improve sleep quality and promote rejuvenation, with the added benefit of naturally sustained energy.

The influence of light on human health stems from its role in regulating the internal clock of the body. The circadian rhythm governs diverse physiological functions, from sleep-wake cycles and mood to overall health. This system is orchestrated by the suprachiasmatic nucleus (SCN) in the brain, which relies on consistent light-dark patterns, reflecting our attunement to the diurnal and seasonal rhythms of daylight availability.

The melanopic daylight efficacy ratio (melanopic DER) and melanopic equivalent daylight illuminance (melanopic EDI) provide metrics for assessing light's efficacy in supporting our biological rhythms.

In practice, morning light acts as a critical entraining cue, signalling the body to transition to a state of wakefulness and activity. Exposure to bright light during the day further strengthens the circadian rhythm, which plays a vital role in regulating sleep-wake cycles, daytime engagement, and mood. Conversely, darkness at night-time is essential for promoting restorative sleep, a process crucial for overall health and well-being.

NOTE — The early 2 000 s saw the discovery of specialized retinal light-sensitive cells, peaking at around 480 nm (cyan), leading to the concepts of 'biologically active' or 'circadian light'.

4.5.1 *Need for Supplementary Artificial Circadian Lighting*

Artificial circadian lighting is advised in spaces where permanent day-active occupants spend more than 4 h between sunrise and sunset and do not have a direct line of sight to any external windows from their general working area.

In spaces where artificial circadian lighting cannot be incorporated due to functional considerations (for example, museums, movie theatres), break rooms for day-active permanent occupants may be equipped with circadian lighting.

4.5.2 *Characteristics of Supplementary Artificial Circadian Lighting*

In spaces where supplementary artificial circadian lighting is implemented, it should have the following features:

a) The lighting system shall include dynamic controls that enable gradual changes in light intensity and colour temperature to mimic natural daylight cycles; and

b) Lux levels (vertical illuminance at the occupant positions) shall be modulated based on time of day to ensure sufficient light exposure during the day and reduced exposure in the evening time following the best-practice for circadian lighting design.

4.6 Outdoor Lighting

Outdoor lighting plays a crucial role in ensuring safety, security and functionality in various environments, while contributing to energy conservation and minimizing environmental impacts. To achieve these objectives, outdoor lighting should be designed and managed in accordance with the good practice [D-1(3)], focussing on energy efficiency and minimizing light pollution.

4.6.1 *Lighting Design and Light Zones*

Outdoor lighting designs should adhere to energy efficiency measures and address the requirements of different light zones, as per the good practice [D-1(3)]. The following guidelines should be considered for the design in various zone:

a) *Urban zones* — Lighting intensity should be optimized for high activity areas, using energy-efficient technologies such as LEDs and lighting controls to ensure energy savings;

b) *Suburban zones* — Lighting should be designed for moderate activity areas with an emphasis on reducing unnecessary energy consumption, utilizing dimming controls or motion sensors; and

c) *Rural zones* — Lighting should be kept minimal, ensuring safety while limiting light pollution. Energy-efficient, low-intensity lighting should be implemented.

These zones should serve as guidelines and lighting levels should align with the specific needs of the location while minimizing energy consumption as required by specialist literature.

NOTE — The specialist literature may be Energy Conservation and Sustainable Building Code 2024.

4.6.2 *Energy Efficiency and Light Pollution Mitigation*

To comply with the good practice [D-1(3)] and reduce light pollution, outdoor lighting systems should incorporate the following:

a) *Energy-efficient light sources* — Use of LEDs or other high-efficiency light sources with appropriate lumen output to reduce energy consumption;

b) *Fully shielded and full cut-off fixtures* — These should be implemented to prevent upward light emission and sky glow, focusing light where needed to minimize spill over and improve energy use;

c) *Lighting controls* — The good practice [D-1(3)] compliant controls, such as timers, dimmers, and motion sensors, should be employed to reduce lighting during periods of low activity, contributing to energy savings; and

d) *Luminaire efficacy* — All outdoor lighting luminaires should meet the minimum efficacy requirements as specified in the good practice [D-1(3)] for energy conservation and reduced power consumption.

4.6.3 *Effects of Light Pollution on Life*

Excessive outdoor lighting, if not properly controlled, may have adverse effects on human, animal and plant life:

a) *Human health* — Exposure to artificial light at night can disrupt circadian rhythms, leading to potential health risks such as sleep disorders and increased stress. Lighting design should prioritize human well-being by controlling glare and unnecessary brightness;

b) *Animal life* — Wildlife, particularly nocturnal species, may experience disruptions in natural behaviours, such as feeding and mating, due to poorly managed artificial lighting. The good practice [D-1(3)] compliant lighting should minimize impact on ecosystems; and

c) *Plant life* — Artificial lighting may affect plant growth cycles, leading to ecological imbalance. Properly designed lighting should reduce this risk by controlling light spill and adhering to the lighting recommendations of good practice [D-1(3)].

5 VENTILATION

5.1 General

Natural ventilation of buildings is required to supply outdoor air for the respiration of occupants, to remove any products of combustion or other contaminants in the air and to provide such thermal environments as will assist in the maintenance of heat balance of the body in order to prevent discomfort and injury to the health of the occupants. The natural ventilation through building envelope elements such as operable windows, skylights and ventilators help maintain the desired quality of air and thermal comfort conditions when outdoor air and thermal environments are conducive to the cause.

5.2 Design Considerations

5.2.1 *Respiration*

Supply of fresh air to provide oxygen for the human body for elimination of waste products and to maintain carbon dioxide concentration in the air within safe limits rarely calls for special attention as enough outside air for this purpose normally enters the areas of occupancy through crevices and other openings.

In normal habitable rooms devoid of smoke generating source, the content of carbon dioxide in air rarely exceeds 0.5 percent to 1 percent and is, therefore, incapable of producing any ill effect. The amount of air required to keep the concentration down to 1 percent is very small. The change in oxygen content is also too small under normal conditions to have any ill effects; the oxygen content may vary quite appreciably without noticeable effect, if the carbon dioxide concentration is unchanged.

5.2.2 *Vitiation by Body Odours*

Where no products of combustion or other contaminants are to be removed from air, the amount of fresh air required for dilution of inside air to prevent vitiation of air by body odours, depends on the air space available per person and the degree of physical activity; the amount of air decreases as the air space available per person increases, and it may vary from 20 m^3 to 30 m^3 per person per hour. In rooms occupied by only a small number of persons such an air change will automatically be attained in cool weather by normal leakage around windows and other openings and this may easily be secured in warm weather by keeping the openings open.

No standards have been laid down under the *Factories Act*, 1948 as regards the amount of fresh air required per worker or the number of air changes per hour. Section 16 of the *Factories Act*, 1948 relating to over-crowding requires that at least 14 m^3 to 16 m^3 of space shall be provided for every worker and for the purpose of that section no account shall be taken of any space in a work room which is more than 4.25 m above the floor level.

NOTE — Vitiation of the atmosphere can also occur in factories by odours given off due to contaminants of the product itself, say for example, from tobacco processing in a '*Beedi*' factory. Here the ventilation will have to be augmented to keep odours within unobjectionable levels.

5.2.2.1 *Recommended values for air changes*

The standards of general ventilation are recommended/based on maintenance of required oxygen, carbon dioxide and other air quality levels and for the control of body odours when no products of combustion or other contaminants are present in the air; the values of air changes should be as follows:

Sl No. (1)	*Application* (2)	*Air Change per Hour* (3)
i)	Assembly rooms	4 to 8
ii)	Bakeries	20 to 30
iii)	Banks/building societies	4 to 8
iv)	Bathrooms	6 to 10
v)	Bedrooms	2 to 4
vi)	Billiard rooms	6 to 8
vii)	Boiler rooms	*See* Note 2
viii)	Cafes and coffee bars	10 to 12
ix)	Canteens	8 to 12
x)	Cellars	3 to 10
xi)	Changing rooms	6 to 10
xii)	Churches	1 to 3
xiii)	Cinemas and theatres	10 to 15
xiv)	Club rooms	12, *Min*
xv)	Compressor rooms	10 to 12
xvi)	Conference rooms	8 to 12
xvii)	Corridors	5 to 10
xviii)	Dairies	8 to 12
xix)	Dance halls	12, *Min*
xx)	Dye works	20 to 30
xxi)	Electroplating shops	10 to 12
xxii)	Engine rooms/DG Rooms/GG Rooms	*See* Note 2
xxiii)	Entrance halls	3 to 5
xxiv)	Factories and work shops	8 to 10
xxv)	Foundries	15 to 30
xxvi)	Garages	6 to 8
xxvii)	Glass houses	25 to 60
xxviii)	Gymnasium	6, *Min*

Table (*Concluded*)

Sl No. (1)	*Application* (2)	*Air Change per Hour* (3)
xxix)	Hair dressing saloon	10 to 15
xxx)	Hospitals sterilising	15 to 25
xxxi)	Hospital wards	6 to 8
xxxii)	Hospital domestic	15 to 20
xxxiii)	Laboratories	6 to 15
xxxiv)	Launderettes	10 to 15
xxxv)	Laundries	10 to 30
xxxvi)	Lavatories	6 to 15
xxxvii)	Lecture theatres	5 to 8
xxxviii)	Libraries	3 to 5
xxxix)	Lift cars	20, *Min*
xl)	Living rooms	3 to 6
xli)	Mushroom houses	6 to 10
xlii)	Offices	6 to 10
xliii)	Paint shops (not cellulose)	10 to 20
xliv)	Photo and X-ray dark room	10 to 15
xlv)	Public house bars	12, *Min*
xlvi)	Recording control rooms	15 to 25
xlvii)	Recording studios	10 to 12
xlviii)	Restaurants	8 to 12
xlix)	Schoolrooms	5 to 7
l)	Shops and supermarkets	8 to 15
li)	Shower baths	15 to 20
lii)	Stores and warehouses	3 to 6
liii)	STP rooms	30, *Min*
liv)	Squash courts	4, *Min*
lv)	Swimming baths	10 to 15
lvi)	Toilets	6 to 10
lvii)	Underground vehicle parking	6, *Min*
lviii)	Utility rooms	15 to 30
lix)	Welding shops	15 to 30

NOTES

1 The ventilation rates may be increased by 50 percent where heavy smoking occurs or if the room is below the ground.

2 The ventilation rate shall be as per **14.2.1** of Part D 'Building Services, Section 3 Air Conditioning, Heating and Mechanical Ventilation' of this NBCS.

5.2.3 *Heat Balance of Body*

Especially in hot weather, when the thermal environment inside the room is worsened by the heat given off by machinery, occupants and other sources, the prime need for ventilation is to provide such a thermal environment as will assist in the maintenance of heat balance of the body in order to prevent discomfort and injury to health. Excess of heat either from increased metabolism due to physical activity of persons or gains from a hot environment has to be offset to maintain normal body temperature (approximately 37 °C). Heat exchange of the human body with respect to the surroundings is determined by the temperature and humidity gradient between the skin and the surroundings and other factors, such as the age of person, clothing, etc and the latter depends on air temperature (dry bulb temperature), relative humidity, radiation from the solid surroundings and rate of air movement. The volume of outside air to be circulated through the room is, therefore, governed by the physical considerations of controlling the temperature, air distribution or air movement. Air movement and air distribution may, however, be achieved by recirculation of the inside air rather than bringing in all outside air. However, fresh air supply or the circulated air will reduce heat stress by dissipating heat from the body by evaporation of the sweat, particularly when the relative humidity is high and the air temperature is near body temperature.

5.2.3.1 *Indices of thermal comfort*

Thermal comfort is that condition of a thermal environment under which a person can maintain a body heat balance at normal body temperature and without perceptible sweating. Limits of comfort vary considerably according to studies carried out in India and abroad.

The thermal indices which find applications for Indian climate are as follows:

- a) Effective temperature (ET);
- b) Tropical summer index (TSI); and
- c) Operative temperature based adaptive thermal comfort.

5.2.3.1.1 *Effective temperature* (*ET*)

Effective temperature is defined as the temperature of still, saturated air which has the same general effect upon comfort as the atmosphere under investigation. Combinations of temperature, humidity and wind velocity producing the same thermal sensation in an individual are taken to have the same effective temperature.

Initially two scales were developed, one of which referred to men stripped to the waist and called the basic scale. The other applies to men fully clad in indoor clothing and called the normal scale of effective temperature. Bedfort (1946) proposed the use of globe temperature reading instead of the air temperature reading to make allowance for the radiant heat. This scale is known as the corrected effective temperature (CET) scale. No allowance, however, was made for the different rates of energy expenditure. The scale was compiled only for men either seated or engaged in light activity.

Figure 5 represents the corrected effective temperature nomogram. The CET can be obtained by connecting the appropriate points representing the dry bulb (or globe) and wet bulb temperatures and reading the CET value at the intersection of this line with the relevant air velocity curve from the family of curves for various air velocities running diagonally upwards from left to right.

The effective temperature scale may be considered to be reasonably accurate in warm climates where the heat stress is not high but it may be misleading at high levels of heat stress. There appears to be an inherent error in this scale if used as an index of physiological strain, the error increasing with the severity of the environmental conditions. For low and moderate degrees of heat stress, the effective temperature scales appear to assess climatic heat stress with an accuracy which is acceptable for most practical purposes.

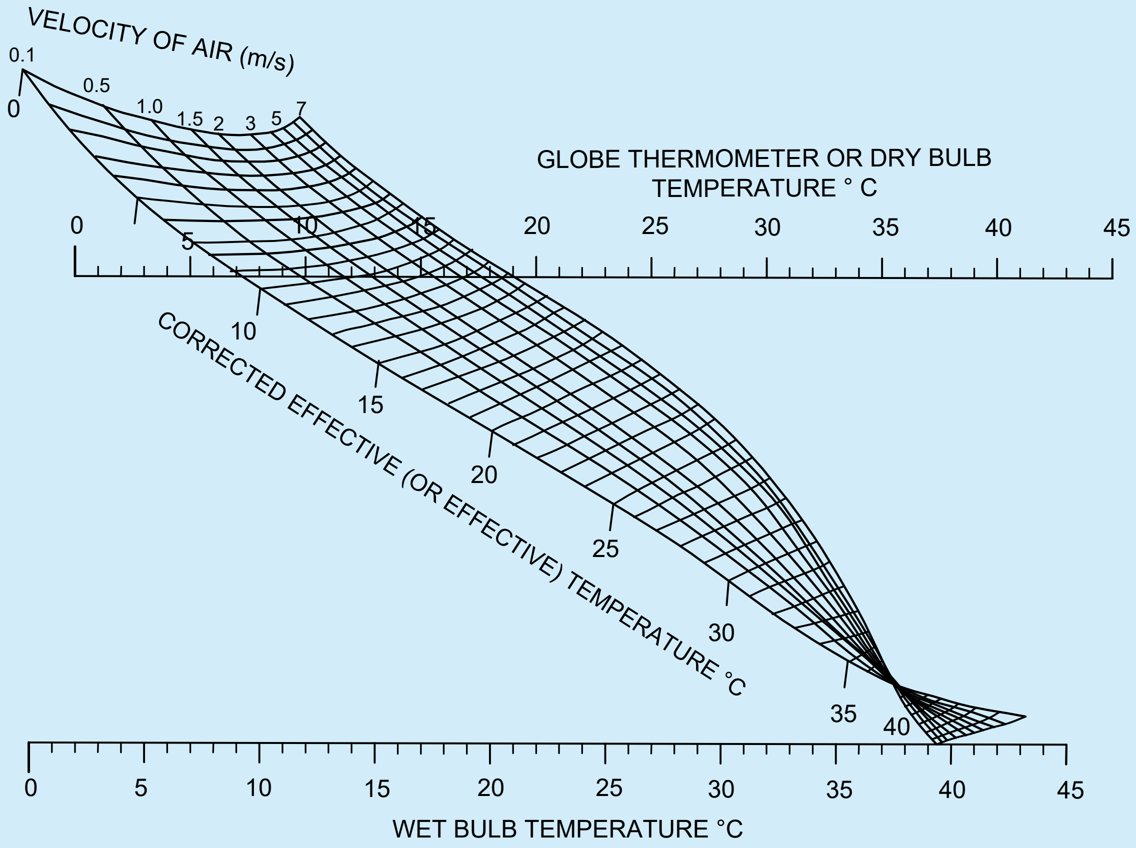

FIG. 5 CORRECTED EFFECTIVE TEMPERATURE NOMOGRAM

5.2.3.1.2 *Tropical Summer Index* (*TSI*)

The TSI is defined as the temperature of calm air, at 50 percent relative humidity which imparts the same thermal sensation as the given environment. The 50 percent level of relative humidity is chosen for this index as it is a reasonable intermediate value for the prevailing humidity conditions. Mathematically, TSI (°C) is expressed as:

$$\text{TSI} = 0.745\text{t}_{\text{g}} + 0.308\text{t}_{\text{w}}\text{-}2.06\sqrt{v + 0.841}$$

where

t_w = wet bulb temperature, in °C;
t_g = globe temperature, in °C; and
v = air speed, in m/s.

The thermal comfort of a person lies between TSI values of 25 °C and 30 °C with optimum condition at 27.5 °C. Air movement is necessary in hot and humid weather for body cooling. A certain minimum desirable wind speed is needed for achieving thermal comfort at different temperatures and relative humidity. Such wind speeds are given in Table 11. These are applicable to sedentary work in offices and other places having no noticeable sources of heat gain. Where somewhat warmer conditions are prevalent, such as in godowns and machine shops and work is of lighter intensity, and higher temperatures can be tolerated without much discomfort, minimum wind speeds for just acceptable warm conditions are given in Table 12. For obtaining values of indoor wind speed above 2.0 m/s, mechanical means of ventilation may have to be adopted (*see also* Part D 'Building Services, Section 3 Air Conditioning, Heating and Mechanical Ventilation' of this NBCS).

The warmth of the environment was found tolerable between 30 °C and 34 °C (TSI), and too hot above this limit. On the lower side, the coolness of the environment was found tolerable between 19 °C and 25 °C (TSI) and below 19 °C (TSI), it was found too cold.

Table 11 Desirable Wind Speeds (m/s) for Thermal Comfort Conditions

(*Clause* 5.2.3.1.2)

Sl No.	**Dry Bulb Temperature,** °C	**Relative Humidity,** percent						
		30	40	50	60	70	80	90
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
i)	28	1)	1)	1)	1)	1)	1)	1)
ii)	29	1)	1)	1)	1)	1)	0.06	0.19
iii)	30	1)	1)	1)	0.06	0.24	0.53	0.85
iv)	31	1)	0.06	0.24	0.53	1.04	1.47	2.10
v)	32	0.20	0.46	0.94	1.59	2.26	3.04	2)
vi)	33	0.77	1.36	2.12	3.00	2)	2)	2)
vii)	34	1.85	2.72	2)	2)	2)	2)	2)
viii)	35	3.20	2)	2)	2)	2)	2)	2)

Table 12 Minimum Wind Speeds (m/s) for Just Acceptable Warm Conditions

(*Clause* 5.2.3.1.2)

Sl No.	**Dry Bulb Temperature,** °C	**Relative Humidity,** percent						
		30	40	50	60	70	80	90
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
i)	28	1)	1)	1)	1)	1)	1)	1)
ii)	29	1)	1)	1)	1)	1)	1)	1)
iii)	30	1)	1)	1)	1)	1)	1)	1)
iv)	31	1)	1)	1)	1)	1)	0.06	0.23
v)	32	1)	1)	1)	0.09	0.29	0.60	0.94
vi)	33	1)	0.04	0.24	0.60	1.04	1.85	2.10
vii)	34	0.15	0.46	0.94	1.60	2.26	3.05	2)
viii)	35	0.68	1.36	2.10	3.05	2)	2)	2)
ix)	36	1.72	2.70	2)	2)	2)	2)	2)

5.2.4 *Design of Indoor Conditions as per Adaptive Thermal Comfort Model*

Air conditioning systems for interior spaces intended for human occupancy should be sized for not more than 26 °C for cooling and for not less than 18 °C for heating at an occupied level. Design based on an adaptive thermal comfort model can play a major role in reducing energy use whilst maintaining the comfort, productivity and well-being of occupants. This approach recognizes that people's thermal comfort needs depend on their past and present context and that these needs vary with the outdoor environmental conditions of their location.

People living year-round in air-conditioned spaces are likely to develop high expectations for homogeneity and cool temperatures and may become quite critical if thermal conditions deviate from the centre of the comfort zone

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1) None.

2) Higher than those acceptable in practice.

they have come to expect. In contrast, people who live or work in naturally ventilated buildings, can control their immediate interior spaces and get accustomed to variable indoor thermal conditions that reflect local patterns of daily and seasonal climate changes. Their thermal perceptions, preferences, as well as tolerances, are likely to extend over a wider range of temperatures. It allows buildings to operate within broader temperature bands. The specification of a broader comfort band suited to the Indian context has the potential to reduce the use of energy-intensive space cooling for buildings in India. The provisions here deal with the adaptive thermal comfort model, which differentiates the thermal response of occupants in air-conditioned and naturally ventilated buildings. It is imperative to specify indoor comfort conditions separately for buildings depending upon their operation, namely, air-conditioned buildings as well as naturally ventilated buildings:

a) Operative temperature is a more suitable index to measure thermal comfort in a building having low indoor air velocities since the index also accounts for the impact of building surface temperatures (radiant temperatures) on human comfort. Indoor operative temperature, for sedentary activities, can be approximated as an arithmetic mean of indoor air and radiant temperatures. For operating an air conditioning system based on operative temperature, the prevalent conditions along with the historical outdoor trend can be used to derive suitable operative temperature limits. Typical climatic conditions of various Indian cities are in the public domain; and

b) In case of buildings having higher indoor air velocity (more than 0.5 m/s), an effective temperature-based approach is recommended since, in addition to all factors considered in operative temperature, it also takes into account heat dissipation from the human body through convective heat transfer. High air velocity can allow keeping higher air temperature without compromising thermal comfort. However, it is also suggested to keep in consideration noise and other effects of high indoor air velocity. For annual indoor design conditions as per the adaptive model, for Indian cities, reference may be made to Annex A of Part D 'Building Services, Section 3 Air Conditioning, Heating and Mechanical Ventilation' of this NBCS. These are indicative, simplified values. They have been derived using typical meteorological year (TMY) files. More accurate design conditions can be derived using the following equations.

5.2.4.1 *Design Conditions for Commercial Buildings*

It is recommended to use the below-mentioned set of adaptive thermal comfort equations for commercial buildings. Equations (a) to (b) are best suited for the 30 day outdoor running mean temperatures between 13 °C and 38.5 °C:

a) For naturally ventilated (NV) commercial buildings — The following equation should be used for the design and operation of naturally ventilated (NV) buildings. It indicates that occupants in NV buildings thermally adapt to the outdoor temperature of their location:

$$Indoor\ operative\ temperature = (0.54 \times Outdoor\ temperature) + 12.83$$

where, indoor operative temperature (in °C) is the neutral temperature, and outdoor temperature is the 30 day outdoor running mean air temperature (in °C). The 90 percent acceptability range for naturally ventilated buildings is ± 2.38 °C.

b) For mixed-mode (MM) operation commercial buildings — Mixed-mode buildings, where HVAC is operated only during extreme outdoor conditions, are becoming prevalent in India. The occupants in mixed-mode buildings are more adaptive when compared to those in air conditioned buildings and somewhat less adaptive compared to occupants in naturally ventilated buildings:

$$Indoor\ operative\ temperature = (0.28 \times Outdoor\ temperature) + 17.87$$

where, indoor operative temperature (in °C) is the neutral temperature, and outdoor temperature is the 30 day outdoor running mean air temperature (in °C). The 90 percent acceptability range for mixed-mode buildings is ± 3.46 °C.

5.2.4.2 *Design Conditions for Residential Buildings*

The following equation should be used for determining adaptive thermal comfort in residential buildings, applicable for outdoor running mean temperatures between 7 °C and 33 °C. It is recommended to use the below-mentioned adaptive thermal comfort equation for residential buildings, for all operation modes:

$$Indoor\ operative\ temperature = (0.42 * Outdoor\ temperature) + 17.45$$

where, indoor operative temperature (in °C) is neutral temperature, and outdoor temperature is the 30 day outdoor running mean air temperature (in °C). The 90 percent acceptability range for conditioned buildings is ± 2.15 °C.

The adaptive comfort values derived using equations given in **5.2.4.1** for commercial, and the equation given in **5.2.4.2** for residential buildings are best suited for indoor relative humidity conditions (RH in percentage) between 25 percent and 75 percent.

5.2.5 *Minimum Outside Fresh Air*

Minimum outside fresh air applicable to only fully air-conditioned buildings. Table 13 prescribes minimum supply rates of acceptable outdoor air required for acceptable indoor air quality. These requirements for ventilation of health care facilities (hospitals, nursing and convalescent homes) are separately covered in Table 14. These values have been prescribed to dilute human bio effluents and other contaminants with an adequate margin of safety and to account for health variations among people and varied activity levels. The values prescribed in the table should be used in conjunction with the accompanying notes. Naturally ventilated spaces and mixed mode spaces, while operating in naturally ventilated mode, will have to rely on outdoor air using fenestration systems. The quantity and distribution of introduced fresh air should take into account the natural infiltration of the building. The proportion of fresh air introduced into air conditioned building may be varied to achieve economical and efficient operation. When the fresh air can provide a useful cooling effect, the quantity should be controlled through an air-side economizer to balance the cooling demand. However, when the air is too warm or humid the quantity may be reduced to a minimum to reduce the cooling load.

5.2.5.1 *Air class characteristic*

The following are the characteristics of the four air classes:

a) Class 1 — Air with low contaminant concentration, low sensory-irritation intensity and inoffensive odour;

b) Class 2 — Air with moderate contaminant concentration, mild sensory-irritation intensity, or mildly offensive odours. This air also includes air that is not necessarily harmful or objectionable but that is inappropriate for transfer or recirculation to spaces used for different purposes;

c) Class 3 — Air with significant contaminant concentration, significant sensory-irritation intensity, or offensive odour; and

d) Class 4 — Air with highly objectionable fumes or gases or with potentially dangerous particles, bio aerosols, or gases, at concentrations high enough to be considered harmful.

Table 13 Minimum Ventilation Rates in Breathing Zone

(*Clauses* 5.2.5)

(This table is not valid in isolation; it shall be used in conjunction with the accompanying notes.)

Sl No.	**Occupancy Category**	**People Outdoor Air Rate, R_p** l/s/person	**Area Outdoor Air Rate, R_a** l/s/m^2	**Notes**	**Default Values**		**Air Class**
					Occupant Density (*see* Note 4) persons per 100 m^2	Combined Outdoor Air Rate (*see* Note 4) l/s/person	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	**Correctional facilities:**						
	a) Cell	2.5	0.6	–	25	4.9	2
	b) Dayroom	2.5	0.3	–	30	3.5	1
	c) Guard stations	2.5	0.3	–	15	4.5	1
	d) Booking/waiting	3.8	0.3	–	50	4.4	2
ii)	**Educational facilities:**						
	a) Daycare (through age 4)	5	0.9	–	25	8.6	2
	b) Daycare sickroom	5	0.9	–	25	8.6	3
	c) Classrooms (age 5 to 8)	5	0.6	–	25	7.4	1
	d) Classrooms (age 9 plus)	5	0.6	–	35	6.7	1
	e) Lecture classroom	3.8	0.3	–	65	4.3	1
	f) Lecture hall (fixed seats)	3.8	0.3	–	150	4.0	1
	g) Art classroom	5	0.9	–	20	9.5	2
	h) Science laboratories	5	0.9	–	25	8.6	2
	j) University/college laboratories	5	0.9	–	25	8.6	2

Table 13 (*Continued*)

Sl No.	**Occupancy Category**	**People Outdoor Air Rate, R_p** l/s/person	**Area Outdoor Air Rate, R_a** l/s/m^2	**Notes**	**Default Values** Occupant Density (*see* Note 4) persons per 100 m^2	Combined Outdoor Air Rate (*see* Note 4) l/s/person	**Air Class**
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	k) Wood/metal shop	5	0.9	–	20	9.5	2
	m) Computer lab	5	0.6	–	25	7.4	1
	n) Media centre	5	0.6	*See* Note 6	25	7.4	1
	p) Music/theatre/dance	5	0.3	–	35	5.9	1
	q) Multi-use assembly	3.8	0.3	–	100	4.1	1
iii)	**Food and beverage service:**						
	a) Restaurant dining rooms	3.8	0.9	–	70	5.1	2
	b) Cafeteria/fast-food dining	3.8	0.9	–	100	4.7	2
	c) Bars, cocktail lounges	3.8	0.9	–	100	4.7	2
iv)	**General:**						
	a) Break rooms	2.5	0.3	–	25	5.1	1
	b) Coffee stations	2.5	0.3	–	20	5.5	1
	c) Conference/meeting rooms	2.5	0.3	–	50	3.1	1
	d) Corridors	–	0.3	–	–	–	1
	e) Storage rooms	–	0.6	*See* Note 7	–	–	1

Table 13 (*Continued*)

Sl No.	Occupancy Category	People Outdoor Air Rate, R_p l/s/person	Area Outdoor Air Rate, R_a l/s/m^2	Notes	Default Values		Air Class
					Occupant Density (*see* Note 4) persons per 100 m^2	Combined Outdoor Air Rate (*see* Note 4) l/s/person	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
v)	**Hotels, motels, resorts, dormitories:**						
	a) Bedroom/living room	2.5	0.3	–	10	5.5	1
	b) Barracks sleeping areas	2.5	0.3	–	20	4.0	1
	c) Laundry rooms, central	2.5	0.6	–	10	8.5	2
	d) Laundry rooms within dwelling units	2.5	0.6	–	10	8.5	1
	e) Lobbies/pre-function	3.8	0.3	–	30	4.8	1
	f) Multipurpose assembly	2.5	0.3	–	120	2.8	1
vi)	**Office buildings:**						
	a) Office space	2.5	0.3	–	5	8.5	1
	b) Reception Areas	2.5	0.3	–	30	3.5	1
	c) Telephone/data entry	2.5	0.3	–	60	3.0	1
	d) Main entry lobbies	2.5	0.3	–	10	5.5	1
				–			
vii)	**Miscellaneous spaces**:						
	a) Bank vaults/safe deposit	2.5	0.3	–	5	8.5	2
	b) Computer (not printing)	2.5	0.3	–	4	10.0	1

Table 13 (*Continued*)

Sl No.	Occupancy Category	People Outdoor Air Rate, R_p l/s/person	Area Outdoor Air Rate, R_a l/s/m^2	Notes	Default Values		Air Class
					Occupant Density (*see* Note 4) persons per 100 m^2	Combined Outdoor Air Rate (*see* Note 4) l/s/person	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	c) Electrical equipment rooms	–	0.3	*See* Note 7	–	–	1
	d) Elevator machine rooms	–	0.6	*See* Note 7	–	–	1
	e) Pharmacy (preparation area)	2.5	0.9	–	10	11.5	2
	f) Photo studios	2.5	0.6	–	10	8.5	1
	g) Shipping/receiving	–	0.6	*See* Note 7	–	–	1
	h) Telephone closets	–	0.0	–	–	–	1
	j) Transportation waiting	3.8	0.3	–	100	4.1	1
	k) Warehouses	–	0.3	*See* Note 7	–	–	2
viii)	**Public assembly spaces:**						
	a) Auditorium seating area	2.5	0.3	–	150	2.7	1
	b) Places of religious worship	2.5	0.3	–	120	2.8	1
	c) Courtrooms	2.5	0.3	–	70	2.9	1
	d) Legislative chambers	2.5	0.3	–	50	3.1	1
	e) Libraries	2.5	0.6	–	10	8.5	1
	f) Lobbies	2.5	0.3	–	150	2.7	1
	g) Museums (children’s)	3.8	0.6	–	40	5.3	1

Table 13 (*Continued*)

Sl No.	**Occupancy Category**	**People Outdoor Air Rate, R_p** l/s/person	**Area Outdoor Air Rate, R_a** l/s/m^2	**Notes**	**Default Values**		**Air Class**
					Occupant Density (*see* Note 4) persons per 100 m^2	Combined Outdoor Air Rate (*see* Note 4) l/s/person	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	h) Museums/galleries	3.8	0.3	–	40	4.6	1
ix)	**Residential:**						
	a) Dwelling unit	2.5	0.3	*See* Notes 8 and 9	*See* Note 8	–	1
	b) Common corridors	–	0.3	–	–	–	1
x)	**Retail:**						
	a) Sales (except as below)	3.8	0.6	–	15	7.8	2
	b) Mall common areas	3.8	0.3	–	40	4.6	1
	c) Barber shop	3.8	0.3	–	25	5.0	2
	d) Beauty and nail salons	10	0.6	–	25	12.4	2
	e) Pet shops (animal areas)	3.8	0.9	–	10	12.8	2
	f) Supermarket	3.8	0.3	–	8	7.6	1
	g) Coin-operated laundries	3.8	0.3	–	20	5.3	2
xi)	**Sports and entertainment:**						
	a) Sports arena (play area)	–	1.5	*See* Note 10	–	–	1
	b) Gym, stadium (play area)	–	1.5	–	30	–	2
	c) Spectator areas	3.8	0.3	–	150	4.0	1

Table 13 (*Concluded*)

Sl No.	**Occupancy Category**	**People Outdoor Air Rate, R_p** l/s/person	**Area Outdoor Air Rate, R_a** l/s/m²	**Notes**	**Default Values**		**Air Class**
					Occupant Density (*see* Note 4) persons per 100 m²	Combined Outdoor Air Rate (*see* Note 4) l/s/person	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	d) Swimming (pool and deck)	-	2.4	*See* Note 11	–	–	2
	e) Disco/dance floors	10	0.3	–	100	10.3	1
	f) Health club/aerobics room	10	0.3	–	40	10.8	2
	g) Health club/weight rooms	10	0.3	–	10	13.0	2
	h) Bowling alley (seating)	5	0.6	–	40	6.5	1
	j) Casinos	3.8	0.9	–	120	4.6	1
	k) Game arcades	3.8	0.9	–	20	8.3	1
	m) Stages, studios	5	0.3	*See* Note 12	70	5.4	1

NOTES

1 The rates in this table are based on all other applicable requirements being met.

2 This table applies to no-smoking areas only. Rates for smoking-permitted spaces shall be determined using other methods.

3 Volumetric airflow rates are based on an air density of 1.2 kg of dry air/m^3, which corresponds to dry air at a barometric pressure of 1 atm (101.3 kPa) and an air temperature of 21 °C. Rates may be adjusted for actual density but such adjustment is not required for compliance with this standard.

4 Actual occupant density should be considered, the default occupant density shall be used only when actual occupant density is not known. Default combined outdoor air (per person) rate is based on the default occupant density.

5 If the occupancy category for a proposed space or zone is not listed, the requirements for the listed occupancy category that is most similar in terms of occupant density, activities and building construction shall be used.

6 For high school and college libraries, use values shown for public assembly spaces-libraries.

7 The prescribed value may not be sufficient when stored materials include those having potentially harmful emissions.

8 Default occupancy for dwelling units shall be two persons for studio and one-bedroom units, with one additional person for each additional bedroom.

9 Air from one residential dwelling shall not be recirculated or transferred to any other space outside of that dwelling.

10 When combustion equipment is intended to be used on the playing surface, additional dilution ventilation and/or source control shall be provided.

11 The prescribed value does not allow for humidity control. Additional ventilation or dehumidification may be required to remove moisture.

12 The prescribed value does not include special exhaust for stage effects, for example, dry ice vapours, smoke.

Table 14 Outdoor Air Requirements for Ventilation of Health Care Facilities

(*Clause* 5.2.5)

Sl No.	**Application**	**Estimated Maximum Occupancy**[1]	**Outdoor Air Requirements**		**Remarks**
		persons/100 m²	l/s per person	l/s per m²	
(1)	(2)	(3)	(4)	(5)	(6)
i)	Patient rooms	10	13	–	Special requirements and pressure relationships may determine minimum ventilation rates and filter efficiency. Procedures generating contaminants may require higher rates.
ii)	Medical procedure	20	8	–	
iii)	Operating rooms	20	15	–	
iv)	Recovery and ICU	20	8	–	
v)	Autopsy rooms	20	–	2.5	Air shall not be recirculated into other spaces.
vi)	Physical therapy	20	8	–	

---

[1] Net occupiable space.

5.2.6 There will be a limit of heat tolerance when air temperatures are excessive and the degree of physical activity is high. This limit is determined when the bodily heat balance is upset, that is, when the bodily heat gain due to conduction, convection and the radiation from the surroundings exceeds the bodily heat loss, which is mostly by evaporation of sweat from the surface of the body. The limits of heat tolerance for Indian workers are based on the study conducted by the Chief Adviser Factories, Government of India, Ministry of Labour and are given in his report on Thermal Stress in Textile Industry (Report No. 17) issued in 1956. According to this report, where workers in industrial buildings wearing light clothing are expected to do work of moderate severity with the energy expenditure in the range 273 W to 284 W, the maximum wet bulb temperature shall not exceed 29 °C and adequate air movement subject to a minimum air velocity of 30 m/min shall be provided, and in relation to the dry bulb temperature, the wet bulb temperature of air in the work room, as far as practicable, shall not exceed that given in Table 15.

Table 15 Maximum Permissible Wet Bulb Temperatures for Given Dry Bulb Temperatures

(*Clause* 5.2.6)

Sl No.	Dry Bulb Temperature °C	Maximum Wet-Bulb Temperature °C
(1)	(2)	(3)
i)	30	29.0
ii)	35	28.5
iii)	40	28.0
iv)	45	27.5
v)	50	27.0

NOTES

1 These are limits beyond which the industry should not allow the thermal conditions to go for more than 1 h continuously. The limits are based on a series of studies conducted on Indian subjects in psychrometric chamber and on other data on heat casualties in earlier studies conducted in Kolar Gold Fields and elsewhere.

2 Figures given in this table are not intended to convey that human efficiency at 50 °C will remain the same as at 30 °C, provided appropriate wet bulb temperatures are maintained. Efficiency decreases with a rise in the dry bulb temperature as well, as much as possible. Long exposures to temperatures of 50 °C dry bulb/27 °C wet bulb may prove dangerous.

3 Refrigeration or some other method of cooling is recommended in all cases where conditions would be worse than those shown in this table.

5.3 Methods of Ventilation

General ventilation involves providing a building with relatively large quantities of outside air in order to improve general environment of the building. This may be achieved in one of the following ways:

a) Natural supply and natural exhaust of air;

b) Natural supply and mechanical exhaust of air;

c) Mechanical supply and natural exhaust of air; and

d) Mechanical supply and mechanical exhaust of air.

5.3.1 *Control of Heat*

Although it is recognized that general ventilation is one of the most effective methods of improving thermal environmental conditions in factories, in many situations, the application of ventilation should be preceded by and considered along with some of the following other methods of control. This would facilitate better design of buildings for general ventilation, either natural or mechanical or both and also reduce their cost.

5.3.1.1 *Isolation*

Sometimes it is possible to locate heat producing equipment, such as furnaces in such a position as would expose only a small number of workers to hot environment. As far as practicable, such sources of heat in factories should be isolated.

In situations where relatively few people are exposed to severe heat stress and their activities are confined to limited areas as in the case of rolling mill operators and crane operators, it may be possible to enclose the work areas and provide spot cooling or supply conditioned air to such enclosures.

5.3.1.2 *Insulation*

A considerable portion of heat in many factories is due to the solar radiation falling on the roof surfaces, which, in turn, radiate heat inside the building. In such situations, insulations of the roof or providing a false ceiling or double roofing would be very effective in controlling heat. Some reduction can also be achieved by painting the roof in heat reflective shades.

Hot surfaces of equipment, such as pipes, vessels, etc, in the building should also be insulated to reduce their surface temperature.

5.3.1.3 *Substitution*

Sometimes, it is possible to substitute a hot process by a method that involves application of localized or more efficiently controlled method of heating, examples include induction hardening instead of conventional heat treatment, cold riveting or spot welding instead of hot riveting, etc.

5.3.1.4 *Radiant shielding*

Hot surfaces, such as layers of molten metal emanate radiant heat, which can best be controlled by placing a shield having a highly reflecting surface between the source of heat and the worker, so that a major portion of the heat falling on the shield is reflected back to the source. Surfaces such as of tin and aluminium have been used as materials for shields. The efficiency of the shield does not depend on its thickness, but on the reflectivity and emissivity of its surface. Care should be taken to see that the shield is not heated up by conduction and for this purpose adequate provision should be made for the free flow upwards of the heated air between the hot surface and the shield by leaving the necessary air space and providing opening at the top and the bottom of the sides.

5.3.2 *Volume of Air Required*

The volume of air required shall be calculated by using both the sensible heat and latent heat gain as the basis. The larger of the two values obtained should be used in actual practice.

In places without sufficient wind speeds and/or in buildings where effective cross ventilation is not possible due to the design of the interior, the indoor air may be exhausted by a fan, with outdoor air entering the building through the open windows.

5.3.2.1 *Volume of air required for removing sensible heat*

When the amount of sensible heat given off by different sources, namely, the sun, the manufacturing processes, machinery, occupants and other sources, is known and a suitable value for the allowable temperature rise is assumed, the volume of outside air to be provided for removing the sensible heat may be calculated from:

$$Q_1 = \frac{2.976\,8\,K_s}{t}$$

where

Q_1 = quantity of air, in m^3/h;

K_s = sensible heat gained, in W; and

t = allowable temperature rise, in °C.

5.3.2.2 Temperature rise refers mainly to the difference between the air temperatures at the outlet (roof exit) and at the inlet openings for outside air. As very little data exist on allowable temperature rise values for supply of outside air in summer months, the values given in Table 16 related to industrial buildings may be used for general guidance.

Table 16 Allowable Temperature Rise Values

(*Clause* 5.3.2.2)

Sl No.	Height of Outlet Opening m	Temperature Rise °C
(1)	(2)	(3)
i)	6	3 to 4.5
ii)	9	4.5 to 6.5
iii)	12	6.5 to 11

NOTES

1 The conditions are limited to light or medium heavy manufacturing processes, freedom from radiant heat and inlet openings not more than 3 m to 4.5 m above floor level.

2 At the working zone between floor level and 1.5 m above floor level, the recommended maximum allowable temperature rise for air is 2 °C to 3 °C above the air temperature at the inlet openings.

5.3.2.3 *Volume of air required for removing latent heat*

If the latent heat gained from the manufacturing processes and occupants is also known and a suitable value for the allowable rise in the vapour pressure is assumed, the volume of air to be provided to remove the latent heat may be calculated from:

$$Q_2 = \frac{4\ 127.26\,K_1}{h}$$

where

Q_2 = quantity of air, in m^3/h;

K_1 = latent heat gained, in W; and

h = allowable vapour pressure difference, in mm of mercury.

NOTE — In majority of the cases, the sensible heat gain will far exceed the latent heat gain, so that the amount of outside air to be drawn by ventilating equipment can be calculated on the basis of the equation given in **5.3.2.1**.

5.3.2.4 Ventilation is also expressed as m^3/h/m^2 of floor area. This relationship fails to evaluate the actual heat relief provided by a ventilation system, but it does give a relationship which is independent of building height. This is a more rational approach, because, with the same internal load, the same amount of ventilation air, properly applied to the work zone with adequate velocity, will provide the desired heat relief quite independently of the ceiling height of the space, with few exceptions. Ventilation rates of 30 m^3/h/m^2 to 60 m^3/h/m^2 have been found to give good results in many plants.

5.4 Natural Ventilation

The rate of ventilation by natural means through windows or other openings depends on,

a) direction and velocity of wind outside and sizes and disposition of openings (wind action); and

b) convection effects arising from temperature of vapour pressure difference (or both) between inside and outside the room and the difference of height between the outlet and inlet openings (stack effect).

5.4.1 *Ventilation of Non-Industrial Buildings*

Ventilation in non-industrial buildings due to stack effect, unless there is a significant internal load, could be neglected, except in cold regions and wind action may be assumed to be predominant.

5.4.1.1 In hot dry regions, the main problem in summer is to provide protection from sun's heat so as to keep the indoor temperature lower than those outside under the sun. For this purpose, windows and other openings are generally kept closed during day time and only minimum ventilation is provided for the control of odours or for removal of products of combustion.

5.4.1.2 In warm humid regions, the problem in the design of non-industrial buildings is to provide free passage of air to keep the indoor temperature as near to those outside in the shade as possible, and for this purpose the buildings are oriented to face the direction of prevailing winds and windows and other openings are kept open on both windward and leeward sides.

5.4.1.3 In winter months in cold regions, the windows and other openings are generally kept shut, particularly during night; and ventilation necessary for the control of odours and for the removal of products of combustion can be achieved either by stack action or by some infiltration of outside air due to wind action.

5.4.2 *Ventilation of Industrial Buildings*

In providing natural ventilation of all industrial buildings having significant internal heat loads due to manufacturing process, proper consideration should be given to the size and distribution of windows and other inlet openings in relation to outlet openings so as to give, with due regard to orientation, prevailing winds, size and configuration of the building and manufacturing processes carried on, maximum possible control of thermal environment.

5.4.2.1 In the case of industrial buildings wider than 30 m, the ventilation through windows may be augmented by roof ventilation.

5.4.3 *Design Guidelines for Natural Ventilation*

5.4.3.1 *By wind action*

a) A building need not necessarily be oriented perpendicular to the prevailing outdoor wind; it may be oriented at any convenient angle between 0° and 30° without losing any beneficial aspect of the breeze. If the prevailing wind is from east or west, building may be oriented at 45° to the incident wind so as to diminish the solar heat without much reduction in air motion indoors;

b) Inlet openings in the buildings should be well distributed and should be located on the windward side at a low level, and outlet openings should be located on the leeward side. Inlet and outlet openings at high levels may only clear the top air at that level without producing air movement at the level of occupancy;

c) Maximum air movement at a particular plane is achieved by keeping the sill height of the opening at 85 percent of the critical height (such as head level) for the following recommended levels of occupancy:

    1) For sitting on chair 0.75 m;

    2) For sitting on bed 0.60 m; and

    3) For sitting on floor 0.40 m.

d) Inlet openings should not as far as possible be obstructed by adjoining buildings, trees, sign boards or other obstructions or by partitions inside in the path of air flow;

e) In rooms of normal size having identical windows on opposite walls the average indoor air speed increases rapidly by increasing the width of window up to two-third of the wall width; beyond that the increase is in much smaller proportion than the increase of the window width. The air motion in the working zone is maximum when window height is 1.1 m. Further increase in window height promotes air motion at higher level of window, but does not contribute additional benefits as regards air motion in the occupancy zones in buildings;

f) Greatest flow per unit area of openings is obtained by using inlet and outlet openings of nearby equal areas at the same level;

g) For a total area of openings (inlet and outlet) of 20 percent to 30 percent of floor area, the average indoor wind velocity is around 30 percent of outdoor velocity. Further increase in window size increases the available velocity but not in the same proportion as shown in Fig. 6. In fact, even under most favourable conditions the maximum average indoor wind speed does not exceed 40 percent of outdoor velocity;

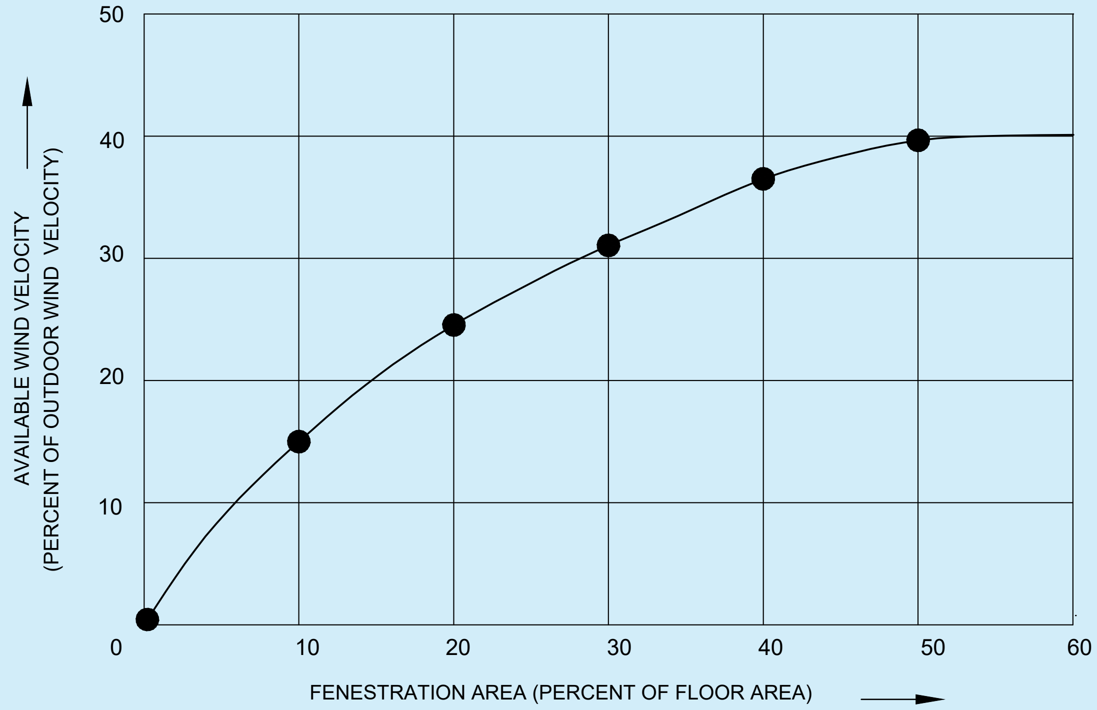


FIG. 6 EFFECT OF AREA OF OPENING ON AVERAGE INDOOR WIND VELOCITY

h) Where the direction of wind is quite constant and dependable, the size of the inlet should be kept within 30 percent to 50 percent of the total area of openings and the building should be oriented perpendicular to the incident wind. Where direction of the wind is quite variable the openings may be arranged so that as far as possible there is approximately equal area on all sides. Thus, no matter what the wind direction be, there would be some openings directly exposed to wind pressure and others to air suction and effective air movement through the building would be assured;

j) Windows of living rooms should open directly to an open space. In places where building sites are restricted, open space may have to be created in the buildings by providing adequate courtyards;

k) In the case of rooms with only one wall exposed to outside, provision of two windows on that wall is preferred to that of a single window;

m) Windows located diagonally opposite to each other with the windward window near the upstream corner give better performance than other window arrangements for most of the building orientations;

n) Horizontal louvers, that is, sunshades atop windows deflect the incident wind upward and reduce air motion in the zone of occupancy. A horizontal slot between the wall and horizontal louver prevents upward deflection of air in the interior of rooms. Provision of inverted L type (Γ) louver increases the room air motion provided that the vertical projection does not obstruct the incident wind (*see* Fig. 7);

p) Provision of horizontal sashes inclined at an angle of 45° in appropriate direction helps to promote the indoor air motion. Sashes projecting outward are more effective than projecting inward;

q) Air motion at working plane 0.4 m above the floor can be enhanced by 30 percent using a pelmet type wind deflector (*see* Fig. 8);

r) Roof overhangs help promoting air motion in the working zone inside buildings;

s) In case of room with windows on one wall, with single window, the room wind velocity inside the room on the windward side is 10 percent of outdoor velocity at points up to a distance one-sixth of room width from the window and then decreases rapidly and hardly any air movement is produced in the leeward half portion of the room. The average indoor wind velocity is generally less than 10 percent of outdoor velocity. When two windows are provided and wind impinges obliquely on them, the inside velocity increases up to 15 percent of the outdoor velocity;

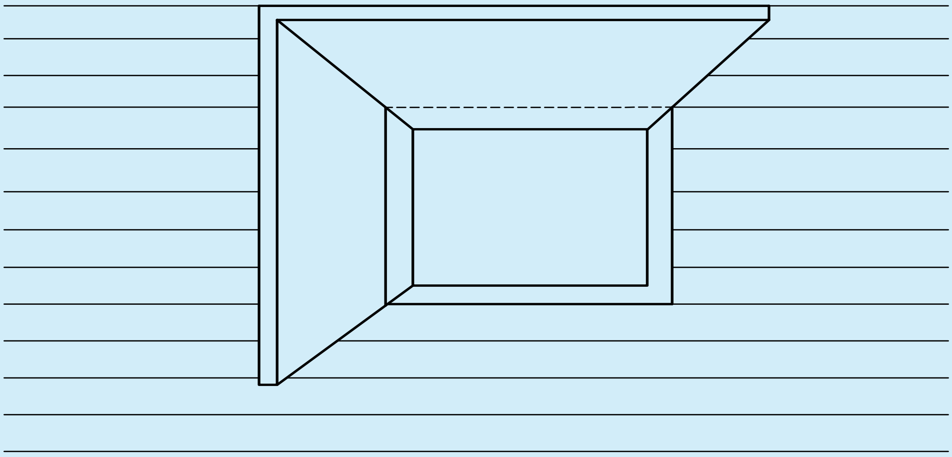


FIG. 7 L-TYPE LOUVER

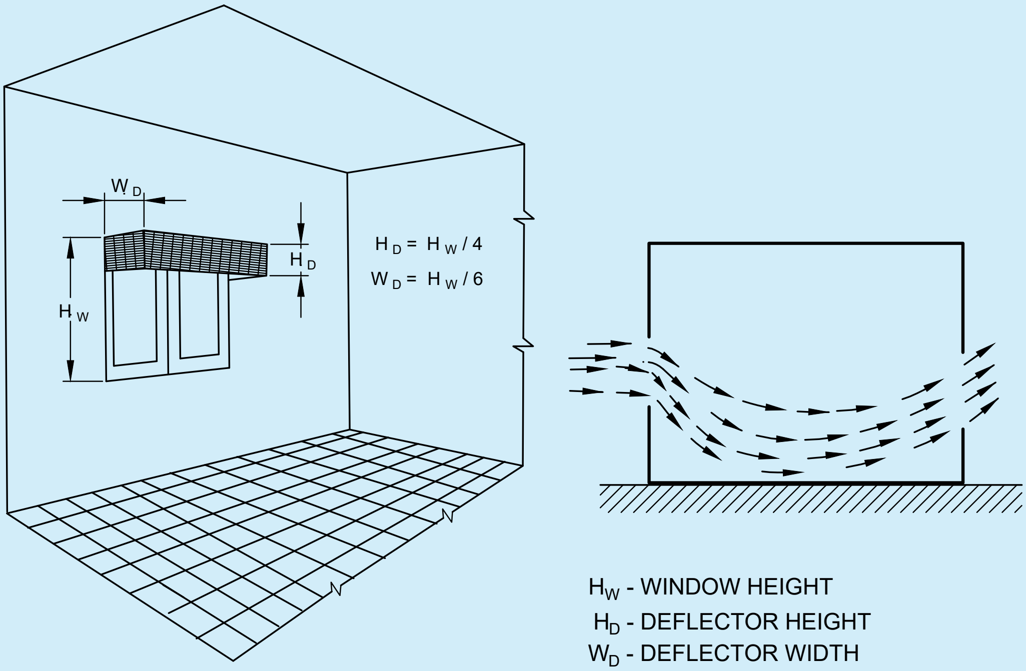

W_D
H_D
H_W
$H_D = H_W / 4$
$W_D = H_W / 6$
H_W - WINDOW HEIGHT
H_D - DEFLECTOR HEIGHT
W_D - DEFLECTOR WIDTH

FIG. 8 SKETCH OF A PELMET TYPE WIND DEFLECTOR

t) Cross ventilation can be obtained through one side of the building to the other, in case of narrow buildings with the width common in the multistoreyed type by the provision of large and suitably placed windows or combination of windows and wall ventilators for the inflow and outflow of air;

u) *Verandah* open on three sides is to be preferred since it causes an increase in the room air motion for most of the orientations of the building with respect to the outdoor wind;

v) A partition placed parallel to the incident wind has little influence on the pattern of the air flow, but when located perpendicular to the main flow, the same partition creates a wind shadow. Provision of a partition with spacing of 0.3 m underneath helps augmenting air motion near floor level in the leeward compartment of wide span buildings;

w) Air motion in a building unit having windows tangential to the incident wind is accelerated when another unit is located at end-on position on downstream side (*see* Fig. 9);

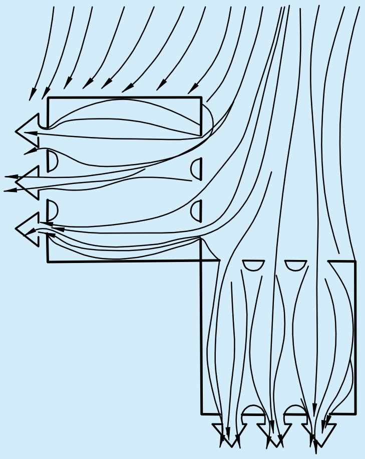


FIG. 9 TWO UNITS LOCATED AT THE END-ON POSITION

y) Air motion in two wings oriented parallel to the prevailing breeze is promoted by connecting them with a block on downstream side;

z) Air motion in a building is not affected by constructing another building of equal or smaller height on the leeward side; but it is slightly reduced if the leeward building is taller than the windward block;

aa) Air motion in a shielded building is less than that in an unobstructed building. To minimize shielding effect, the distances between two rows should be 8 H for semi-detached houses and 10 H for long rows houses. However, for smaller spacing the shielding effect is also diminished by raising the height of the shielded building;

bb) Hedges and shrubs deflect the air away from the inlet openings and cause a reduction in indoor air motion. These elements should not be planted at a distance of about 8 m from the building because the induced air motion is reduced to minimum in that case. However, air motion in the leeward part of the building can be enhanced by planting a low hedge at a distance of 2 m from the building;

cc) Trees with large foliage mass having trunk bare of branches up to the top level of window, deflect the outdoor wind downwards and promotes air motion in the leeward portion of buildings;

dd) Ventilation conditions indoors can be ameliorated by constructing buildings on earth mound having a slant surface with a slope of 10° on upstream side;

ee) In case of industrial buildings, the window height should be about 1.6 m and width about two-third of wall width. These should be located at a height of 1.1 m above the floor. In addition to this, openings around 0.9 m high should be provided over two-third length of the glazed area in the roof lights;

ff) Height of industrial buildings, although determined by the requirements of industrial processes involved, are generally kept large enough to protect the workers against hot stagnant air below the ceiling as also to dilute the concentration of contaminant inside. However, if high level openings in roof or walls are provided, building height can be reduced to 4 m without in any way impairing the ventilation performance; and

gg) The maximum width up to which buildings of height usually found in factories, being effectively ventilated by natural means by wind action, is 30 m, beyond which sufficient reliance cannot be placed on prevailing winds. Approximately half the ventilating area of openings should be between floor level and a height of 2.25 m from the floor.

NOTE — For data on outdoor wind speeds at a place, reference may be made to 'The Climatic Data Handbook prepared by Central Building Research Institute, Roorkee, 1999'.

5.4.3.2 *By stack effect*

Natural ventilation by stack effect occurs when air inside a building is at a different temperature than air outside. Thus, in heated buildings or in buildings wherein hot processes are carried on and in ordinary buildings during summer nights and during pre-monsoon periods, the inside temperature is higher than that of outside, cool outside air will tend to enter through openings at low level and warm air will tend to leave through openings at high level. It would, therefore, be advantageous to provide ventilators as close to ceilings as possible. Ventilators can also be provided in roofs as, for example, cowl, vent pipe, covered roof and ridge vent.

5.4.4 *Design Charts for Natural Ventilation*

Openings for natural ventilation can be sized without the need for complex and expensive computer simulation methods using analytical techniques. The design charts (DCs) provided hereunder can be used to assist in the sizing of ventilation openings to deliver natural ventilation.

The design charts are derived from analytical techniques. They provide either the geometrical free area (A_f) of openings to deliver a recommended air flow rate, or the achieved flow rate for a given free area.

Based on information for inside-outside air temperature difference (ΔT), wind speed (U) and wind pressure co-efficient (ΔC_p), the DCs are applicable for a wide range of weather conditions and parameters appropriate for residential buildings located in the selected Indian climatic zones.

These are considered to be the most common configurations encountered in practice in Indian residences. The corresponding DCs are:

a) DC-01 — Buoyancy-driven flow; single-sided ventilation with one opening (Fig. 10A and Fig. 11);

b) DC-02 — Buoyancy-driven flow; cross-ventilation with multiple openings (Fig. 10B and Fig. 12);

c) DC-03 — Wind-driven flow; single-sided ventilation with one opening (Fig. 10C and Fig. 13); and

d) DC-04 — Wind-driven flow; cross-ventilation with multiple openings (Fig. 10D and Fig. 14).

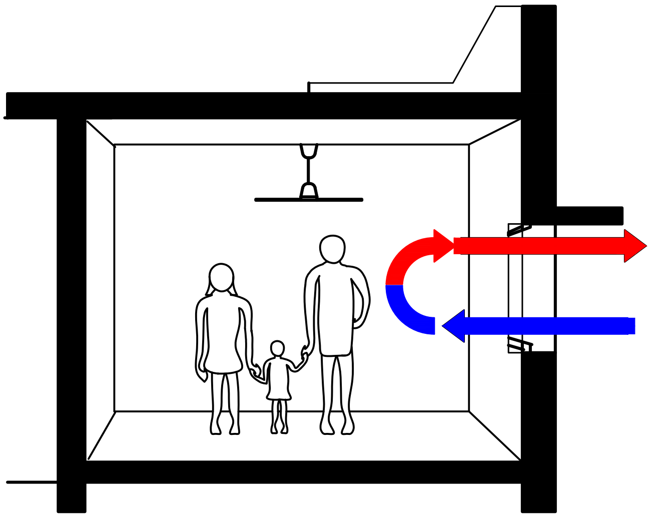


FIG. 10A DC-01

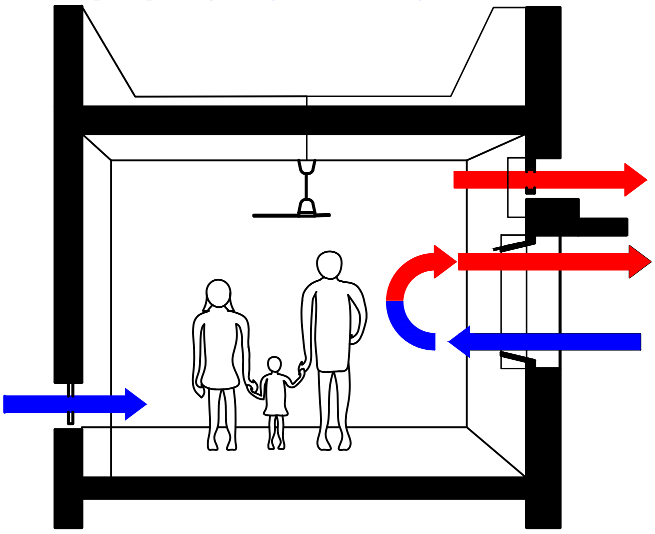


FIG. 10B DC-02

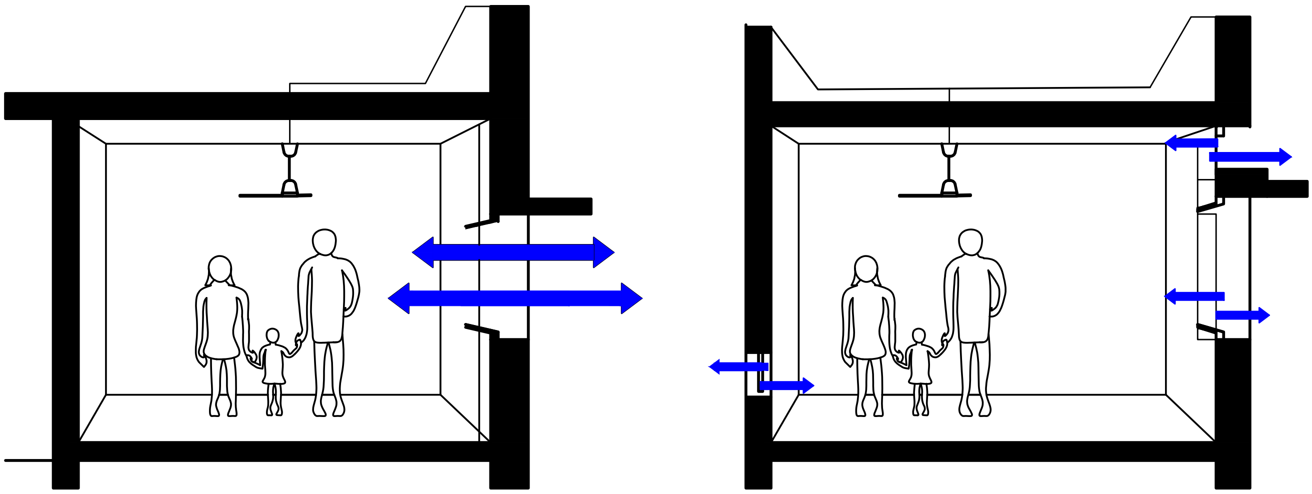


FIG. 10C DC-03 FIG. 10D DC-04

FIG. 10 CROSS-SECTION SKETCHES OF THE DRIVING FORCES FOR THE NATURAL VENTILATION SYSTEMS PRESENTED IN THE FOUR DESIGN CHARTS

5.4.4.1 *Design charts for natural ventilation — by stack effect*

a) DC-01 — Buoyancy-driven flow; single-sided ventilation with one opening;

The DC-01 is derived from the equation below (*see also* Fig. 11). For single opening, the value for C_d adopted is 0.25:

$$A_f = \frac{q_{rec}}{C_d}\sqrt{\frac{(T_{inside}+273)}{g\,h_a\Delta T_{inside\text{-}outside}}}$$ (*see also* **C-1.2.1**)

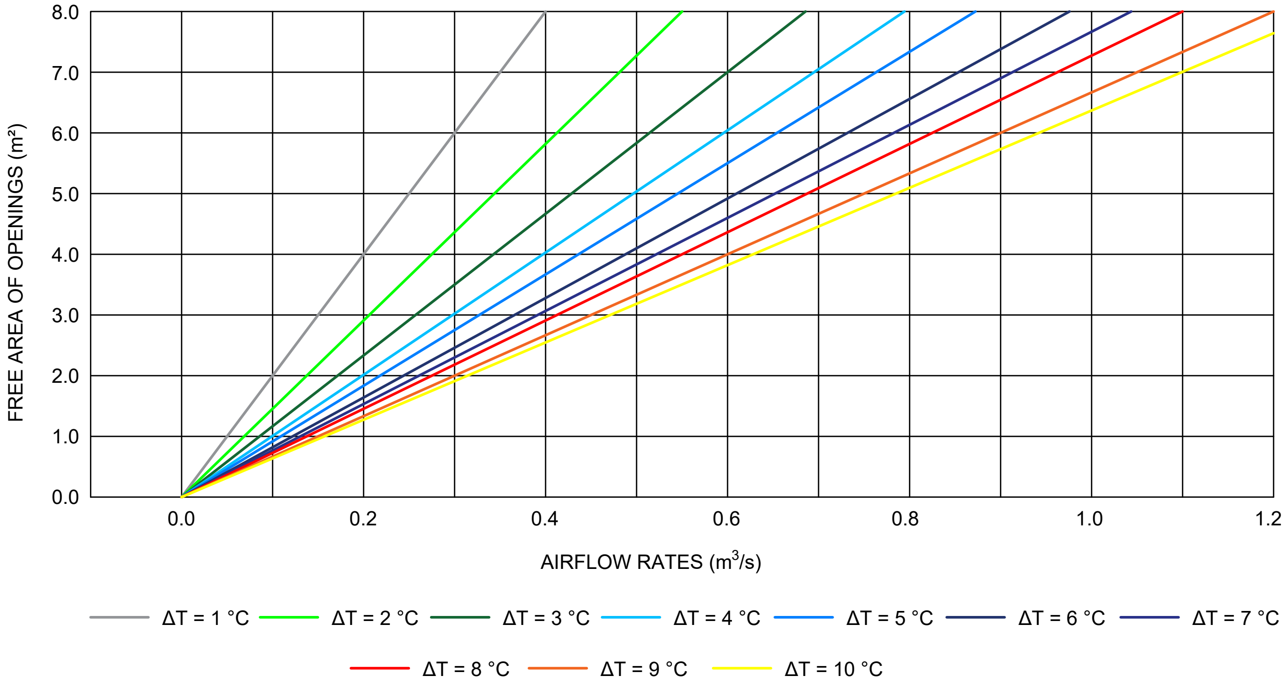


FIG. 11 DESIGN CHART DC-01 FOR SINGLE-SIDED SINGLE OPENING BUOYANCY DRIVEN FLOW

b) DC-02 — buoyancy-driven flow; cross-ventilation;

The DC-02 is also derived from the equation below (*see also* Fig. 12). Conversely, for multiple openings, the value for C_d adopted is 0.61:

$$V_z = V_{ref}\ k\ z^{\alpha}(m/s)$$ (*see also* **C-1.2.3.1**)

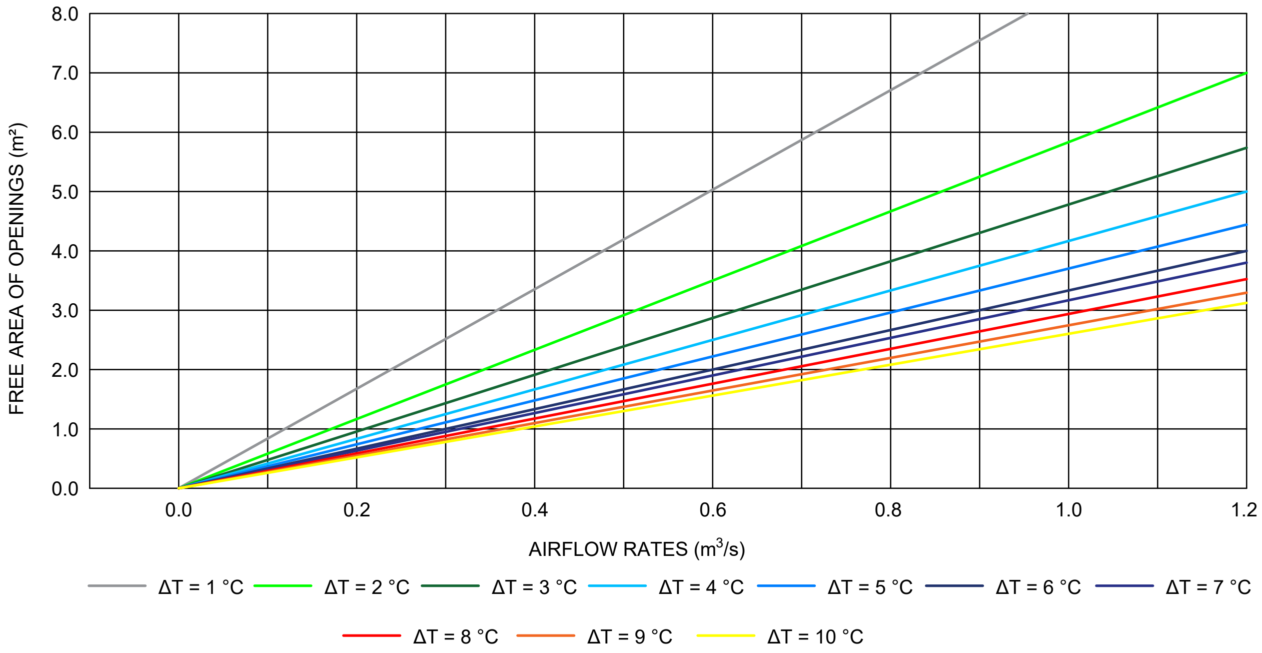


FIG. 12 DESIGN CHART DC-02 FOR MULTIPLE OPENINGS AND BUOYANCY-DRIVEN FLOW

5.4.4.2 *Design charts for natural ventilation — by wind effect*

a) DC-03 — Wind-driven flow; single-sided ventilation with one opening;

The DC-03 is derived from the following equation (*see also* Fig. 13):

$$A_f = {}^{q_{rec}}/_{C\,V_z}$$ (*see also* **C-1.2.3**)

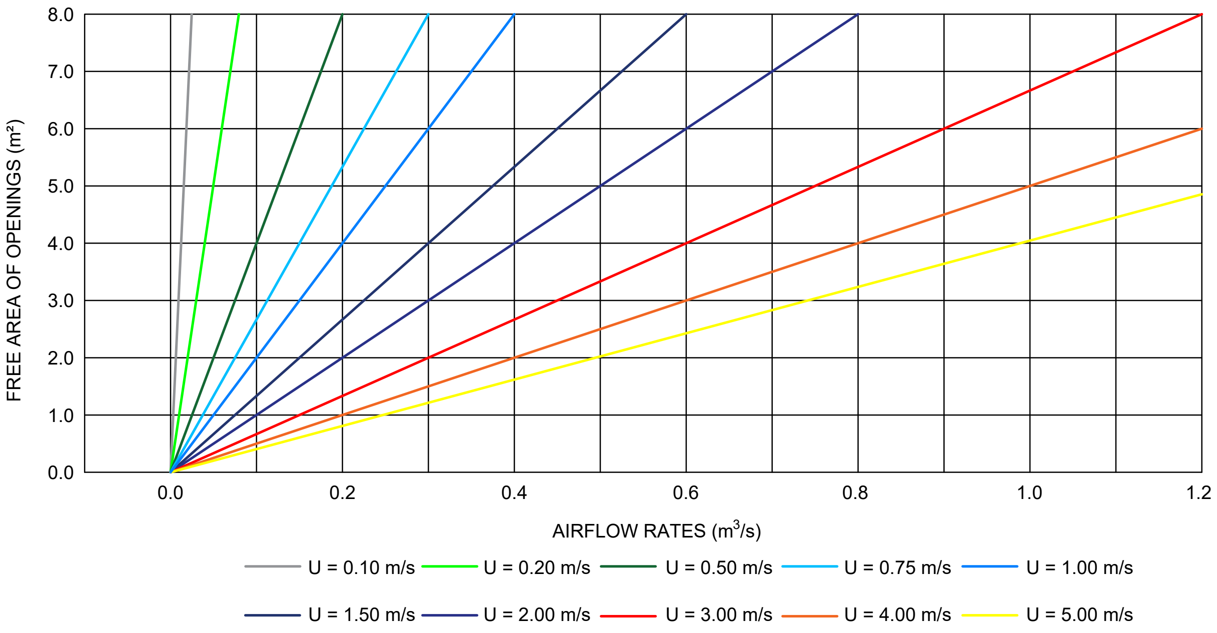


FIG. 13 DESIGN CHART DC-03 FOR SINGLE-SIDED SINGLE OPENINGS AND WIND-DRIVEN FLOW

b) DC-04 — Wind-driven flow; cross-ventilation with multiple openings;

The DC-04 is derived from the following equation (*see also* Fig. 14):

$$A_f = q_{ref}\left(C_d V_z \sqrt{\frac{\Delta C_p}{2}}\right)^{-1}$$ (*see also* **C-1.2.4**)

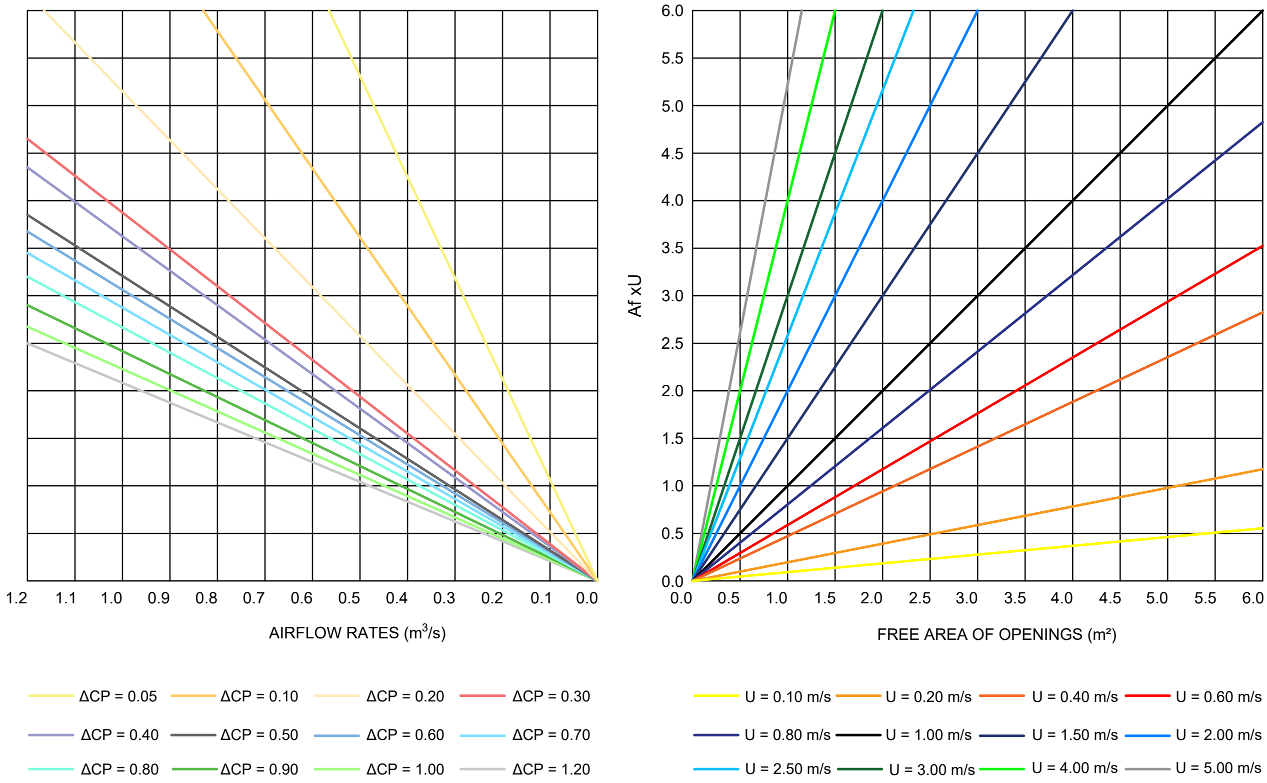


FIG. 14 DESIGN CHART DC-04 FOR MULTIPLE OPENINGS AND WIND-DRIVEN FLOW

5.4.4.3 For detailed application and use of the design charts for natural ventilation, reference may be made to Annex C.

5.5 Mechanical Ventilation

The requirements of mechanical ventilation should be in accordance with Part D ‘Building Services, Section 3 Air Conditioning, Heating and Mechanical Ventilation’ of this NBCS.

5.6 Determining Rate of Ventilation

5.6.1 *Natural Ventilation*

This is difficult to measure as it varies from time to time. The amount of outside air through windows and other openings depends on the direction and velocity of wind outside (wind action) and/or convection effects arising from temperature or vapour pressure differences (or both) between inside and outside of the building (stack effect).

5.6.1.1 *Wind action*

For determining the rate of ventilation based on wind action the wind may be assumed to come from any direction within 45° of the direction of prevailing wind. Ventilation due to external wind is given by the following formula:

$$Q_w = K \times A \times V$$

where

Q_w = rate of air flow, in m^3/h;

K = coefficient of effectiveness, which may be taken as 0.6 for wind perpendicular to openings and 0.3 for wind at an angle less than 45° to the openings;

A = free area of inlet openings, in m^2; and

V = wind speed, in m/h.

NOTE — For wind data at a place, the local Meteorological Department may be consulted.

5.6.1.2 *Stack effect* (*thermal action*)

Ventilation due to convection effects arising from temperature difference between inside and outside is given by:

$$Q_T = 7.0\,A\sqrt{h\,(t_r - t_o)}$$

where

Q_T = rate of air flow, in m^3/h;

A = free area of inlet openings, in m^2;

h = vertical distance between inlets and outlets, in m;

t_r = average temperature of indoor air at height h, in °C; and

t_o = temperature of outdoor air, in °C.

NOTE — The equation is based on 0.65 times the effectiveness of openings. This should be reduced to 0.50 if conditions are not favourable.

5.6.1.3 When areas of inlet and outlet openings are unequal, the value of A may be calculated using the equation:

$$\frac{2}{A^2} = \frac{1}{A^2_{\text{inlet}}} + \frac{1}{A^2_{\text{outlet}}}$$

5.6.1.4 *Combined effect of wind and thermal action*

When both forces (wind and thermal) act together in the same direction, even without interference, the resulting air flow is not equal to the two flows estimated separately.

When acting simultaneously, the rate of air flow through the building may be computed by the following equation:

$$Q^2 = {Q_w}^2 + {Q_t}^2$$

where

Q = resultant volume of air flow, in m^3/min;

Q_w = volume of air flow due to wind force, in m^3/min; and

Q_t = volume of air flow due to thermal force, in m^3/min.

Wind velocity and direction, outdoor temperature, and indoor distribution cannot be predicted with certainty, and refinement in calculation is not justified. A simple method is to calculate the sum of the flows produced by each force separately. Then using the ratio of the flow produced by thermal forces to the aforementioned sum, the actual flow due to the combined forces can be approximated from Fig. 15. When the two flows are equal, the actual flow is about 30 percent greater than the flow caused by either force acting independently (*see* Fig. 15).

Judgment is necessary for proper location of openings in a building specially in the roof, where heat, smoke and fumes are to be removed. Usually, windward monitor openings should be closed, but if wind is so slight that temperature head can overcome it, all openings may be opened.

5.6.1.5 For method for determining the rate of ventilation based on probable indoor wind speed with typical illustrative example for residential building, reference may be made to **A-4** of good practice [D-1(9)].

5.6.2 *Mechanical Ventilation*

The determination of rate of ventilation in case of mechanical ventilation shall be done in accordance with Part D 'Building Services, Section 3 Air Conditioning, Heating and Mechanical Ventilation' of this NBCS.

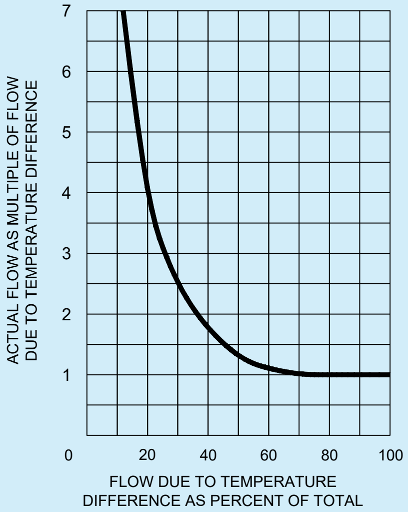


FIG. 15 DETERMINATION OF FLOW CAUSED BY COMBINED FORCES OF WIND AND TEMPERATURE DIFFERENCE

5.6.3 *Combined effect of Different Methods of Ventilation*

When combination of two or more methods of general ventilation is used, the total rate of ventilation shall be reckoned as the highest of the following three, and this rule shall be followed until an exact formula is established by research:

a) 1.25 times the rate of natural ventilation;

b) Rate of positive ventilation; and

c) Rate of exhaust of air.

5.6.4 *Measurement of Air Movement*

The rate of air movement of turbulent type at the working zone shall be measured either with a Kata thermometer (dry silvered type) or heated thermometer or properly calibrated thermocouple anemometer. Whereas anemometer gives the air velocity directly, the Kata thermometer and heated thermometer give cooling power of air and the rate of air movement is found by reference to a suitable nomogram using the ambient temperature.

5.7 Energy Conservation in Ventilation System

5.7.1 Maximum possible use should be made of wind induced natural ventilation. This may be accomplished by following the design guidelines given in 5.7.1.1.

5.7.1.1 Adequate number of circulating fans should be installed to serve all interior working areas during summer months in the hot dry and warm humid regions to provide necessary air movement at times when ventilation due to wind action alone does not afford sufficient relief.

5.7.1.1.1 The capacity of a ceiling fan to meet the requirement of a room with the longer dimension *D* metre should be about 55 D m^3/min.

5.7.1.1.2 The height of fan blades above the floor should be $(3H + W)/4$, where H is the height of the room and W is the height of work plane.

5.7.1.1.3 The minimum distance between fan blades and the ceiling should be about 0.3 m.

5.7.2 Electronic regulators should be used instead of resistance type regulators for controlling the speed of fans.

5.7.3 When actual ventilated zone does not cover the entire room area, then optimum size of ceiling fan should be chosen based on the actual usable area of room, rather than the total floor area of the room. Thus, smaller size of fan can be employed and energy saving could be achieved.

5.7.4 Power consumption by larger fans is obviously higher, but their power consumption per square metre of floor area is less and service value higher. Evidently, improper use of fans irrespective of the rooms' dimensions is likely to result in higher power consumption. From the point of view of energy consumption, the number of fans and the optimum sizes for rooms of different dimensions are given in Table 17.

Table 17 Optimum Size and Number of Fans for Rooms of Different Sizes

(*Clause* 5.7.4)

Sl No.	**Room Width** m	**Optimum Size (mm)/Number of Fans, For Room Length**										
		4 m	5 m	6 m	7 m	8 m	9 m	10 m	11 m	12 m	14 m	16 m
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
i)	3	1 200/1	1 400/1	1 500/1	1 050/2	1 200/2	1 400/2	1 400/2	1 400/2	1 200/3	1 400/3	1 400/3
ii)	4	1 200/1	1 400/1	1 200/2	1 200/2	1 200/2	1 400/2	1 400/2	1 500/2	1 200/3	1 400/3	1 500/3
iii)	5	1 400/1	1 400/1	1 400/2	1 400/2	1 400/2	1 400/2	1 400/2	1 500/2	1 400/3	1 400/3	1 500/3
iv)	6	1 200/2	1 400/2	900/4	1 050/4	1 200/4	1 400/4	1 400/4	1 500/4	1 200/6	1 400/6	1 500/6
v)	7	1 200/2	1 400/2	1 050/4	1 050/4	1 200/4	1 400/4	1 400/4	1 500/4	1 200/6	1 400/6	1 500/6
vi)	8	1 200/2	1 400/2	1 200/4	1 200/4	1 200/4	1 400/4	1 400/4	1 500/4	1 200/6	1 400/6	1 500/6
vii)	9	1 400/2	1 400/2	1 400/4	1 400/4	1 400/4	1 400/4	1 400/4	1 500/4	1 400/6	1 400/6	1 500/6
viii)	10	1 400/2	1 400/2	1 400/4	1 400/4	1 400/4	1 400/4	1 400/4	1 500/4	1 400/6	1 400/6	1 500/6
ix)	11	1 500/2	1 500/2	1 500/4	1 500/4	1 500/4	1 500/4	1 500/4	1 500/4	1 500/6	1 500/6	1 500/6
x)	12	1 200/3	1 400/3	1 200/6	1 200/6	1 200/6	1 400/6	1 400/6	1 500/6	1 200/7	1 400/9	1 400/9
xi)	13	1 400/3	1 400/3	1 200/6	1 200/6	1 200/6	1 400/6	1 400/6	1 500/6	1 400/9	1 400/9	1 500/9
xii)	14	1 400/3	1 400/3	1 400/6	1 400/6	1 400/6	1 400/6	1 400/6	1 500/6	1 400/9	1 400/9	1 500/9

5.7.5 *Acceptable Air Temperature with the Increase in the Air Speed*

The natural ventilation (NV) – mixed mode (MM) solutions combine designed openings for natural ventilation with the simultaneous use of mechanical ceiling fans to deliver thermal comfort with minimal use of energy. The air movement induced by the fan allows a rise in the acceptable operative temperature which is proportional to the increase in the air speed. This combination will be referred to as NV-MM solutions for 'enhanced natural ventilation (NV+).

The total number of hours of the year for which the outdoor conditions are feasible for natural ventilation, calculated as per the adaptive thermal comfort model for India-mixed mode building, and estimated with the NV-MM solutions for NV+, are shown in Fig. 16 for each of the eight Indian cities. This estimation utilizes the values for the corresponding rise in the acceptable air temperature with the increase in the air speed shown in Table 18 for the scenario with $T_{\text{radiant}} = T_{\text{air}}$ (as in specialist literature) and applies to clothing insulation values (in clo) ranging from 0.50 clo to 0.70 clo and to metabolic rates (in met) ranging from 1.00 met ranging from 0.50 clo to 0.70 clo and to metabolic rates (in met) ranging from 1.00 met to 1.30 met.

NOTE — Specialist literature may be ASHRAE 2010.

This scenario is considered likely to occur in a typical residential environment during daytime and in summer season, with NV operating and without any mechanical cooling source (a radiant cooling panel). This scenario yields more conservative values than the scenario when occupants have some control over the local environment (as per specialist literature).

NOTE — Specialist literature may be ASHRAE 2017.

Table 18 Corresponding Rise in the Acceptable Air Temperature with the Increase in the Air Speed

(*Clause* 5.7.5)

Sl No.	**Fan Speed Mode**	**Air Speed** m/s	**Corresponding Rise in Temperature** °C		
			Applying: 0.50 clo to 0.70 clo; 1.00 met to 1.30 met		Applying: 0.50 clo to 1.00 clo; 1.10 met
			$T_{\text{radiant}} - T_{\text{air}} = -10$	$T_{\text{radiant}} - T_{\text{air}} = 0$	
(1)	(2)	(3)	(4)	(5)	(6)
i)	OFF	0.1	–	–	–
ii)	I	0.6	1.20	2.00	2.80
iii)	II	0.9	1.80	2.70	3.40
iv)	III	1.2	2.20	3.30	3.75
v)	IV	1.5	2.50	3.60	4.00

5.7.6 *Mixed-Mode Principles*

Buildings that are designed with a mixed-mode ventilation strategy rely on natural ventilation for much of the occupied hours but also have integrated mechanical ventilation and cooling systems that are used in certain climatic or internal heat gain conditions. Mixed-Mode (MM) systems include naturally ventilated buildings that are designed using one of the following approaches:

a) Concurrent mixed-mode (*see* Fig. 17A) — Where both systems operate at the same space at the same time. The mechanical system operates as supplementary ventilation or cooling while the occupants are free to operate the windows based on their personal preference. This strategy is the most common form of mixed mode ventilation strategy typically employed for open-plan offices and residential buildings;

b) Change-over mixed-mode (*see* Fig. 17B and Fig. 17C) — Where the mechanical systems and natural ventilation operate in the same space at different times of the day or year. This approach requires an automated control system to determine which mode should be used at a particular point in time. The selection is based on a variety of input parameters such as outdoor conditions and occupancy. The system operating as change-over MM in a residence can either run automatically or inform the occupants to open or close the windows and switch on/off HVAC systems; and

c) Zoned mixed-mode (*see* Fig. 17D) — Where the mechanical cooling and natural ventilation operate at the same time but in different spaces of the building. This ventilation strategy is suitable for large office buildings where some offices could use natural ventilation by operating the windows whereas other rooms such as conference rooms may require a mechanical system for fresh air distribution.

Mixed-mode ventilation presents an energy efficient alternative to full air conditioning by capitalizing on the potential for natural ventilation when conditions permit.

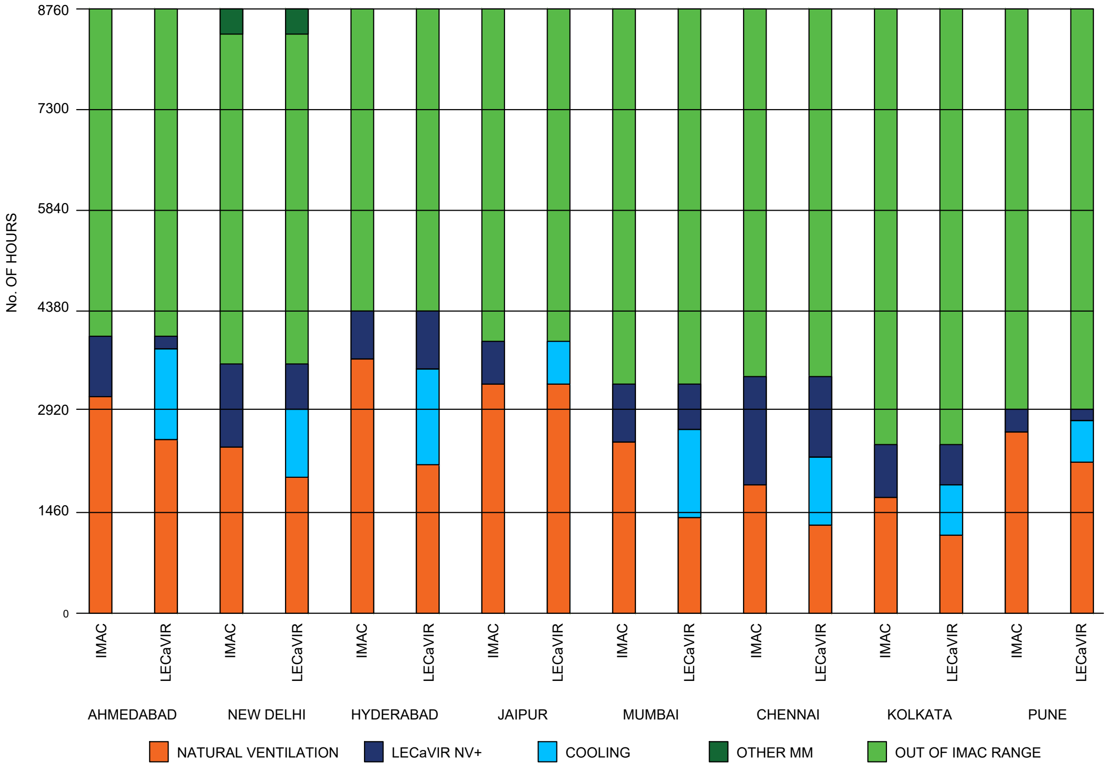


FIG. 16 NUMBER OF HOURS IN A YEAR USING 'NATURAL VENTILATION, MECHANICAL COOLING AND OTHER MM', FROM THE ADAPTIVE THERMAL COMFORT MODEL FOR INDIA-MIXED MODE BUILDINGS, AND USING 'NATURAL VENTILATION, ENHANCED NATURAL VENTILATION (NV+), MECHANICAL COOLING AND OTHER MM', FROM NV-MM SOLUTIONS FOR NV+ FOR EIGHT INDIAN CITIES

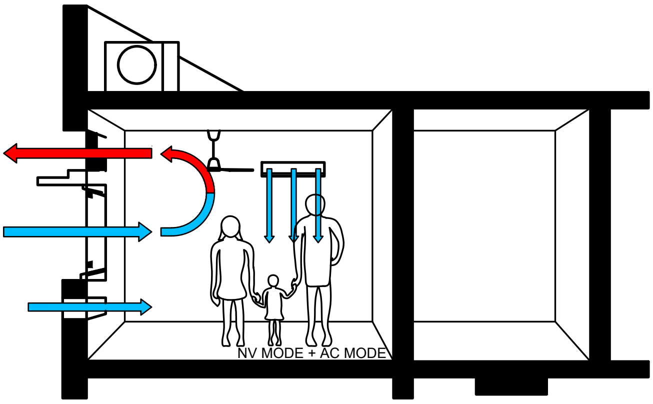


FIG. 17A CONCURRENT MIXED-MODE SYSTEM

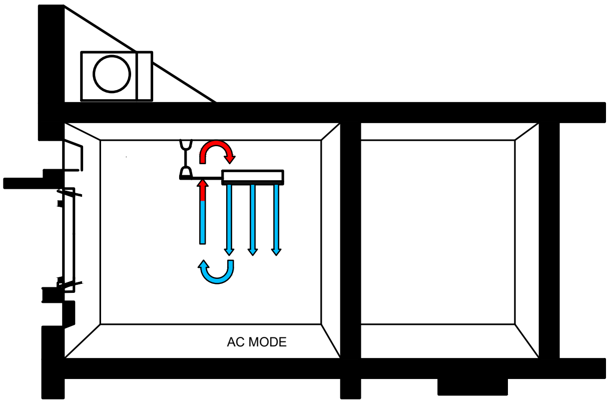


FIG. 17B CHANGE-OVER MIXED-MODE SYSTEM (AC MODE)

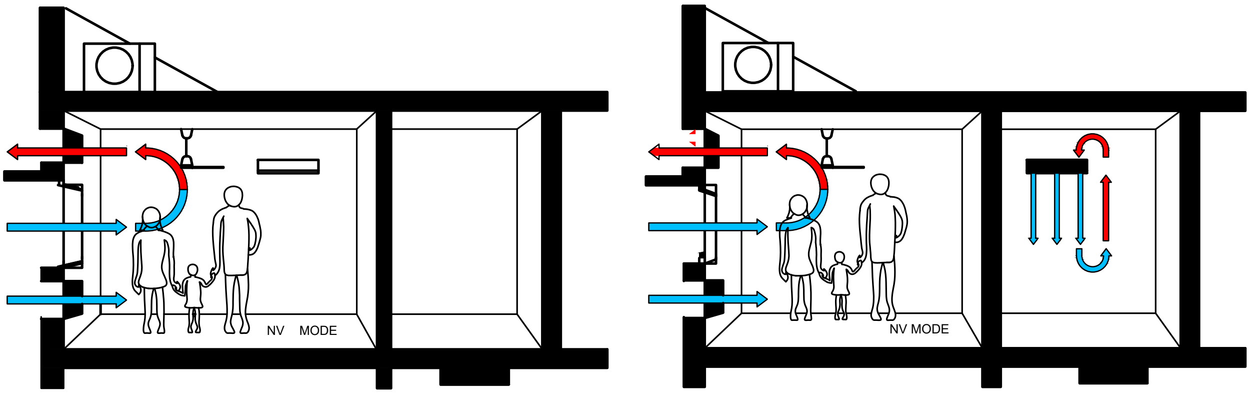


FIG. 17C CHANGE-OVER MIXED-MODE SYSTEM (NV MODE)

FIG. 17D ZONED MIXED-MODE SYSTEM FOR HOT DAY

FIG. 17 CLASSIFICATION OF MIXED-MODE SYSTEMS

ANNEX A

(*Clauses* 3.4.1 *and* 4.2.5.3)

METHOD OF CALCULATING SOLAR LOAD ON VERTICAL SURFACES OF DIFFERENT ORIENTATION

A-1 DETAILS OF CALCULATION

A-1.1 The solar energy above the earth's atmosphere is constant and the amount incident on unit area normal to sun's rays is called solar constant (1.360 8 kWm^{-2} or 2 cal/cm^2/min). This energy, in reaching the earth's surface, is depleted in, the atmosphere due to scattering by air molecules, water vapour, dust particles, and absorption by water vapour and ozone. The depletion varies with varying atmospheric conditions. Another important cause of depletion is the length of path traversed by sun's rays through the atmosphere. This path is the shortest when sun is at the zenith and, as the altitude of the sun decreases, the length of path in the atmosphere increases. Fig. 18 gives the computed incident solar energy/hour on unit surface area normal to the rays under standard atmospheric conditions (*see* Note below) for different altitudes of the sun.

NOTE — The standard atmospheric conditions assumed for this computation are: cloud-free, 300 dust particles per cm^3, 15 mm of precipitable water, 2.5 mm of ozone, at sea level.

A-1.2 In order to calculate the solar energy on any surface other than normal to the rays, the altitude of the sun at that time should be known. The corresponding value of direct solar radiation (I_N) should then be found with the help of Fig. 19. The solar radiation incident on any surface (I_S) is given by:

$$I_S = I_N \left(\sin\beta \sin\phi + \cos\beta \cos\alpha \cos\phi\right)$$

where

β = solar altitude;

ϕ = angle tilt of the surface from the vertical (*see* Fig. 19); and

α = wall solar azimuth angle.

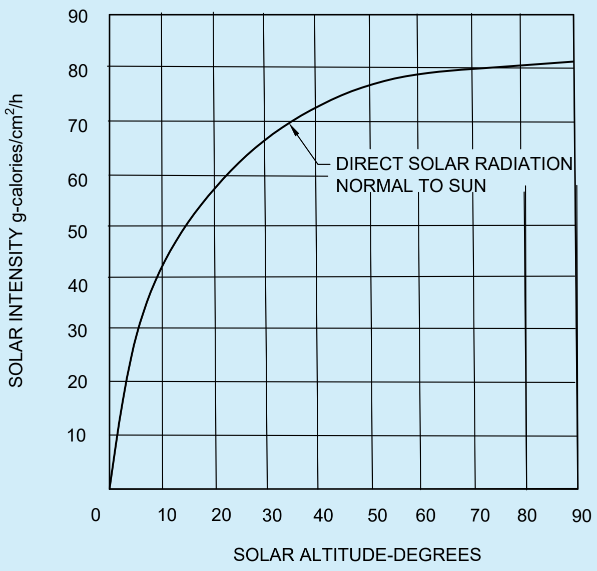


FIG. 18 DIRECT SOLAR INTENSITIES NORMAL TO SUN AT SEA LEVEL FOR STANDARD CONDITION (COMPUTED)

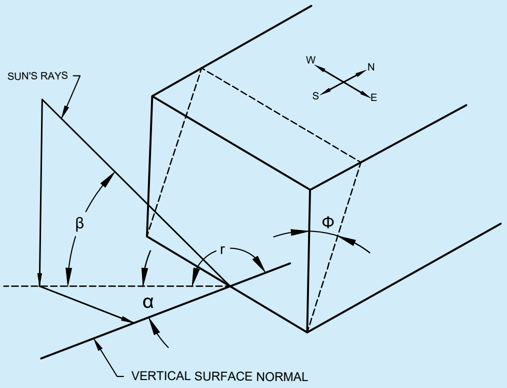


FIG. 19 DEFINITION OF SOLAR ANGLES

A-2 EXAMPLE TO FIND OUT ORIENTATION ON THE BASIS OF SOLAR LOAD

A-2.1 Example

A-2.1.1 As an example, a simple building with flat roof, 10 m × 20 m and 4 m high is dealt with below. For the sake of generalization, no shading device or verandah is taken.

A-2.1.2 As the roof is horizontal, it will receive the same solar heat in any orientation.

A-2.1.3 The area of the vertical surfaces are 4 m × 10 m = A (say) and 4 m × 20 m = $2A$. Since, the external wall surfaces are not in shade except when the sun is not shining on them, the total solar load in a day on a surface can be obtained by multiplying the total load per unit area per day (*see* Table 3) by the area of the surface. For four principal orientations of the building, the total solar load on the building is worked out in Table 19.

A-2.1.4 From Table 19, it can be seen that for the above type of building, orientation 3 (longer surface facing North and South) is appropriate as it affords maximum solar heat gain in winter and in summer. This is true for all places of India from the point of solar heat gain. By further increasing the length to breadth ratio, the advantage of this orientation will be more pronounced. It may also be noted that in higher altitudes, the relative merit of this orientation is more.

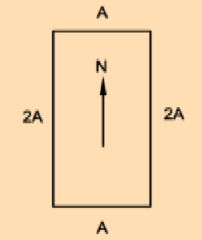
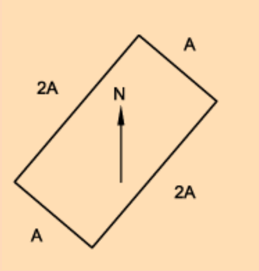
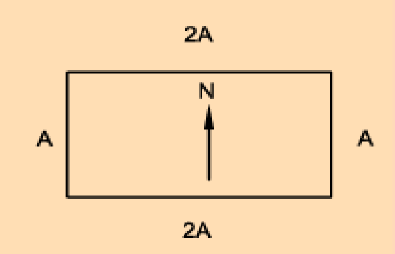
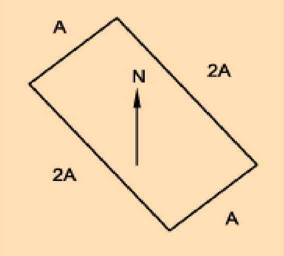
A-2.1.5 It is also seen that the total solar heat on the building is the same for orientation 2 and 4. But if the site considerations require a choice between these two, orientation 2 should be preferred at places north of latitude 23° N and orientation 4 at southern places. This is so because the total solar load per unit area in summer on the north western wall decreases with the increase in latitude and that on the south western wall increases. It would, therefore, be advantageous to face only smaller surface of the building to greater solar load in the summer afternoons, when the air temperature also is higher.

A-2.1.6 At hill stations, winter season cause more discomfort and so sole criterion for optimum orientation should be based on receiving maximum solar energy on building in winter.

Table 19 Solar Heat Gained Due to Orientation of Buildings

(*Clauses* A-2.1.3 *and* A-2.1.4)

Sl No.	Orientation	Solar Heat Gained							
		8º N THIRUVANANTHAPURAM		13º N CHENNAI		19º N MUMBAI		23º N KOLKATA	
		May 16	Dec 22	May 16	Dec 22	May 16	Dec 22	May 16	Dec 22
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
i)	North	2 177 × A = 2 177A	–	1 625 × A = 1 625A	–	962 × A = 962A	–	741 × A = 741A	–
	East	2 618 × 2A = 5 236A	2 177 × 2A = 4 354A	2 697 × 2A = 5 394A	2 019 × 2A = 4 038A	2 795 × 2A = 5 590A	1 830 × 2A = 3 660A	2 871 × 2A = 5 742A	1 703 × 2A = 3 406A
	South	–	4 164 × A = 4 164A	–	4 385 × A = 4 385A	–	4 574 × A = 4 574A	205 × A = 205A	4 637 × A = 4 637A
	West	2 618 × 2A = 5 236A	2 177 × 2A = 4 354A	2 697 × 2A = 5 394A	2 019 × 2A = 4 038A	2 795 × 2A = 5 590A	1 830 × 2A = 3 660A	2 871 × 2A = 5 742A	1 703 × 2A = 3 406A
	Total	12 649A	12 872A	12 413A	12 461A	12 142A	11 894A	12 430A	11 449A
ii)	NE	2 650 × A = 2 650A	410 × A = 410A	2 492 × A = 2 492A	315 × A = 315A	2 255 × A = 2 255A	237 × A = 237A	2 192 × A = 2 192A	173 × A = 173A
	SE	1 167 × 2A = 2 334A	3 391 × 2A = 6 782A	1 341 × 2A = 2 682A	3 423 × 2A = 6 846A	1 640 × 2A = 3 280A	3 438 × 2A = 6 876A	1 845 × 2A = 3 690A	3 454 × 2A = 6 908A
	SW	1 167 × 2A = 2 334A	3 391 × A = 3 391A	1 341 × A = 1 341A	3 423 × A = 3 423A	1 640 × A = 1 640A	3 438 × A = 3 438A	1 845 × A = 1 845A	3 454 × A = 3 454A
	NW	2 650 × 2A = 5 300A	410 × 2A = 820A	2 492 × A = 4 984A	315 × 2A = 630A	2 255 × 2A = 4 510A	237 × 2A = 474A	2 192 × 2A = 4 384A	173 × 2A = 346A
	Total	12 618A	11 403A	11 499A	11 214A	11 685A	11 025A	12 111A	10 881A
iii)	North	2 177 × 2A = 4 354A	–	1 625 × 2A = 3 250A	–	962 × 2A = 1 924A	–	741 × 2A = 1 482A	–
	East	2 618 × A = 2 618A	2 177 × A = 2 177A	2 697 × A = 2 697A	2 019 × A = 2 019A	2 795 × A = 2 795A	1 830 × A = 1 830A	2 871 × A = 2 871A	1 703 × A = 1 703A
	South	–	4 164 × 2A = 8 328A	–	4 385 × 2A = 8 770A	–	4 574 × 2A = 9 148A	205 × 2A = 410A	4 637 × 2A = 9 274A
	West	2 618 × A = 2 618A	2 177 × A = 2 177A	2 697 × A = 2 697A	2 019 × A = 2 019A	2 795 × A = 2 795A	1 830 × A = 1 830A	2 871 × A = 2 871A	1 703 × A = 1 703A
	Total	9 590A	12 602A	8 644A	12 808A	7 514A	12 808A	7 634A	12 680A
iv)	NE	2 650 × 2A = 5 300A	–	2 492 × A = 4 984A	315 × 2A = 630A	2 255 × 2A = 4 510A	237 × 2A = 474A	2 192 × 2A = 4 384A	173 × 2A = 346A
	SE	1 167 × A = 1 167A	2 177 × A = 2 177A	1 341 × A = 1 341A	3 423 × A = 3 423A	1 640 × A = 1 640A	3 438 × A = 3 438A	1 845 × A = 1 845A	3 454 × A = 3 454A
	SW	1 167 × 2A = 2 334A	4 164 × 2A = 8 328A	1 341 × 2A = 2 682A	3 423 × 2A = 6 846A	1 640 × 2A = 3 280A	3 438 × 2A = 6 876A	1 845 × 2A = 3 690A	3 454 × 2A = 6 908A
	NW	2 650 × A = 2 650A	2 177 × A = 2 177A	2 492 × A = 2 492A	315 × A = 315A	2 255 × A = 2 255A	237 × A = 237A	2 192 × A = 2 192A	173 × A = 173A
	Total	11 451A	12 682A	11 499A	11 214A	11 685A	11 025A	12 111A	10 881A

		29º N DELHI		
		May 16	Dec 22	
i)	North	536 × A = 536A	–	 ORIENTATION 1
	East	2 950 × 2A = 5 900A	1 467 × 2A = 2 934A	
	South	741 × A = 741A	4 543 × A = 4 543A	
	West	2 950 × 2A = 5 900A	1 467 × 2A = 2 934A	
	Total	13 077A	10 411A	
ii)	NE	2 098 × A = 2 098A	110 × A = 110A	 ORIENTATION 2
	SE	2 192 × 2A = 4 384A	3 265 × 2A = 6 530A	
	SW	2 192 × A = 2 192A	3 265 × A = 3 265A	
	NW	2 098 × 2A = 4 196A	110 × 2A = 220A	
	Total	12 870A	10 125A	
iii)	North	536 × 2A = 1 072A	–	 ORIENTATION 3
	East	2 950 × A = 2 950A	1 467 × A = 1 467A	
	South	741 × 2A = 1 482A	4 543 × 2A = 9 086A	
	West	2 950 × A = 2 950A	1 467 × A = 1 467A	
	Total	8 454A	12 020A	
iv)	NE	2 098 × 2A = 4 196A	110 × 2A = 220A	 ORIENTATION 4
	SE	2 192 × A = 2 192A	3 265 × A = 3 265A	
	SW	2 192 × 2A = 4 384A	3 265 × 2A = 6 530A	
	NW	2 098 × A = 4 196A	110 × A = 110A	
	Total	12 870A	10 125A	

ANNEX B

(*Clauses* 4.2.5, 4.2.5.2, 4.2.5.3, 4.2.5.4 *and* 4.2.6)

SKY COMPONENT TABLES

B-1 DESCRIPTION OF TABLES

B-1.1 The three sky component tables are as given below:

a) Table 20 — Percentage sky components on the horizontal plane due to a vertical rectangular opening for the clear design sky;

b) Table 21 — Percentage sky components on the vertical plane perpendicular to a vertical rectangular opening for the clear design sky; and

c) Table 22 — Percentage sky components on the vertical plane parallel to a vertical rectangular opening for the clear design sky.

B-1.2 All the Table 20, Table 21 and Table 22 are for an unglazed opening illuminated by the clear design sky.

B-1.3 The values tabulated are the components at a point *P* distant from the opening on a line perpendicular to the plane of the opening through one of its lower corners, and *l* and *h* are the width and height respectively of the rectangular opening (*see* Fig. 20).

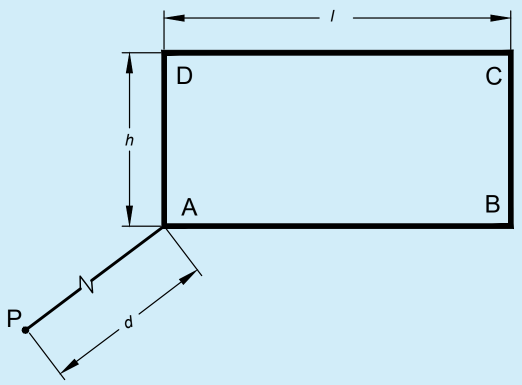


FIG. 20 DEPICTION OF OBSERVATIN POINT ' P '

B-1.4 Sky component for different *h*/*d* and *l*/*d* values are tabulated, that is, for windows of different size and for different distances of the point *P* from the window.

B-1.5 By suitable combination of the values obtained from the Table 20, Table 21 and Table 22, for a given point for a given window, the sky component in any plane passing through the point may be obtained.

B-1.6 Method of Using the Tables

B-1.6.1 Method of using the Table 20, Table 21 and Table 22 to get the sky component at given point is explained with help of the following example.

B-1.6.2 *Example*

It is desired to calculate the sky component (F) due to a vertical window ABCD with width 1.8 m and height 1.5 m at a point P on a horizontal plane 3.0 m from the window wall located as shown in the Fig. 21. Foot of the perpendicular N is 0.6 m below the sill and 0.9 m to the left of AD.

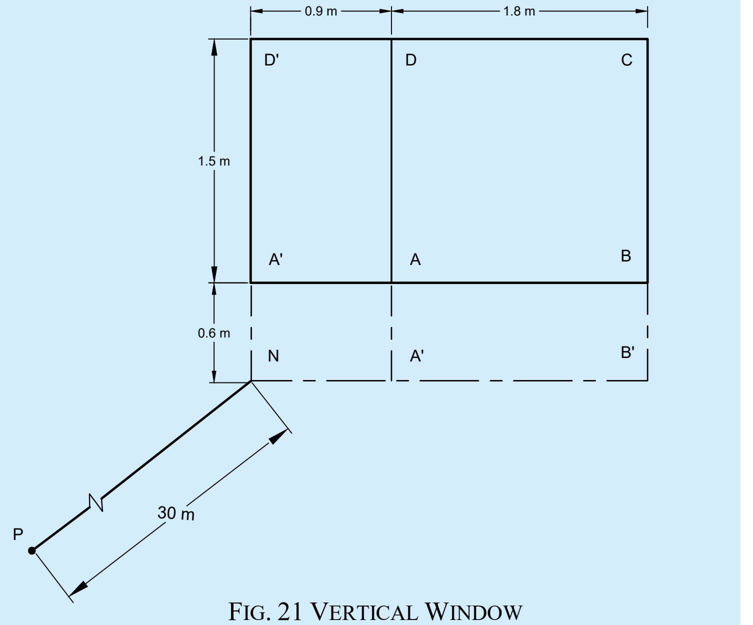


FIG. 21 VERTICAL WINDOW

Consider ABCD extended to NB'CD'

a) For NB'CD'

$l/d = (1.8 + 0.9)/3 = 0.9$

$h/d = (1.5 + 0.6)/3 = 0.7$

$F_1 = 5.708$ percent (from Table 20)

b) For NA'DD'

$l/d = 0.9/3 = 0.3$

$h/d = (1.5 + 0.6)/3 = 0.7$

$F_2 = 2.441$ percent (from Table 20)

c) For NB'BA'

$l/d = (1.8 + 0.9)/3 = 0.9$

$h/d = 0.6/3 = 0.2$

$F_3 = 0.878$ percent (from Table 20)

d) For NA'AA'

$l/d = 0.9/3 = 0.3$

$h/d = 0.6/3 = 0.2$

F_4 = 0.40 3 percent (from Table 20)

Since ABCD = NB’CD’ – NA’DD’ – NB’BA’ + NA’AA’

Sky component, F = $F_1 - F_2 - F_3 + F_4$
= 5.708 – 2.441 – 0.878 + 0.403
= 2.792

B-2 GENERAL INSTRUCTIONS

B-2.1 For irregular obstructions like row of trees parallel to the plane of the window, equivalent straight boundaries horizontal and vertical, maybe drawn.

B-2.2 Waldram diagrams are an effective early-stage design tool for planning daylight and direct solar illuminance for extremely irregular obstructions or obstructions not in a plane parallel to the window. Fig. 22 and Fig. 23 show two possible massing schemes for a site located at 17° N latitude, while Fig. 24 and Fig. 25 illustrate the corresponding Waldram diagrams drawn from the central open area of the site. The white area above the shadow silhouettes in Fig. 24 and Fig. 25 indicate unobstructed sky (48 percent sky view in case of Fig. 24 and 65 percent sky view in case of Fig. 25). The yellow lines in Fig. 24 and Fig. 25 indicate the annual sun path as seen from the middle of the central open area of the site, aiding in evaluating sky visibility and optimizing site layouts for improved daylight performance.

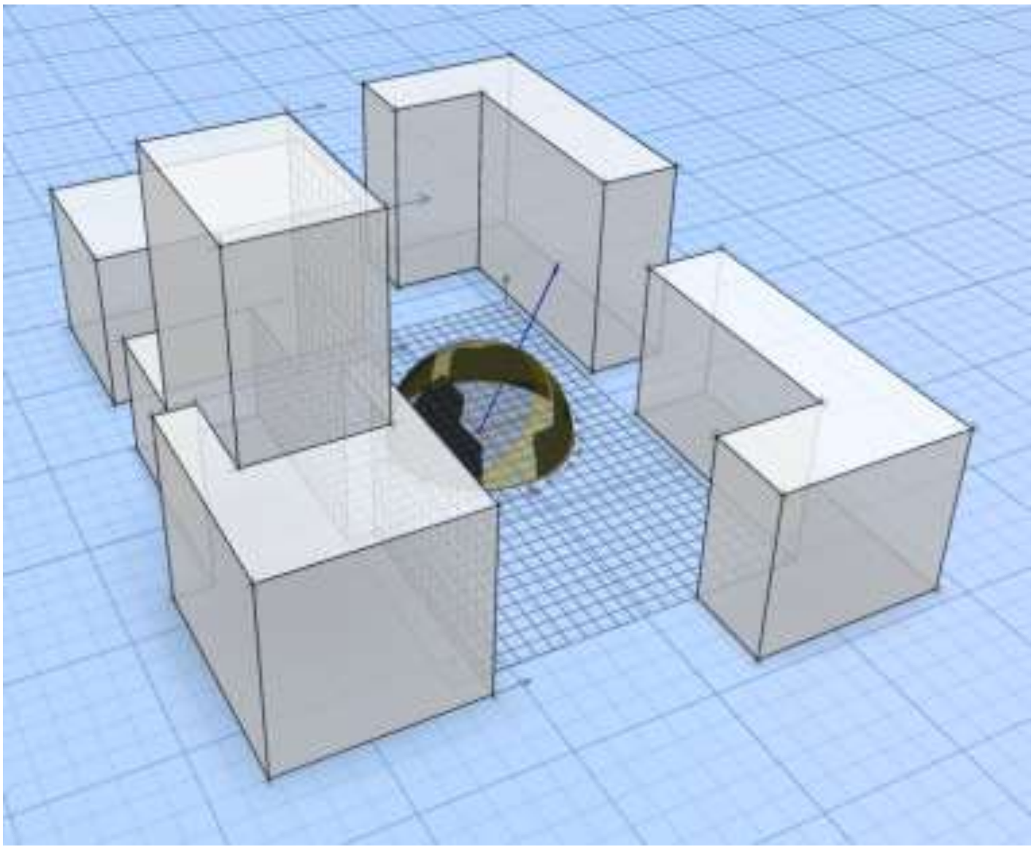


FIG. 22 MASSING SCHEME A

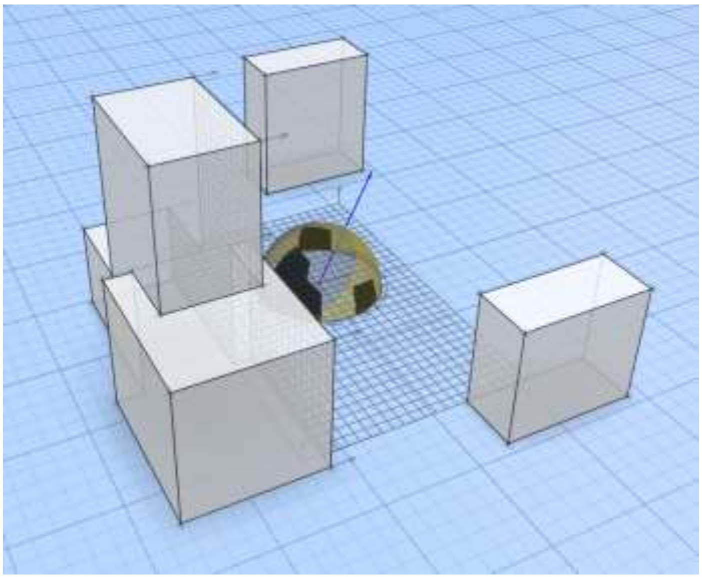


FIG. 23 MASSING SCHEME B

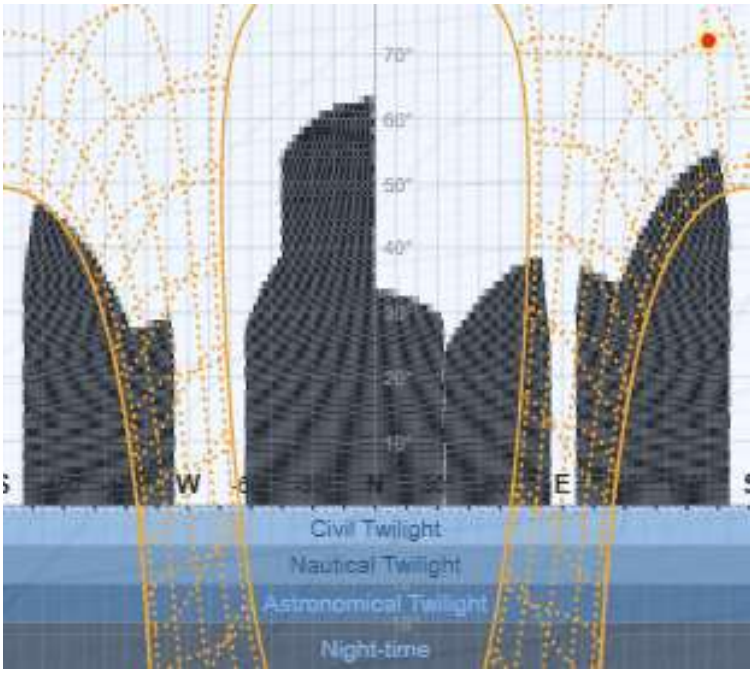


FIG. 24 WALDRAM DIAGRAM A

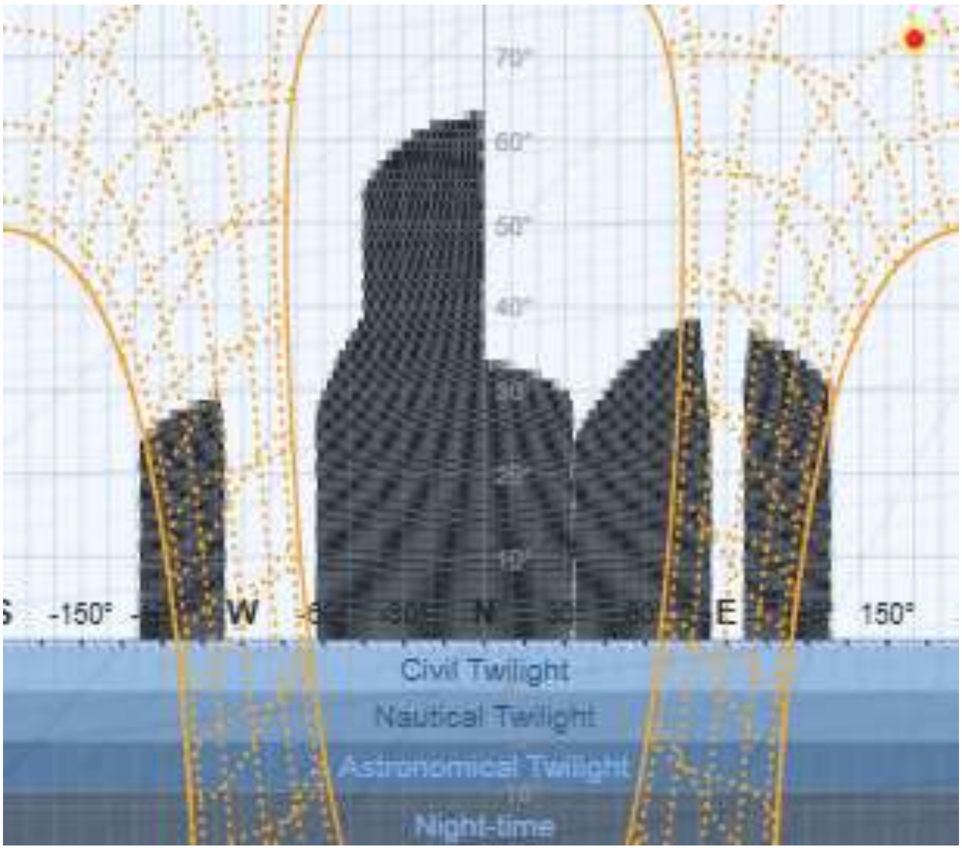


FIG. 25 WALDRAM DIAGRAM B

B-2.3 For bay windows, dormer windows or corner windows the effective dimensions of window opening computed should be taken when using the Table 20, Table 21 and Table 22 to find the sky components.

B-3 CALCULATION OF INTERNAL REFLECTED COMPONENT

B-3.1 The internal reflected component (IRC) is a variable quantity which varies from point to point in a room depending upon the interior finish. IRC value is maximum at the centre of the room and decreases elsewhere in all directions. For processing calculations of IRC at any given point of the room, special techniques have to be made out. The internal reflected component may be calculated by using the formula:

$$IRC = \frac{0.85W}{A(1\text{-R})} \left(CR_{\text{fw}} + 10R_{\text{cw}}\right)$$

where

W = window area;

C = constant of value 78 when there is no external obstruction but it has different values as shown in the following table when there are obstructions;

R_{fw} = average reflection factor of the floor and those parts of the wall below the plane of the mid-height of the window (excluding the window wall);

R_{cw} = average reflection factor of the ceiling and those parts of the wall above the plane of the mid-height of the window (excluding the window wall);

A = area of all the surfaces in the room (ceiling walls, floor and windows); and

R = average reflection factor of all surfaces in the room (ceiling, walls, floor and windows) expressed as a decimal part of unity.

Sl No. (1)	*Angle of Obstruction* Degree (2)	*Sky + External Obstruction* C (3)
i)	5	68.9
ii)	15	50.6
iii)	25	36.2
iv)	35	26.7
v)	45	20.1
vi)	55	15.8
vii)	65	12.9
viii)	75	11.1
ix)	85	10.36

B-3.2 Example

Consider two rooms of dimensions:

Room X = 6 m (l) × 5 m (w) × 3 m (ht)

Room Y = 3.7 m × 3 m × 3 m

Let the window area be 15 percent of the floor area and be glazed.

Window size in room X = 2.5 m × 1.8 m

Window size in room Y = 3.7 m × 3 m

The windows are on the 6 m × 3 m side in room X and 3.7 m × 3 m side in room Y, and the sill heights are 0.9 m from floor level.

Reflection coefficients of:

walls and ceiling = 70 percent
floor = 20 percent
glazing = 15 percent

a) Value of IRC in room X:

1) Total interior area, $A = 2\,(30 + 18 + 15) = 126\ \text{m}^2$;

2) Average reflection factor of interior:

$$R = \frac{(61.5 \times 0.7) + (30 \times 0.7) + (30 \times 0.2) + (4.5 \times 0.15)}{(61.5 + 30 + 30 + 4.5)} = 0.56$$

3) $1 - R = 0.44$;

4) Mid-height of window is 1.83 m from floor, average reflection factor of room below 1.83 m level excluding the wall containing the window:

$$R_{\text{fw}} = \frac{(29.28 \times 0.7) + (30 \times 0.2)}{(29.28 + 30)} = 0.45$$

5) Average reflection factor of room above 1.83 m level excluding the wall containing the window:

$$R_{\mathrm{cw}} = \frac{(18.72 \times 0.7) + (30 \times 0.7)}{(18.72 + 30)} = 0.7$$

6) IRC = $\frac{0.85 \times 4.5}{126 \times 0.44}$ [(78 × 0.45) + (10 × 0.7)] = 2.904.

b) Value of IRC in room Y:

1) Total interior area:

$$A = 2[(3.7 \times 3) + (3.7 \times 3) + (3 \times 3)] = 62.4 \text{ m}^2$$

2) Average reflection factor:

$$R = \frac{(38 \times 55 \times 0.7 \times 3 \times 0.7) + (3.7\times 3 \times 0.2) + (1.5 \times 1.1 \times 0.15)}{(38.55 + 11.1 + 11.1 + 1.65)} = 0.596$$

3) Mid-height of window from floor = 1.46 m;

4) Average reflection factor below 1.46 m level:

$$R_{\mathrm{fw}} = \frac{(3.7 \times 3 \times 0.7) + (1.54 \times 9.7 \times 0.7)}{(11.1 + 14.94)} = 0.48$$

5) Average reflection factor above 1.46 m level:

$$R_{\mathrm{cw}} = \frac{(3.7 \times 3 \times 0.7) + (1.54 \times 9.7 \times 0.7)}{(11.1 + 14.94)} = 0.7$$

6) IRC = $\frac{0.85 \times 1.65}{62.4 \times 0.404}$ [(78 × 0.48) +(10 × 0.7)] = 2.472.

B-4 GENERAL NOTE ON DAYLIGHTING OF BUILDING

B-4.1 The main aim of day lighting design is how to admit enough light for good visibility without setting up uncomfortable glare. No simple solution may be given as the sky varies so much in its brightness from hour to hour, and from season to season.

B-4.2 Different visual tasks need differing amounts of lights for the same visual efficiency. The correct amount of light for any task is determined by the following:

a) *Characteristics of the tasks* — Size of significant detail, contrast of detail with background and how close it is to the eyes;

b) *Sight of the worker* — For example, old people need more light;

c) Speed and accuracy necessary in the performance of work. If no errors are permissible, much more light is needed; and

d) *Ease and comfort of working* — Long and sustained tasks should be done easily whereas workers can make a special effort for tasks of very short duration.

These factors have been made the subject of careful analysis as a result of which tables of necessary levels of illumination have been draw up.

B-4.3 Levels of lighting determined analytically shall be translated into levels of daylight and then into size of window opening or vice versa for checking the size of window assumed for required levels of daylight.

B-4.4 One of the many important factors involved in the translation is the lightness of the room surface. The illumination levels in a given room with a finite window will be higher when the walls are light coloured than when these are dark coloured. It is necessary, therefore, at an early stage to consider the colouring of the rooms of the building and not to leave this until later. Lighting is not merely a matter of window openings and quite half the eventual level of lighting may be dependent on the decoration in the room. Whatever may be the colour the occupant wants to use, it is most desirable to maintain proper values of reflectance factors for ceiling, wall and floors so that the level of daylight illumination is maintained.

Table 20 Percentage Sky Components on the Horizontal Plane Due to a Vertical Rectangular Opening for the Clear Design Sky

(*Clauses* 4.2.5, B-1.1, B-1.2, B-1.5, B-1.6.1, B-1.6.2, *and* B-2.3)

Sl No.	***l/d*** ***h/d***	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1.0**	**1.1**	**1.2**
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
i)	0.1	0.036	0.071	0.104	0.133	0.158	0.179	0.198	0.213	0.225	0.235	0.243	0.250
ii)	0.2	0.141	0.277	0.403	0.516	0.614	0.699	0.770	0.829	0.878	0.918	0.950	0.977
iii)	0.3	0.300	0.589	0.859	1.102	1.315	1.499	1.653	1.782	1.888	1.976	2.048	2.108
iv)	0.4	0.460	0.905	1.322	1.702	2.041	2.337	2.590	2.804	2.984	3.134	3.258	3.361
v)	0.5	0.604	1.189	1.741	2.247	2.700	3.099	3.444	3.740	3.992	4.204	3.383	4.553
vi)	0.6	0.732	1.443	2.114	2.732	3.289	3.781	4.211	4.582	4.900	5.171	5.401	5.596
vii)	0.7	0.844	1.665	2.441	3.159	3.808	4.385	4.891	5.330	5.708	6.034	6.311	6.548
viii)	0.8	0.942	1.858	2.727	3.532	4.262	4.914	5.488	5.989	6.423	6.798	7.119	7.395
ix)	0.9	1.026	2.025	2.974	3.855	4.657	5.375	6.011	6.567	7.051	7.470	7.832	8.144
x)	1.0	1.099	2.169	3.188	4.135	5.000	5.776	6.465	7.071	7.600	8.060	8.458	8.803
xi)	1.1	1.161	2.294	3.372	4.377	5.296	6.124	6.861	7.510	8.079	8.576	9.008	9.383
xii)	1.2	1.215	2.401	3.531	4.586	5.553	6.425	7.204	7.893	8.498	9.027	9.489	9.892
xiii)	1.3	1.262	2.493	3.668	4.767	5.775	6.687	7.503	8.226	8.863	9.422	9.912	10.339
xiv)	1.4	1.302	2.573	3.787	4.924	5.968	6.915	7.764	8.517	9.183	9.769	10.283	10.733
xv)	1.5	1.337	2.643	3.891	5.060	6.136	7.114	7.991	8.772	9.664	10.073	10.609	11.080
xvi)	1.6	1.367	2.703	3.981	5.179	6.283	7.287	8.190	8.996	9.710	10.341	10.897	11.386
xvii)	1.7	1.394	2.756	4.060	5.283	6.412	7.440	8.366	9.192	9.927	10.577	11.151	11.657
xviii)	1.8	1.417	2.803	4.129	5.375	6.526	7.574	8.520	9.366	10.119	10.786	11.376	11.898
xix)	1.9	1.438	2.844	4.190	5.456	6.626	7.693	8.656	9.520	10.289	10.972	11.577	12.112
xx)	2.0	1.456	2.880	4.244	5.527	6.714	7.798	8.778	9.656	10.440	11.137	11.755	12.303
xxi)	3.0	1.559	3.087	4.553	5.937	7.223	8.403	9.478	10.448	11.321	12.103	12.804	13.431
xxii)	4.0	1.600	3.168	4.676	6.100	7.426	8.646	9.759	10.768	11.678	12.498	13.235	13.897
xxiii)	5.0	1.620	3.208	4.735	6.179	7.525	8.765	9.897	10.925	11.854	12.693	13.448	14.128
xxiv)	10.0	1.648	3.263	4.818	6.289	7.662	8.930	10.089	11.144	12.100	12.965	13.747	14.454
xxv)	INF	1.657	3.282	4.846	6.327	7.710	8.986	10.155	11.220	12.186	13.060	13.851	14.567

Table 20 (*Concluded*)

Sl No.	***l/d*** ***h/d***	**1.3**	**1.4**	**1.5**	**1.6**	**1.7**	**1.8**	**1.9**	**2.0**	**3.0**	**4.0**	**5.0**	**10.0**	**INF**
(1)	(2)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)
i)	0.1	0.256	0.261	0.264	0.268	0.270	0.272	0.274	0.276	0.284	0.286	0.287	0.288	0.288
ii)	0.2	0.999	1.018	1.033	1.046	1.056	1.065	1.072	1.079	1.110	1.118	1.122	1.125	1.125
iii)	0.3	2.157	2.197	2.231	2.259	2.282	2.302	2.318	2.333	2.401	2.421	2.429	2.436	2.437
iv)	0.4	3.446	3.516	3.574	3.623	3.664	3.699	3.728	3.753	3.873	3.909	3.922	3.935	3.937
v)	0.5	4.659	4.765	4.853	4.928	4.990	5.043	5.088	5.126	5.312	5.366	5.387	5.408	5.410
vi)	0.6	5.761	5.901	6.020	6.121	6.208	6.281	6.344	6.397	6.661	6.739	6.769	6.798	6.802
vii)	0.7	6.751	6.924	7.071	7.198	7.307	7.400	7.481	7.551	7.902	8.006	8.047	8.087	8.092
viii)	0.8	7.632	7.836	8.011	8.162	8.292	8.405	8.502	8.587	9.029	9.164	9.217	9.268	9.276
ix)	0.9	8.413	8.645	8.846	9.019	9.170	9.301	9.415	9.515	10.045	10.214	10.280	10.345	10.355
x)	1.0	9.102	9.361	9.585	9.780	9.950	10.098	10.228	10.343	10.957	11.162	11.243	11.323	11.335
xi)	1.1	9.709	9.992	10.239	10.454	10.642	10.806	10.951	11.078	11.776	12.017	12.114	12.209	12.224
xii)	1.2	10.243	10.549	10.816	11.050	11.254	11.434	11.593	11.732	12.509	12.786	12.900	13.013	13.030
xiii)	1.3	10.713	11.040	11.326	11.577	11.797	11.992	12.163	12.314	13.167	13.478	13.609	13.742	13.762
xiv)	1.4	11.127	11.473	11.777	12.044	12.279	12.487	12.670	12.833	13.758	14.102	14.251	14.404	14.427
xv)	1.5	11.493	11.857	12.176	12.458	12.707	12.927	13.122	13.295	14.289	14.666	14.832	15.006	15.033
xvi)	1.6	11.817	12.196	12.531	12.826	13.088	13.319	13.525	13.708	14.768	15.176	15.359	15.555	15.585
xvii)	1.7	12.104	12.498	12.846	13.154	13.427	13.669	13.885	14.078	15.199	15.638	15.838	16.056	16.091
xviii)	1.8	12.359	12.766	13.127	13.446	13.730	13.983	14.208	14.409	15.590	16.058	16.274	16.516	16.554
xix)	1.9	12.587	13.006	13.378	13.708	14.002	14.264	14.498	14.707	15.944	16.441	16.673	16.937	16.980
xx)	2.0	12.789	13.220	13.603	13.943	14.246	14.516	14.758	14.975	16.265	16.790	17.037	17.325	17.372
xxi)	3.0	13.993	14.496	14.947	15.353	15.718	16.048	16.346	16.676	18.301	19.051	19.432	19.943	20.046
xxii)	4.0	14.493	15.030	15.514	15.951	16.347	16.706	17.033	17.330	19.241	20.142	20.623	21.322	21.495
xxiii)	5.0	14.742	15.296	15.798	16.252	16.664	17.040	17.382	17.695	19.740	20.740	21.293	22.148	22.393
xxiv)	10.0	15.094	15.674	16.201	16.681	17.118	17.518	17.885	18.222	20.491	21.681	22.390	23.676	24.238
xxv)	INF	15.217	15.806	16.342	16.831	17.278	17.688	18.064	18.410	20.770	22.046	22.838	24.463	26.111

Table 21 Percentage Sky Components on the Vertical Plane Perpendicular to a Vertical Rectangular Opening for the Clear Design Sky

(*Clause* 4.2.5, B-1.1, B-1.2, B-1.5, B-1.6.1 *and* B-2.3)

Sl No.	***l/d*** ***h/d***	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1.0**	**1.1**	**1.2**
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
i)	0.1	0.036	0.141	0.303	0.506	0.734	0.971	1.207	1.432	1.643	2.836	1.011	2.168
ii)	0.2	0.071	0.277	0.594	0.993	1.442	1.910	2.374	2.820	3.236	3.618	3.964	4.276
iii)	0.3	0.103	0.401	0.863	1.445	2.100	2.793	3.475	4.180	4.743	5.306	5.818	6.278
iv)	0.4	0.126	0.491	1.059	1.779	2.597	3.460	4.326	5.166	5.958	6.691	7.359	7.967
v)	0.5	0.142	0.554	1.197	2.015	2.947	3.937	4.938	5.914	6.842	7.707	8.503	9.228
vi)	0.6	0.154	0.600	1.298	2.187	3.204	4.288	5.389	6.468	7.498	8.464	9.358	10.177
vii)	0.7	0.162	0.634	1.372	2.316	3.397	4.552	5.729	6.887	7.997	9.042	10.013	10.907
viii)	0.8	0.169	0.660	1.429	2.413	3.543	4.754	5.990	7.209	8.382	9.490	10.523	11.476
ix)	0.9	0.174	0.680	1.472	2.487	3.655	4.909	6.192	7.460	8.683	9.841	10.924	11.926
x)	1.0	0.178	0.695	1.505	2.545	3.743	5.030	6.350	7.657	8.921	10.120	11.243	12.284
xi)	1.1	0.181	0.707	1.532	2.591	3.812	5.126	6.475	7.814	9.110	10.342	11.498	12.573
xii)	1.2	0.183	0.716	1.552	2.626	3.866	5.202	6.575	7.939	9.261	10.521	11.705	12.807
xiii)	1.3	0.185	0.723	1.568	2.655	3.910	5.263	6.655	8.040	9.384	10.666	11.873	12.998
xiv)	1.4	0.186	0.729	1.582	2.678	3.945	5.312	6.720	8.122	9.484	10.785	12.011	13.155
xv)	1.5	0.188	0.734	1.592	2.697	3.973	5.352	6.773	8.189	9.566	10.883	12.124	13.285
xvi)	1.6	0.189	0.738	1.601	2.712	3.996	5.385	6.816	8.244	9.634	10.963	12.219	13.394
xvii)	1.7	0.189	0.741	1.608	2.724	4.016	5.412	6.852	8.290	9.690	11.031	12.298	13.484
xviii)	1.8	0.190	0.744	1.614	2.735	4.032	5.434	6.882	8.328	9.737	11.087	12.364	13.561
xix)	1.9	0.191	0.746	1.619	2.743	4.045	5.453	6.908	8.360	9.777	11.135	12.420	13.625
xx)	2.0	0.191	0.748	1.623	2.751	4.056	5.469	6.929	8.387	9.811	11.175	12.468	13.680
xxi)	3.0	0.193	0.756	1.642	2.785	4.109	5.544	7.030	8.517	9.972	11.371	12.699	13.950
xxii)	4.0	0.194	0.759	1.648	2.794	4.124	5.566	7.058	8.540	10.018	11.427	12.767	14.029
xxiii)	5.0	0.194	0.760	1.650	2.798	4.129	5.574	7.069	8.568	10.036	11.449	12.793	14.060
xxiv)	10.0	0.194	0.761	1.652	2.801	4.135	5.581	7.080	8.582	10.053	11.470	12.818	14.095
xxv)	INF	0.194	0.761	1.652	2.802	4.136	5.582	7.081	8.584	10.056	11.473	12.822	14.095

Table 21 (*Concluded*)

Sl No.	***l/d*** ***h/d***	**1.3**	**1.4**	**1.5**	**1.6**	**1.7**	**1.8**	**1.9**	**2.0**	**3.0**	**4.0**	**5.0**	**10.0**	**INF**
(1)	(2)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)
i)	0.1	2.308	2.433	2.544	2.642	2.730	2.808	2.878	2.940	3.309	3.461	3.536	3.641	3.678
ii)	0.2	4.554	4.802	5.022	5.219	5.393	5.549	5.688	5.812	6.547	6.850	7.000	7.211	7.284
iii)	0.3	6.690	7.058	7.385	7.677	7.936	8.168	8.375	8.560	9.657	10.110	10.335	10.651	10.760
iv)	0.4	8.507	8.900	9.420	9.804	10.146	10.451	10.724	10.968	12.421	13.024	13.323	13.743	13.889
v)	0.5	9.883	10.472	10.999	11.476	11.897	12.273	12.610	12.912	14.712	15.462	15.835	16.360	16.542
vi)	0.6	10.922	11.596	12.204	12.752	13.244	13.686	14.084	14.441	16.583	17.478	17.924	18.552	18.771
vii)	0.7	11.723	12.465	13.138	13.746	14.296	14.793	15.241	15.646	18.111	19.148	19.665	20.397	20.653
viii)	0.8	12.350	13.147	13.873	14.531	15.129	15.670	16.161	16.606	19.361	20.538	21.127	21.961	22.253
ix)	0.9	12.847	13.690	14.459	15.159	15.796	16.375	16.902	17.381	20.387	21.701	22.360	23.397	23.625
x)	1.0	13.245	14.126	14.931	15.666	16.337	16.948	17.504	18.012	21.237	22.680	23.408	24.446	24.810
xi)	1.1	13.356	14.478	15.314	16.079	16.778	17.416	17.999	18.531	21.946	23.508	24.303	25.441	25.841
xii)	1.2	13.827	14.766	15.628	16.418	17.141	17.802	18.407	18.961	22.543	24.208	25.072	26.309	26.745
xiii)	1.3	14.041	15.003	15.887	16.698	17.442	18.123	18.747	19.320	23.049	24.809	25.735	27.070	27.542
xiv)	1.4	14.217	15.198	16.101	16.931	17.692	18.391	19.032	19.621	23.480	25.326	26.308	27.441	28.249
xv)	1.5	14.364	15.361	16.280	17.125	17.902	18.616	19.272	19.875	23.850	25.772	26.808	28.336	28.880
xvi)	1.6	14.486	15.497	16.430	17.289	18.079	18.806	19.475	20.090	24.169	26.161	27.245	28.866	29.445
xvii)	1.7	14.589	15.511	16.556	17.427	18.229	18.968	19.648	20.274	24.444	26.501	27.629	29.340	29.955
xviii)	1.8	14.675	15.708	16.663	17.545	18.357	19.105	19.795	20.431	24.684	26.799	27.969	29.765	30.416
xix)	1.9	14.749	15.791	16.755	17.645	18.466	19.224	19.922	20.567	24.893	27.062	28.270	30.149	30.835
xx)	2.0	14.811	15.861	16.833	17.731	18.560	19.325	20.031	20.684	25.077	27.294	28.537	30.496	31.217
xxi)	3.0	15.120	16.211	17.224	18.164	19.036	19.844	20.594	21.289	26.082	28.619	30.108	32.676	32.742
xxii)	4.0	15.212	16.316	17.343	18.298	19.185	20.008	20.772	21.483	26.439	29.128	30.745	33.687	35.064
xxiii)	5.0	15.248	16.357	17.390	18.351	19.243	20.073	20.844	21.562	26.592	29.359	31.049	34.232	35.872
xxiv)	10.0	15.283	16.398	17.436	18.403	19.302	20.138	20.917	21.641	26.758	29.624	31.419	35.049	37.513
xxv)	INF	15.288	16.404	17.443	18.411	19.311	20.148	20.928	21.654	26.785	29.672	31.490	35.274	39.172

Table 22 Percentage Sky Components on the Vertical Plane Parallel to a Vertical Rectangular Opening for the Clear Design Sky

(*Clauses* 4.2.5, B-1.1, B-1.2, B-1.5, B-1.6.1 *and* B-2.3)

Sl No.	***l/d*** ***h/d***	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1.0**	**1.1**	**1.2**	**1.3**
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
i)	0.1	0.728	1.429	2.078	2.600	3.167	3.660	3.964	4.265	4.513	4.717	4.883	5.020	5.132
ii)	0.2	1.429	2.803	4.007	5.221	6.220	7.073	7.790	8.385	8.876	9.278	9.609	9.880	10.103
iii)	0.3	2.068	4.061	5.913	7.580	9.040	10.285	11.337	12.212	12.934	13.528	14.016	14.417	14.747
iv)	0.4	2.529	4.970	7.249	9.312	11.133	12.707	14.042	15.164	16.097	16.870	17.507	18.025	18.458
v)	0.5	2.852	5.608	8.186	10.529	12.606	14.401	15.952	17.256	18.350	19.262	20.021	20.652	21.177
vi)	0.6	3.086	6.070	8.867	11.415	13.681	15.656	17.353	18.793	20.008	21.027	21.879	22.592	23.189
vii)	0.7	3.259	6.413	9.373	12.074	14.482	16.588	18.402	19.949	21.257	22.359	23.285	24.063	24.716
viii)	0.8	3.389	6.672	9.755	12.573	15.090	17.296	19.201	20.830	22.212	23.380	24.365	25.195	25.895
ix)	0.9	3.489	6.869	10.046	12.955	15.556	17.840	19.817	21.511	22.952	24.173	25.206	26.078	26.816
x)	1.0	3.565	7.024	10.272	13.250	15.917	18.263	20.297	22.043	23.531	24.795	25.866	26.773	27.542
xi)	1.1	3.625	7.139	10.447	13.481	16.200	18.594	20.674	22.462	23.989	25.288	26.391	27.326	28.121
xii)	1.2	3.672	7.233	10.586	13.663	16.423	18.857	20.973	22.795	24.353	25.681	26.810	27.770	28.587
xiii)	1.3	3.709	7.307	10.696	13.807	16.602	19.067	21.213	23.062	24.646	25.998	27.148	28.128	28.963
xiv)	1.4	3.739	7.366	10.784	13.924	16.745	19.236	21.406	23.278	24.884	26.255	27.424	28.420	29.271
xv)	1.5	3.763	7.414	10.856	14.018	16.861	19.373	21.563	23.454	25.077	26.465	27.649	28.660	29.523
xvi)	1.6	3.783	7.453	10.914	14.095	16.956	19.485	21.692	23.599	25.236	26.638	27.835	28.857	29.732
xvii)	1.7	3.799	7.485	10.962	14.158	17.034	19.578	21.798	23.718	25.368	26.781	27.989	29.022	29.906
xviii)	1.8	3.812	7.512	11.002	14.211	17.099	19.655	21.886	23.817	25.478	26.900	28.118	29.160	30.052
xix)	1.9	3.824	7.534	11.035	14.254	17.153	19.719	21.960	23.900	25.570	27.001	28.226	26.276	30.175
xx)	2.0	3.833	7.553	11.062	14.291	17.199	19.773	22.022	23.970	25.647	27.086	28.318	29.374	31.279
xxi)	3.0	3.876	7.639	11.192	14.463	17.412	20.027	22.316	24.302	26.016	27.491	28.757	29.846	30.783
xxii)	4.0	3.888	7.663	11.228	14.511	17.471	20.098	22.398	24.398	26.121	27.606	28.884	29.983	30.930
xxiii)	5.0	3.893	7.672	11.241	14.529	17.494	20.125	22.430	24.432	26.161	27.650	28.932	30.035	30.986
xxiv)	10.0	3.897	7681	11.254	14.546	17.515	20.150	22.459	24.466	26.199	27.693	28.978	30.085	31.041
xxv)	INF	3.898	7.682	11.256	44.548	17.518	20.154	22.464	24.471	26.205	27.699	28.985	30.093	31.049

Table 22 (*Concluded*)

Sl No.	***l/d***	**1.4**	**1.5**	**1.6**	**1.7**	**1.8**	**1.9**	**2.0**	**3.0**	**4.0**	**5.0**	**10.0**	**INF**
	h/d												
(1)	(2)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)
i)	0.1	5.225	5.301	5.365	5.418	5.463	5.501	5.533	5.687	5.733	5.749	5.765	5.766
ii)	0.2	10.286	10.439	10.565	10.671	10.760	10.835	10.899	11.207	11.296	11.330	11.362	11.365
iii)	0.3	15.020	15.246	15.434	15.591	15.724	15.836	15.931	16.390	16.523	16.574	16.623	16.627
iv)	0.4	18.816	19.113	19.360	19.568	19.742	19.890	20.015	20.624	20.801	20.868	20.933	20.939
v)	0.5	21.613	21.978	22.275	22.530	22.746	22.923	23.082	23.836	24.056	24.140	24.222	24.229
vi)	0.6	23.689	24.109	24.462	24.761	25.014	25.229	25.412	26.229	26.561	26.662	26.759	26.768
vii)	0.7	25.267	25.731	26.124	26.458	26.742	26.984	27.192	28.214	28.517	28.634	28.748	28.758
viii)	0.8	26.486	26.987	27.412	27.775	28.084	28.350	28.578	29.720	30.065	30.198	30.327	30.339
ix)	0.9	27.441	27.972	28.424	28.810	29.141	29.426	29.672	30.927	31.303	31.451	31.596	31.610
x)	1.0	28.196	28.572	29.226	29.633	29.982	30.283	30.544	31.889	32.302	32.467	32.627	32.643
xi)	1.1	28.798	29.375	29.869	30.293	30.658	30.973	31.246	32.670	33.117	33.297	33.473	33.491
xii)	1.2	29.283	29.878	30.388	30.826	31.204	31.532	31.816	33.309	33.796	33.981	34.173	34.193
xiii)	1.3	29.676	30.286	30.810	31.261	31.651	31.989	32.283	33.836	34.350	34.550	34.756	34.779
xiv)	1.4	29.998	30.621	31.157	31.618	32.018	32.365	32.667	34.374	34.813	35.035	35.247	35.271
xv)	1.5	30.262	30.897	31.443	31.914	32.322	32.677	32.986	34.641	35.202	35.436	35.663	35.689
xvi)	1.6	30.482	31.226	31.680	32.160	32.575	32.937	33.253	34.950	35.532	35.776	36.017	36.046
xvii)	1.7	30.665	31.317	31.879	32.366	32.888	33.156	33.477	35.211	35.812	36.067	36.321	36.352
xviii)	1.8	30.818	31.477	32.046	32.539	32.967	33.340	33.666	35.435	36.052	36.316	36.584	36.617
xix)	1.9	30.948	31.613	32.188	32.686	33.119	33.497	33.828	35.626	35.259	36.532	36.812	36.847
xx)	2.0	31.058	31.728	32.308	32.811	33.249	33.631	33.965	35.791	36.438	36.719	37.011	37.048
xxi)	3.0	31.592	32.291	32.898	33.427	33.889	34.294	34.551	36.640	37.380	37.715	38.107	38.157
xxii)	4.0	31.748	32.457	33.074	33.611	34.082	34.496	34.860	36.915	37.699	38.063	38.510	38.579
xxiii)	5.0	31.808	32.521	33.142	33.683	34.157	34.574	34.943	37.028	37.834	38.214	38.696	38.781
xxiv)	10.0	31.867	32.584	33.208	33.753	34.231	34.652	35.024	37.144	37.978	38.382	38.927	39.057
xxv)	INF	31.876	32.593	33.218	33.764	34.243	34.664	35.037	37.162	38.003	38.411	38.978	39.172

ANNEX C

(*Clauses* 4.2.6 *and* 5.4.4.3)

USE OF DESIGN CHARTS FOR NATURAL VENTILATION

C-1 APPLICATION OF THE DESIGN CHARTS

C-1.1 The application of the design charts for natural ventilation (NV) is demonstrated here. The openings for the master-bedroom of the apartment two BHK case in Fig. 26 are sized to deliver the recommended airflow rates for two scenarios of input parameters.

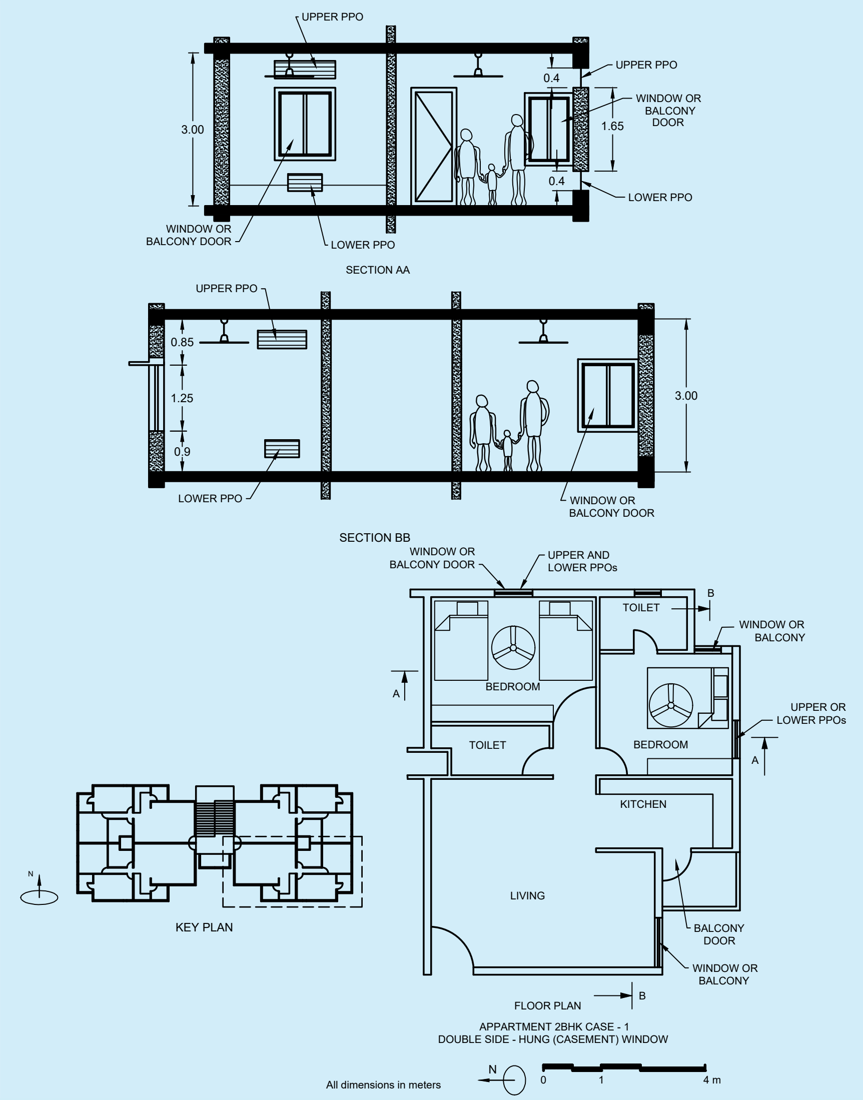

UPPER PPO
UPPER PPO
0.4
WINDOW OR BALCONY DOOR
3.00
1.65
0.4
LOWER PPO
WINDOW OR BALCONY DOOR
LOWER PPO
SECTION AA
UPPER PPO
0.85
1.25
0.9
3.00
LOWER PPO
WINDOW OR BALCONY DOOR
SECTION BB
WINDOW OR BALCONY DOOR
UPPER AND LOWER PPOs
B
TOILET
WINDOW OR BALCONY
A
BEDROOM
UPPER OR LOWER PPOs
TOILET
BEDROOM
A
KITCHEN
N
KEY PLAN
LIVING
BALCONY DOOR
WINDOW OR BALCONY
B
FLOOR PLAN
APPARTMENT 2BHK CASE - 1
DOUBLE SIDE - HUNG (CASEMENT) WINDOW
All dimensions in meters
N
0
1
4 m

Fig. 26 Case Study Apartment Two BHK Case: the Floor Plan with Suggested Layout, Cross - Section AA Showing the Horizontal Sliding (Sash) Windows and Louvers of the Auxiliary PPOs for Ventilation

C-1.2 The input parameters used for the demonstration of the design charts are shown in Table 23. The demonstration is shown for DC-01 in Fig. 26, for DC-02 in Fig. 27, for DC-03 in Fig. 28 and for DC-04 in Fig. 29. The free area for the openings A_f calculated with the DCs are shown in Table 25.

C-1.2.1 *DC*-01 — *Buoyancy-Driven Flow*; *Single-Sided Ventilation with One Opening*

$$A_\mathrm{f} = \frac{q_\mathrm{rec}}{C_\mathrm{d}} \sqrt{\frac{(T_\mathrm{inside} + 273)}{g\, h_\mathrm{a} \Delta T_\mathrm{inside\text{-}outside}}}$$

where

A_f = free area of the openings for NV, m^2;

C_d = discharge coefficient [-];

q_{rec} = ventilation rate achieved, m^3/s;

T_{inside} = temperature inside, °C;

g = acceleration due to gravity, m/s^2;

h_a = vertical distance between the centres of the openings, m; and

$\Delta T_{inside\text{-}outside}$ = [temperature inside (°C) - temperature outside (°C)].

DC-01 is derived from the equation given in **C-1.2.1**. For single openings, the value for C_d adopted is 0.25. The demonstration of the application of this DC for two scenarios (a set of values) and for the input parameters as per Table 23 is shown in Fig. 27.

C-1.2.2 *DC*-02 — *Buoyancy-Driven Flow*; *Cross-Ventilation with Multiple Openings Shown in Fig. 28*

The DC-02 is also derived from the equation given in **C-1.2.3.1**. Conversely, for multiple openings, the value for C_d adopted is 0.61. The demonstration of the application of this DC for two scenarios (a set of values) and for the input parameters shown in Table 23 is shown in Fig. 28.

C-1.2.3 *DC*-03 — *Wind-Driven Flow*; *Single-Sided Ventilation with One Opening Shown in Fig. 29*

DC-03 is derived from the following equation:

$$A_f = q_{rec}/CV_z$$

where

A_f = free area of the openings for NV, m^2;

q_{rec} = ventilation rate achieved, m^3/s;

C = opening shape coefficient, [-]; and

V_z = wind speed at height 'Z', m/s.

C-1.2.3.1 The wind speed is calculated based on the height of the opening and the wind profile adjusted according to the terrain roughness. The equation below defines the wind speed (V_z) at height 'Z' based on the mean wind velocity at 10 m height (V_{ref}) and the characteristics of the roughness of the terrain, employed as an exponent of this power law. For this demonstration 'city terrain' is adopted in the calculations of V_z (input parameters and calculated values are shown in Table 23 and Table 24).

$$V_z = V_{ref}\, k\, z^{\alpha} (\text{m/s})$$

where

V_z = wind speed at height 'Z', m/s;

V_{ref} = mean wind velocity, m/s;

k = terrain-roughness coefficient;

z = height above ground level, m; and

α = terrain roughness exponent.

Table 23 Input Parameters Used for the Demonstration of the Design Charts

(*Clauses* C-1.2, C-1.2.1, C-1.2.2, C-1.2.3.1, C-1.2.3.2, C-1.2.4.1 *and* C-1.2.5)

Sl No.	Input Parameters	Scenario 1	Scenario 2
(1)	(2)	(3)	(4)
i)	q_{rec} (m/s)	0.18	0.35
ii)	ΔT (°C)	3.4	2.6
iii)	T_{inside} (°C)	31.3	31
iv)	$T_{outside}$ (°C)	27.9	28.4
v)	V_{ref} (m/s)	1.8	2.03
vi)	V_r (m/s)	0.98	1.10
vii)	ΔC_p	0.36	0.36
viii)	C_d for single openings	0.25	0.25
ix)	C_d for multiple openings	0.61	0.61
x)	C for single openings	0.05	0.05
xi)	h_a (m)	1.20	1.20
xii)	z (m)	18.00	18.00
xiii)	α	0.33	0.33
xiv)	k	0.21	0.21

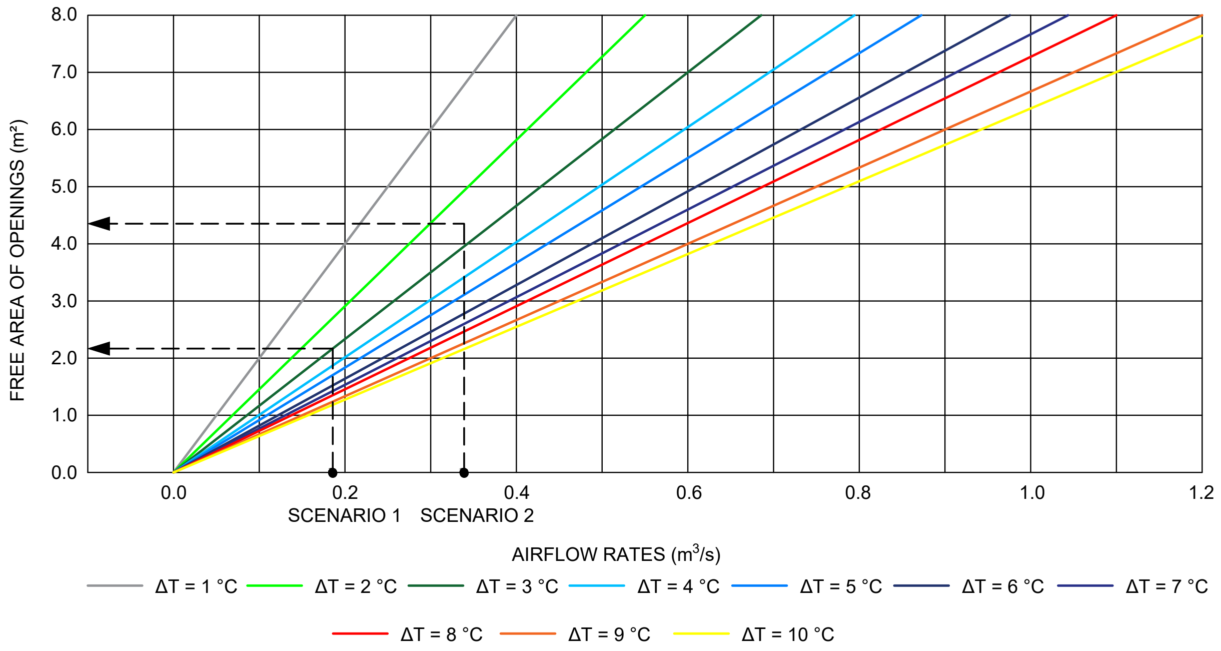


FIG. 27 DEMONSTRATION OF THE APPLICATION OF THE DC-01 (BUOYAN CY-DRIVEN FLOW; SINGLE-SIDED VENTILATION WITH ONE OPENING) FOR BOTH SCENARIOS OF INDIAN CITIES

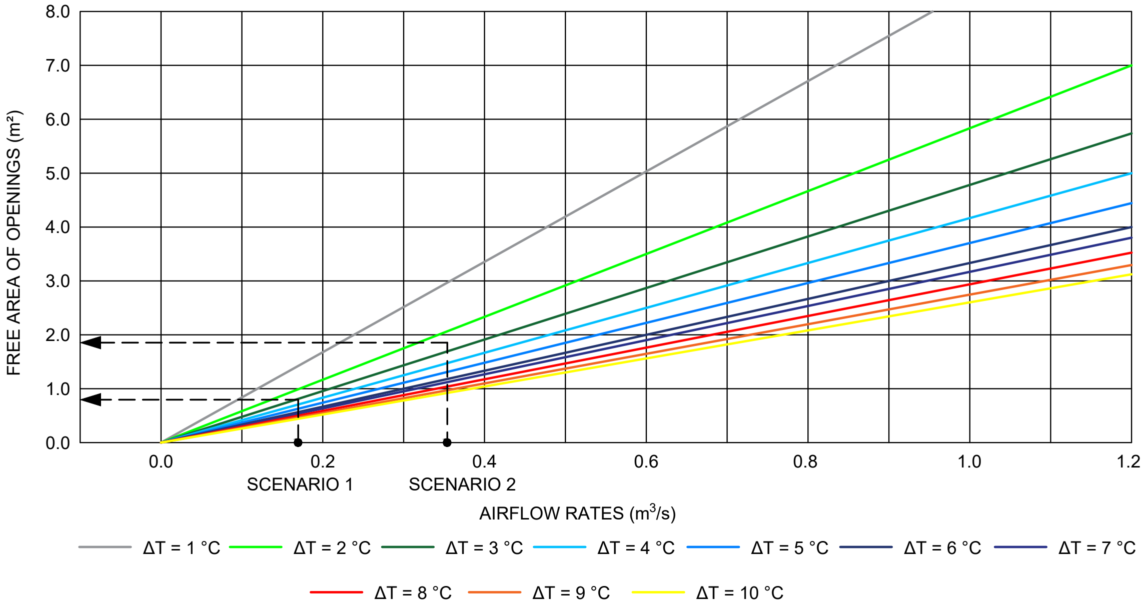


Fig. 28 Demonstration of the Application of the DC-02 (Buoyancy-Driven Flow; Cross-Ventilation with Multiple Openings) for Both Scenarios of Indian Cities

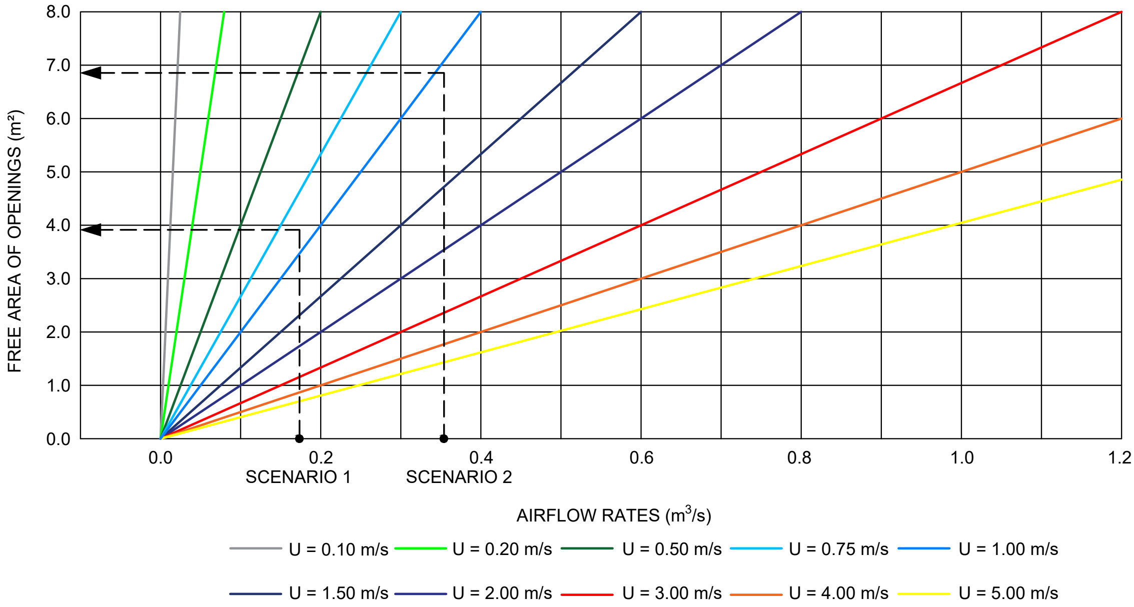


Fig. 29 Demonstration of the Application of the DC-03 (Wind-Driven Flow; Single-Sided Ventilation with One Opening) for Both Scenarios of Indian Cities

Table 24 Exponent Values Based on the Terrain Roughness

(*Clause* C-1.2.3.1)

Sl No.	Terrain Roughness	α	k
(1)	(2)	(3)	(4)
i)	Open country	0.17	0.68
ii)	Few blockages	0.20	0.52
iii)	Urban	0.25	0.35
iv)	City	0.33	0.21

C-1.2.3.2 The demonstration of the application of this DC for both scenarios of Indian cities and for the input parameters shown in Table 23 is shown in Fig. 29.

C-1.2.4 *DC-*04 — *Wind-Driven Flow*; *Cross-Ventilation with Multiple Openings is Derived from the Equation:*

$$A_f = q_{rec}\left(C_d V_z \sqrt{\frac{\Delta C_p}{2}}\right)^{-1}$$

C-1.2.4.1 For orthogonal wind and for the floor plan presented in Fig. 26 for the two bedroom, kitchen and hall, apartment block a pressure coefficient difference (ΔC_p) between inlets and outlets of 0.36 is adopted for this application demonstration (*see* Table 23).

C-1.2.5 The free areas of the openings calculated utilizing the four design charts provided in this design guide for the recommended airflow rates presented in Table 23 and for two scenarios of Indian cities, are given in Table 25.

Table 25 Free Areas of the Openings Calculated Utilizing the Design Charts for Both Scenarios of Indian Cities

(*Clauses* C-1.2 *and* C-1.2.5)

Sl No.	Design Chart	Scenario 1 m^2	Scenario 2 m^2
(1)	(2)	(3)	(4)
i)	DC-01	2.03	4.36
ii)	DC-02	0.83	1.79
iii)	DC-03	4.02	6.90
iv)	DC-04	0.78	1.33

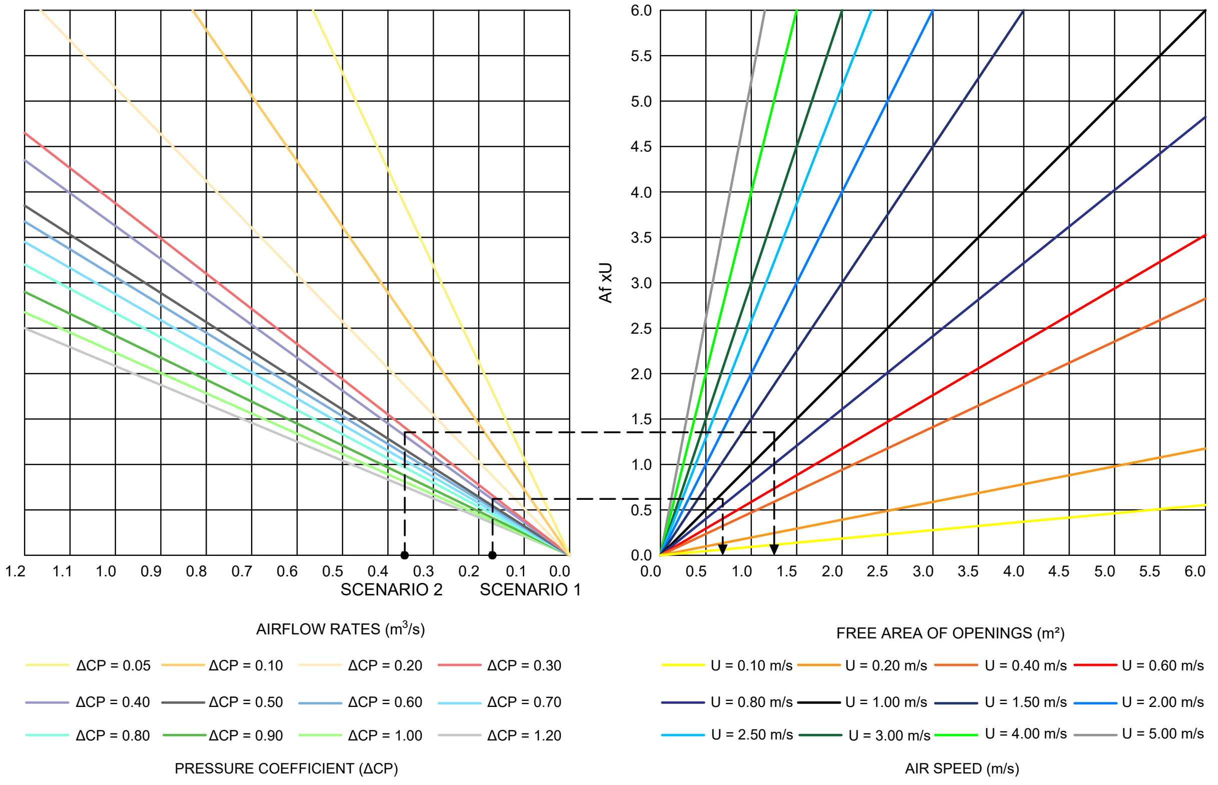


FIG. 30 DEMONSTRATION OF THE APPLICATION OF THE DC-04 (WIND-DRIVEN FLOW; CROSS-VENTILATION WITH MULTIPLE OPENINGS) FOR BOTH SCENARIOS OF INDIAN CITIES

LIST OF STANDARDS

The following list records those standards which are acceptable as 'good practice' and 'accepted standards' in the fulfilment of the requirements of this NBCS. The latest version of a standard shall be adopted at the time of enforcement of this NBCS. The standards listed may be used as a guide in conformance with the requirements of the referred clauses in this NBCS.

	IS No.	*Title*
(1)	IS 7662 (Part 1) : 1974	Recommendations for orientation of buildings: Part 1 Nonindustrial buildings
(2)	IS 4963 : 2025	Accessibility in built environment for older adults and persons with disabilities — Requirements (*second revision*)
(3)	SP 72 : 2025	National Lighting Code of India 2025 (*first revision*)
(4)	IS 3646 (Part 1) : 2025	Interior illumination — Code of practice: Part 1 General requirements and recommendations for working interiors (*second revision*)
(5)	IS 2440 : 1975	Guide for daylighting of buildings (*second revision*)
(6)	IS 6060 : 1971	Code of practice for daylighting of factory buildings
	IS 7942 : 1976	Code of practice for daylighting of educational buildings
(7)	SP 41 (S&T) : 1987	Handbook on functional requirements of buildings (other than industrial buildings)
(8)	IS 1944	Code of practice for lighting of public thoroughfares:
	(Parts 1 and 2) : 1970	Part 1 General Principles and Part 2 Lighting for traffic routes (Groups A1, A2, B1 and B2) (*first revision*)
	(Part 6) : 1981	Lighting for town and city centres and areas of civic importance (Group E)
	IS 2672 : 1966	Code of practice for library lighting
	IS 4347 : 1967	Code of practice for hospital lighting
	IS 6074 : 1971	Code of practice for functional requirements of hotels, restaurants and other food service establishments
	IS 6665 : 1972	Code of practice for industrial lighting
	IS 10894 : 1984	Code of practice for lighting of educational institutions
	IS 10947 : 1984	Code of practice for lighting for ports and harbours
(9)	IS 3362 : 1977	Code of practice for natural ventilation of residential buildings (*first revision*)

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NATIONAL BUILDING CONSTRUCTION STANDARDS

PART D BUILDING SERVICES

SECTION 2 ELECTRICAL AND ALLIED INSTALLATIONS

BUREAU OF INDIAN STANDARDS

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National Building Code Sectional Committee, CED 46

FOREWORD

This NBCS (Part D/Section 2) covers the general requirements for electrical and allied installations in buildings. For more details, it is essential to refer to the relevant Indian Standards on the subject.

This Section was first published in 1970 as part of the National Building Code of India and was subsequently revised in 1983, 2005 and 2016. In the first revision in 1983, general guidance for electrical wiring installation in industrial location where voltage supply normally exceeds 650 V was included. This Section was also updated based on the existing version of the Indian Standards. The importance of pre-planning and exchange of information among all concerned agencies from the earlier stages of building work was emphasized.

In the second revision of 2005, the title of this Section was modified from the erstwhile 'Electrical Installations' to 'Electrical and Allied Installations' to reflect the provisions included on certain allied installations. The significant changes incorporated in this revision included, thorough change in the risk assessment procedure for lightning including some other changes in the provision of lightning protection of building; alignment of some of the provisions of wiring with the practices prevalent at that time; modification of definitions in line with terminologies used at national and international levels and addition of some new definitions; incorporation of provisions on installation of distribution transformer inside the multistoreyed buildings; introduction of concept of energy conservation in lighting and introduction of concept of various types of earthing in building installations.

In the third revision in 2016, various updates were made including: location and other requirements relating to layout, environmental and safety aspects for different substation apparatus/equipment and generating sets were reviewed and updated; location of compact substations was included; requirements for electrical supply system for life and safety services were included; provisions relating to reception and distribution of supply and wiring installations were updated; installation best practices of energy meters were updated; discrimination, cascading and limitation concepts for the coordination of protective devices in electrical circuits were introduced; socket outlets with suitable circuit breakers, conforming to Indian Standards were recommended for industrial and commercial applications, either indoors or outdoors; provisions relating to earthing/grounding were substantially revised and updated; provisions relating to lightning protection of buildings were revamped based on the national and international developments then; provisions relating to renewable energy sources for building, such as solar PV system, aviation obstacle lights, electrical supply for electric vehicle charging and car park management, etc, were included; provisions relating to electrical installations for construction sites and demolition sites were included; provisions relating to protection of human beings from electrical hazards and protection against fire in the building due to leakage current were included; typical formats for checklists for handing over and commissioning of substation equipment and earthing pit were included; and the terminologies updated.

In this revision, the publication has been renamed as National Building Construction Standards (NBCS).

All electrical installations in India come under the purview of *The Indian Electricity Act*, 2003 and the rules and regulations framed thereunder. In the context of the buildings, both buildings (the structure itself) and the building services (not just the electrical services, but all other services that use electricity or have an interface with the electrical system) are required to follow these. The erstwhile *Indian Electricity Rules*, 1956 were modified by various Central Electricity Authority Regulations. While revising the provisions of this Section of the NBCS, care has been taken to align the same with the provisions of the relevant regulations, particularly, *Central Electricity Authority* (*Measures Relating to Safety and Electric Supply*) *Regulations*, 2023. In this revision, in addition to above, the following major modifications have been incorporated:

a) Various terms and their definitions have been reviewed based on current developments at national and international level. In addition, few more definitions have been added for more clarity and better understanding;

b) Voltage categorization for building has been made considering revision in voltage norms by CEA, Indian Standards and various State Electricity Boards;

c) Provisions relating to location and other requirements relating to layout, environmental and safety aspects for different substation apparatus/equipment and generating sets have been reviewed and updated;

d) Requirements for electrical supply system for life and safety services have been reviewed;

e) Provisions relating to reception and distribution of supply and wiring installations have been updated with due cognizance to Indian Standards formulated for various wiring systems;

f) Provisions relating to installation of energy meters have been updated;

g) Discrimination, cascading and limitation concepts for the coordination of protective devices in electrical circuits have been updated;

h) Socket-outlets with suitable circuit breakers, conforming to IS 1293 : 2019 'Plugs and socket-outlets for household and similar purposes of rated voltage up to and including 250 V and rated current up to and including 16 A — Specification (*fourth revision*)' have been recommended for industrial and commercial applications, either indoors or outdoors.

j) Provisions relating to earthing/grounding have been substantially revised and updated;

k) Provisions relating to lightning protection of buildings have been reviewed and updated based on the current national and international developments;

m) Provisions relating to renewable energy sources for building, such as rooftop solar photovoltaic (PV) system has been updated and building integrated photovoltaic (BIPV) system and solar water heating system have been included;

n) Provisions relating to electrical installations for construction sites and demolition sites have been reviewed and updated;

p) Provisions related to electric vehicles (EV) charging have been updated as per present norms;

q) Provisions relating to protection of human beings from electrical hazards and protection against fire in the building due to leakage current have been reviewed and updated;

r) Provisions on building management systems (BMS) have been updated in **10.4**; and

s) Provisions on power fence (electrical fence) system has been included in **10.11**.

This Section has to be read together with Part D 'Building Services, Section 1 Lighting and Natural Ventilation' of this NBCS for making provision for the desired levels of illumination as well as ventilation for different locations in different occupancies; Part D 'Building Services, Section 6 Information and Communication Enabled Installations'; Part F 'Fire and Life Safety' of this NBCS for list of emergency fire and life safety services and other sections of Part D 'Building Services' and Part E 'Plumbing Services' for electricity related requirements and integration thereof. Utmost importance should be given in the installation of electrical wiring to prevent short circuiting and the hazards associated therewith.

Notwithstanding the provisions given in this Section and the National Electrical Code 2023, the provisions of the *Central Electrical Authority* regulations framed under the *Indian Electricity Act*, 2003 as amended up to date have to be necessarily complied with.

The information contained in this section is largely based on the following Indian Standards/Special Publications:

IS 732 : 2019	Code of practice for electrical wiring installations (*fourth revision*)
IS 3043 : 2018	Code of practice for earthing (*second revision*)
IS 4648 : 1968	Guide for electrical layout in residential buildings
IS 19127 : 2025	Graphical symbols for diagrams in the field of electrotechnology
IS/IEC 62305-1 : 2010	Protection against lightning: Part 1 General principles
IS/IEC 62305-2 : 2010	Protection against lightning: Part 2 Risk management
IS/IEC 62305-3 : 2010	Protection against lightning: Part 3 Physical damage to structures and life hazard

IS/IEC 62305-4 : 2010	Protection against lightning: Part 4 Electrical and electronic systems within structures
IS 17017-1 : 2018	Electric vehicle conductive charging system: Part 1 General requirement
IS 17017-2 : 2020	Electric vehicle conductive charging system: Part 2 Plugs, socket-outlets, vehicle connectors, and vehicle inlets (*all sections*)
IS 18925 : 2025 (Parts 1 to 8)	Lightning protection system components
SP 30 : 2023	National Electrical Code of India, 2023 (*second revision*)

It may be noted that some of the above standards are currently under revision. The revised version when available should be referred.

Considerable assistance has also been drawn from following International Standards while formulating this Section:

IEC 62305 : 2024	Protection against lightning:
(Part 1) : 2024	General principles
(Part 2) : 2024	Risk management
(Part 3) : 2024	Physical damage to structures and life hazard
(Part 4) : 2024	Electrical and electronic systems within structures
IEC 60335-2-76 : 2018	Household and similar electrical appliances — Safety — Part 2-76: Particular requirements for electric fence energizers
IEC 60364-4-41 : 2005	Low-voltage electrical installations — Part 4-41: Protection for safety — Protection against electric shock
IEC 60364-4-43 : 2023	Low-voltage electrical installations — Part 4-43: Protection for safety — Protection against overcurrent
IEC 60364-4-44 : 2007	Low-voltage electrical installations — Part 4-44: Protection for safety — Protection against voltage disturbances and electromagnetic disturbances
IEC 60364-5-51 : 2005	Electrical installations of buildings — Part 5-51: Selection and erection of electrical equipment – Common rules
IEC 60364-5-54 : 2011	Low-voltage electrical installations — Part 5-54: Selection and erection of electrical equipment — Earthing arrangements and protective conductors
IEC 60364-7 series	Low-voltage electrical installations — Part 7: Requirements for special installations or locations
IEC 61439-1 : 2020	Low-voltage switchgear and controlgear assemblies — Part 1: General rules
IEC 61439-2 : 2020	Low-voltage switchgear and controlgear assemblies — Part 2: Power switchgear and controlgear assemblies
IEC 61439-6 : 2012	Low-voltage switchgear and controlgear assemblies — Part 6: Busbar trunking systems (busways)

All standards, whether given herein above or cross-referred to in the main text of this Section, are subject to revision. The parties to agreement based on this Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

As the regulation of land development and buildings is a State subject and is dealt by the States and local bodies such as urban local bodies within their jurisdiction through building regulatory documents like building regulations, building byelaws, and fire regulations, this document is voluntary in nature and is non-binding. The implementation depends on adoption by concerned parties or stipulations in a contract or by appropriate adoption by the concerned authorities.

For the purpose of deciding whether a particular requirement of this Section is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 ‘Rules for rounding off numerical values (*second revision*)’. The number of significant places retained in the rounded off value should be the same as that of the specified value in this Section of the NBCS.

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Important Explanatory Note for Users of this NBCS

In any Part/Section of this NBCS, where reference is made to **'good practice'** in relation to design, constructional procedures or other related information, and where reference is made to **'accepted standard'** in relation to material specification, testing, or other related information, the Indian Standards listed at the end of the Part/Section shall be used as a guide to the interpretation.

At the time of publication, the editions indicated in the standards were valid. All standards are subject to revision and parties to agreements based on any Part/Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

In the list of standards given at the end of a Part/Section, the number appearing within parentheses in the first column indicates the number of the reference of the standard in the Part/Section. For example:

a) Good practice [D-2(1)] refers to the Indian Standard/Special Publication given at serial number (1) of the List of Standards given at the end of this Part D/Section 2, that is, SP 30 : 2023, 'National Electrical Code of India, 2023 (*second revision*)'

NATIONAL BUILDING COSTRUCTION STANDARDS

PART D BUILDING SERVICES

SECTION 2 ELECTRICAL AND ALLIED INSTALLATIONS

1 SCOPE

This NBCS (Part D/Section 2) covers the essential requirements for electrical installations in buildings to ensure efficient use of electricity including safety from fire and shock, reliability and sustainability. This Section also includes general requirements relating to renewable energy sources, EV charging, lightning protection of buildings and brief provisions on allied installations.

2 TERMINOLOGY AND CONVENTIONAL SYMBOLS

2.1 For the purpose of this Section, the following definitions shall apply. For definition of other terms, reference may be made to good practice [D-2(1)] and accepted standard [D-2(2)].

2.1.1 *Accessory* — A device, other than current using equipment, associated with such equipment or with the wiring of an installation.

2.1.2 *Apparatus* — Electrical apparatus including all machines, appliances and fittings in which conductors are used or of which they form a part.

2.1.3 *Appliance* — An item of current using equipment other than a luminaire or an independent motor.

2.1.4 *Back-up Protection* — Protection which is intended to operate when a system fault is not cleared or abnormal condition not detected in the required time, because of failure or inability of other protection to operate or failure of appropriate circuit-breaker to trip.

2.1.5 *Barrier* — A part providing a defined degree of protection against contact with live parts, from any usual direction of access.

2.1.6 *Basic Protection* — Protection against electric shock under fault-free condition.

NOTE — For low voltage installations, systems and equipment, basic protection generally corresponds to protection against direct contact that is ‘contact of persons or live parts’.

2.1.7 *Battery Energy Storage System* (*BESS*) — Electrical energy storage system with an accumulation subsystem based on batteries fitted with secondary cells.

2.1.8 *Bonding Conductor* — A protective conductor providing equipotential bonding.

2.1.9 *Bonding Ring Conductor* (*BRC*) — A bus earthing conductor in the form of a closed ring.

NOTE — Normally the bonding ring conductor, as part of the bonding network, has multiple connections to the common bonding network (CBN) that improves its performance.

2.1.10 *Branch Switch* — A miniature circuit breaker that protects a specific branch circuit within a larger power distribution circuit, such as a house or building. It acts as a safety device, automatically interrupting the flow of electricity in the event of an overload or short circuit, preventing damage to wiring and appliances.

2.1.11 *Bunched* — Cables are said to be ‘bunched’ when two or more are contained within a single conduit, duct, ducting, or trunking, or, if not enclosed, are not separated from each other.

2.1.12 *Buried Direct* — A cable laid in the ground in intimate contact with the soil.

2.1.13 *Busbar Trunking System* — A type-tested assembly, in the form of an enclosed conductor system of comprising solid conductors separated by insulating materials. The assembly may consist of units such as:

a) Busbar trunking units, with or without tap-off facilities;

b) Tap-off units where applicable; and

c) Phase-transposition, expansion, building-movement, flexible, end-feeder and adaptor units.

2.1.14 *Bypass Equipotential Bonding Conductor* — Bonding conductor connected in parallel with the screens of cables.

2.1.15 *Cable* — A length of single-insulated conductor (solid or stranded), or two or more such conductors, each provided with its own insulation, which are laid up together. The insulated conductor or conductors may or may not be provided with an overall mechanical protective covering.

2.1.16 *Cable*, *Fire Survival* — A cable which continues to function and maintain the circuit integrity under circumstances of fire (against a specified temperature and period of the test) {*see* accepted standards [D-2(3)]}.

2.1.17 *Cable, Flame Retardant* (*FR*) — A cable which is flame retardant as per the accepted standard [D-2(4)].

2.1.18 *Cable*, *Flame Retardant Low Smoke and Halogen* (FR-LSH) — A cable which is flame retardant and emits low smoke and halogen as per the accepted standard [D-2(5)].

2.1.19 *Cable*, *Flexible* — A cable containing one or more cores, each formed of a group of wires, the diameters of the cores and of the wires being sufficiently small to afford flexibility.

2.1.20 *Cable*, *Metal-Sheathed* — An insulated cable with a metal sheath.

2.1.21 *Cable*, *PVC Sheathed-Insulated* — A cable in which the insulation of the conductor is a polyvinylchloride (PVC) compound; with PVC sheath also providing mechanical protection to the conductor core or cores in the cable.

2.1.22 *Cable*, *Weatherproof* — A cable so constructed that when installed in uncovered locations, it will withstand all kinds of weather variations (*see* **2.1.195** for definition of weatherproof).

2.1.23 *Cable*, *XLPE* — A cable in which the insulation of the conductor is cross-linked polythene and the mechanical protection is provided for the core or cores by a sheath of a polyvinyl chloride compound.

2.1.24 *Cable Armoured* — A cable provided with a wrapping of metal (usually in the form of tape or wire) serving as a mechanical protection.

2.1.25 *Cable Bracket* — A cable support consisting of single devices fixed to elements of building or plant construction.

2.1.26 *Cable Channel* — An enclosure situated above or in the ground, open or ventilated or closed, and having dimensions which do not permit the access of persons but allow access to the conductor and/or cables throughout their length during and after installation.

NOTE — A cable channel may or may not form part of the building construction.

2.1.27 *Cable Cleat* — A component of a support system which consists of elements spread at intervals along the length of the cable or conduits and which mechanically retains the cable or conduit.

2.1.28 *Cable Coupler* — A means enabling the connection, at will, of two flexible cables. It consists of a connector and a plug.

2.1.29 *Cable Ducting* — A manufactured enclosure of metal or insulating material, other than conduit or cable trunking, intended for the protection of cables which are drawn-in after erection of the ducting, but which is not specifically intended to form part of a building structure.

2.1.30 *Cable Ladder* — A cable support occupying less than 10 percent of the plan area and consisting of a series of supporting elements rigidly fixed to each other or to a main supporting member or members.

2.1.31 *Cable Raceways* — An enclosed channel of metal or non-metallic materials designed expressly for holding wires, cables or busbars, with openable/maintainable construction having provision of ventilation. These include electrical non-metallic tubing, electrical metallic tubing, underfloor raceways, cellular concrete floor raceways, cellular metal floor raceways, surface raceways and wireways.

2.1.32 *Cable Support and Fixing Materials* (*Fire Survival*) — Supports and fixing materials for supporting fire survival cable (*see* **2.1.16**), which continues in service after exposure to fire for a specified duration.

2.1.33 *Cable Tray* — A cable support consisting of a continuous base with raised edges and no covering. The classification and perforation of cable tray shall be as per accepted standard [D-2(6)].

2.1.34 *Cable Trunking* — A factory made closed support and protection system into which conductors and/or cables are laid after removal of the cover.

2.1.35 *Cable Tunnel* — An enclosure (corridor) containing supporting structures for conductors and/or cables and joints and whose dimensions allow free access to persons throughout the entire length.

2.1.36 *Cartridge Fuse Link* — A device comprising a fuse element or several fuse elements connected in parallel enclosed in a cartridge usually filled with an arc-extinguishing medium and connected to terminations. The fuse link is the part of a fuse which requires replacing after the fuse has operated.

2.1.37 *Ceiling Rose* — A fitting (usually used to attach to the ceiling) designed for the connection between the electrical installation wiring and a flexible cord (which is in turn connected to a lamp holder).

2.1.38 *Circuit* — An assembly of electrical equipment supplied from the same origin and protected against overcurrent by the same protective device(s). Circuits are categorized as follows:

a) *Category* 1 *circuit* — A circuit (other than a fire alarm annunciation or emergency lighting circuit and other circuits required to work during fire in a building) operating at low voltage and supplied directly from a mains supply system;

b) *Category* 2 *circuit* — With the exception of Category 3 circuits, any circuit for extra low-voltage (ELV)/telecommunication [for example, radio, telephone, sound distribution, building management system (BMS), public address system (PAS), intruder alarm, bell and call and data transmission circuits] which is supplied from a safety source; and

c) *Category* 3 *circuit* — A fire alarm circuit or an emergency lighting circuit and other circuits required to work during fire in a building.

2.1.39 *Circuit Breaker* — A mechanical switching device, capable of making, carrying and breaking currents under normal circuit conditions and also of making, carrying for a specified time, and breaking currents under specified abnormal circuit conditions such as those of short circuit.

NOTE — A circuit breaker is usually intended to operate infrequently, although some types are suitable for frequent operation.

2.1.39.1 *Miniature circuit breaker* (*MCB*) — A compact mechanical switching device capable of making, carrying and breaking currents under normal circuit conditions and also making and carrying currents for specified times and automatically breaking currents under specified abnormal circuit conditions, such as those of overload and short circuits.

2.1.39.2 *Circuit breaker*, *linked* — A circuit breaker, the contacts of which are so arranged as to make or break all poles simultaneously or in a definite sequence.

2.1.39.3 *Moulded case circuit breaker* (*MCCB*) — A circuit breaker having a supporting housing of moulded insulating material forming an integral part of the circuit breaker.

2.1.39.4 *Air circuit breaker* (*ACB*) — A circuit breaker in which the contacts open and close in air at atmospheric pressure.

2.1.40 *Circuit*, *Final Sub* — An outgoing circuit connected to one-way distribution board and intended to supply electrical energy at one or more points to current, using appliances without the intervention of a further distribution board other than a one-way board. It includes all branches and extensions derived from that particular way in the board.

2.1.41 *Compact Substation or Prefabricated Substation* — Prefabricated and type-tested assembly which can to be operated from inside (walk-in type) or outside (non-walk-in type) comprising components such as power transformer, high-voltage switchgear and controlgear, low-voltage switchgear and controlgear, corresponding interconnections (cable, busbar or other) and auxiliary equipment and circuits located next to each other, maintaining segregation and integrity of each compartment in which they are located along with external interconnecting cables, earthing, protections, etc. The components shall be enclosed by either a common enclosure or by an assembly of enclosures.

NOTE — *See* accepted standard [D-2(7)] for requirements of prefabricated substation.

2.1.42 *Conductor, Aerial* — Any conductor which is supported by insulators above the ground and is directly exposed to the weather.

NOTE — Following four classes of aerial conductors are recognized:

a) Bare aerial conductors;

b) Covered aerial conductors;

c) Insulated aerial conductors; and

d) Weatherproof neutral-screened cable.

2.1.43 *Conductor*, *Bare* — A conductor not covered with insulating material.

2.1.44 *Conductor, Earthed* — A conductor with no provision for its insulation from earth.

2.1.45 *Conductor*, *Insulated* — A conductor adequately covered with insulating material of such quality and thickness as to prevent danger.

2.1.46 *Conductor of a Cable or Core* — The conducting portion consisting of a single wire or group of wires, assembled together and in contact with each other or connected in parallel.

2.1.47 *Conduit* — A part of a closed wiring system, a circular or non-circular cross section for conductors and/or cables in electrical installations, allowing them to be drawn in and/or replaced. Conduits should be sufficiently closed-jointed so that the conductors can only be drawn in and not inserted laterally.

2.1.48 *Connector* — The part of a cable coupler or of an appliance coupler which is provided with female contact and is intended to be attached to the flexible cable connected to the supply.

2.1.49 *Connector Box or Joint Box* — A box forming a part of wiring installation, provided to contain joints in the conductors of cables of the installations.

2.1.50 *Connector for Portable Appliances* — A combination of a plug and socket arranged for attachment to a portable electrical appliance or to a flexible cord.

2.1.51 *Consumer's Terminals* — The ends of the electrical conductors situated upon any consumer's premises and belonging to him, at which the supply of energy is delivered from the service line.

2.1.52 *Continuous Operating Voltage* (U_c) — Maximum rms voltage which may be continuously applied to a surge protection device's mode of protection. This is equal to rated voltage.

2.1.53 *Cord, Flexible* — A flexible cable having a large number of strands of conductors of small cross-sectional area. Two flexible cords twisted together are known as twin ‘flexible cord’.

NOTE — Large number of fine strands of wires for each conductor makes the conductor capable of withstanding frequent bends thereby improving their flexibility.

2.1.54 *Core of a Cable* — A single conductor of a cable with its insulation but not including any mechanical protective covering.

2.1.55 *Current Carrying Capacity of a Conductor* — The maximum current which can be carried by a conductor under specified conditions without its steady state temperature exceeding a specified value.

2.1.56 *Current Using Equipment* — Equipment which converts electrical energy in to another form of energy, such as light, heat, or motive power.

2.1.57 *Cut-out* — Any appliance for automatically interrupting the transmission of energy through any conductor when the current rises above a pre-determined amount.

2.1.58 *Damp Situation* — A situation in which moisture is either permanently present or intermittently present to such an extent as likely to impair the effectiveness of an installation conforming to the requirements for ordinary situations.

2.1.59 *Danger* — Danger to health or danger to life or limb from shock, burn or injury from mechanical movement to persons (and livestock where present), or from fire attendant upon the use of electrical energy.

2.1.60 *Datacentre* — A structure, or group of structures, dedicated to the centralized accommodation, interconnection and operation of information technology and network telecommunications equipment providing data storage and processing with the necessary levels of resilience and security required to provide the desired service availability.

2.1.61 *Dead* — A portion of an electrical circuit (normally expected to carry a voltage) at or near earth potential or apparently disconnected from any live system. A circuit apparently disconnected from all sources is expected to be at earth potential; but capacitive storage of charge in cables, capacitors, etc, can keep the electric circuit at a significant voltage (and often dangerous voltages from aspects of shock). Such circuits with storage components will be dead only on connection to earth.

2.1.62 *Design Current* (*of a Circuit*) — The magnitude of the current intended to be carried by the circuit in normal service.

2.1.63 *Direct Contact* — Contact of persons or live stock with live parts which may result in electric shock.

2.1.64 *Discrimination* (*Selectivity-Over-Current Discrimination*) — Coordination of the operating characteristics of two or more over-current protective devices should be such that, on the incidence of over-currents within stated limits, the device intended to operate would be the device closest to the point of fault or abnormality, and if proper discrimination is achieved within these limits, only that device closest should operate, while the other circuit breakers upstream do not operate, thereby ensuring that there is minimum area of power supply which is interrupted.

NOTES

1 Protective devices should have discrimination so that only the affected part (minimum section) of the circuit is isolated, even though a number of protective devices may be in the path of the overcurrent.

2 The electrical network requires the discrimination for all the fault circuits, including overload, short-circuit, etc. The downstream device should take care of the fault up to the level of ultimate short-circuit breaking capacity (*I*cu) of the downstream breaker which should be equal to the bus which is connected.

3 Distinction is made between series discrimination involving different over-current protective devices passing substantially the same over-current and network discrimination involving identical protective devices passing different proportions of the over-current.

4 Different types of protective devices may have to be used to ensure effective discrimination in circuits where proper and effective discrimination is necessary. Apart from the built-in sensors and actuators in circuit breakers, external relays operating on different parameters, and comparison of parameters between two or more points will have to be used for complex installations.

5 *See also* relevant parts of the accepted standard [D-2(8)].

2.1.65 *Disconnector* — A mechanical switching device which, in the open position, complies with the requirements specified for the isolation function.

NOTES

1 A disconnector is otherwise known as isolator.

2 A disconnector is capable of opening and closing a circuit when either a negligible current is broken or made, or when no significant change in the voltage across the terminals of each pole of the disconnector occurs. It is also capable of carrying currents under normal circuit conditions and carrying for a specified time, current under abnormal conditions, such as those of short-circuit.

2.1.66 *Distance Area or Resistance Area* (*for an Earth Electrode Only*) — The surface area of ground (around an earth electrode) on which a significant voltage gradient may exist.

2.1.67 *Diversity Factor* — A measure of the probability that a particular piece of equipment will turn on coincidentally to another piece of equipment. For aggregate systems it is defined as the ratio of the sum of the individual non-coincident maximum loads of various subdivisions of the system to the maximum demand of the complete system.

2.1.68 *Duct* — A closed passage way formed underground or in a structure and intended to receive one or more cables which may be drawn in.

2.1.69 *Ducting — See* **2.1.29**.

2.1.70 *Earth* — The conductive mass of the earth, whose electric potential at any point is conventionally taken as zero.

2.1.71 *Earth Continuity Conductor* — The conductor, including any clamp, connecting to the earthing lead or to each other, those parts of an installation which are required to be earthed. It may be in whole or in part, the metal conduit or the metal sheath or armour of the cables, or the special continuity conductor of a cable or flexible cord incorporating such a conductor.

2.1.72 *Earthed Concentric Wiring* — A wiring system in which one or more insulated conductors are completely surrounded throughout their length by a conductor, for example a sheath, which acts as a PEN conductor.

2.1.73 *Earth Electrode* — A conductor or group of conductors in intimate contact with the ground to provide a low resistance path for flow of current to earth.

2.1.74 *Earth Electrode Network* — Part of an earthing arrangement comprising of only the earth electrodes and their interconnections.

2.1.75 *Earth Electrode Resistance* — The resistance of an earth electrode to earth.

2.1.76 *Earth Fault* — An unintended and undesirable connection of phase/neutral conductor to earth. When the impedance is negligible, the connection is called a dead earth fault.

2.1.77 *Earth Fault Current* — A current resulting from a fault of negligible impedance between a line conductor and an exposed conductive part or a protective conductor.

2.1.78 *Earth Fault Loop Impedance* (Z_s) — The total impedance of the path that a fault current would take during an earth fault, starting at the point of the fault and returning to the supply's neutral point.

2.1.79 *Earthing* — Connection of the exposed conductive parts of an installation to the main earthing terminal of that installation.

2.1.80 *Earthing Conductor* — A protective conductor connecting the main earth terminal (or equipotential bonding conductor of an installation when there is no earth bus) to an earth electrode or to other means of earthing.

2.1.81 *Earthing Lead* — The final conductor by which the connection to the earth electrode is made.

2.1.82 *Earth Leakage Current* — A current which flows to earth, or to extraneous conductive parts, in a circuit which is electrically sound.

NOTE — This current may have a capacitive component including that resulting from the deliberate use of capacitors.

2.1.83 *Earthing Resistance*, *Total* — The resistance between the main earthing terminal and the earth.

2.1.84 *Electrical Equipment* (*abb: Equipment*) — Any item for such purposes as generation, conversion, transmission, distribution or utilization of electrical energy, such as machines, transformers, apparatus, measuring instruments, protective devices, wiring materials, accessories, and appliances.

2.1.85 *Electrically Independent Earth Electrodes* — Earth electrodes located at such a distance from one another that the maximum current likely to flow through one of them does not significantly affect the potential of the other(s).

2.1.86 *Electrical Supply System for Life and Safety Services* — A supply system intended to maintain the operation of essential parts of an electrical installation and equipment:

a) for health and safety of persons and livestock; and
b) to avoid damage to the environment and to other equipment.

NOTES

1 The supply system includes the source and the circuit(s) up to the terminals of the electrical equipment.

2 *See also* Part F 'Fire and Life Safety' of this NBCS regarding emergency fire and life safety services.

2.1.87 *Electric Shock* — A dangerous patho-physiological effect resulting from the passing of an electric current through a human body or an animal.

2.1.88 *Electric Vehicle* (*EV*) — A vehicle that is propelled by one or more electric motors, using electrical energy stored in rechargeable batteries offering various benefits, including reduced emissions, lower running costs and potentially quieter operation compared to traditional gasoline-powered vehicles.

2.1.89 *EV Connector* — Different types of EV charging connectors, also called plugs, that works with different vehicles, charging speeds and locations.

2.1.90 *Electric Vehicle Supply Equipment* (*EVSE*) — Equipment or a combination of equipment, providing dedicated functions to supply electric energy from a fixed electrical installation or supply network to an EV for the purpose of charging.

2.1.91 *Emergency Switching* — Rapid cutting off of electrical energy to remove any hazard to persons, livestock, or property which may occur unexpectedly.

2.1.92 *Enclosure* — A part providing protection of equipment against certain external influences and, in any direction, protection against direct contact.

2.1.93 *Enclosed Distribution Board* — An enclosure containing busbars with one or more control and protected devices for the purpose of protecting, controlling or connecting more than one outgoing circuits fed from one or more incoming circuits.

2.1.94 *Equipotential Bonding* — Electrical connection putting various exposed conductive parts and extraneous conductive parts at a substantially equal potential.

NOTE — In a building installation equipotential bonding conductors shall interconnect the following conductive parts:

a) Protective conductor;
b) Earth continuity conductor; and
c) Risers of air conditioning system and heating systems (if any).

2.1.95 *Exothermic Welding* — A welding process that uses a chemical reaction to generate intense heat, typically reaching temperatures of around 1 400 °C. This heat is used to melt metal and create a permanent, high-quality weld without the need for an external heat or power source. The process is particularly useful for joining conductors, such as in earthing and lightning protection systems, and can be used to weld dissimilar metals.

2.1.96 *Exposed Conductive Part* — A conductive part of electrical equipment, which can be touched and which is not normally live, but which may become live under fault conditions.

2.1.97 *Exposed Metal* — All metal parts of an installation which are easily accessible other than:

a) parts separated from live parts by double insulation;

b) metal name-plates, screw heads, covers, or plates, which are supported on, or attached, or connected to substantial non-conducting material only in such a manner that they do not become alive in the event of failure of insulation of live parts and whose means of fixing do not come in contact with any internal metal; and

c) parts which are separated from live parts by other metal parts which are themselves earthed or have double insulation.

2.1.98 *External Influence* — Any influence external to an electrical installation which affects the design and safe operation of that installation.

2.1.99 *Extraneous Conductive Part* — A conductive part not forming part of the electrical installation and liable to introduce a potential, generally the earth potential.

2.1.100 *Fault* — A circuit condition in which current flows through an abnormal or unintended path. This may result from an insulation failure or a bridging of insulation. Conventionally the impedance between live conductors or between live conductors and exposed or extraneous conductive parts at the fault position is considered negligible.

2.1.101 *Fault Current* — A current resulting from a fault.

2.1.102 *Fault Protection* — Protection against electric shock under single fault conditions.

NOTE — For low voltage installation, system's and equipment's fault protection generally corresponds to protection against indirect contact, mainly with regards to failure of basic insulation. Indirect contact is 'contact of persons or livestock with exposed-conductive parts which have become live under fault conditions'.

2.1.103 *Final Circuit* — A circuit connected directly to current using equipment, or to socket-outlets or other outlet points for the connection of such equipment.

2.1.104 *Fire Survival Distribution Board* — A distribution board which continues in service after exposure to fire to the required system rating.

2.1.105 *Fish Wire* — A draw wire to pull electrical wires or other cables through concealed spaces like conduits in ceilings/walls/floors.

2.1.106 *Fitting, Lighting* — A device for supporting or containing a lamp or lamps [for example, fluorescent or incandescent or halogen or compact fluorescent lamp (CFL) or light-emitting diode (LED)] together with any holder, shade, or reflector, for example, a bracket, a pendant with ceiling rose, an electrolier, or a portable unit.

2.1.107 *Fixed Equipment* — Equipment fastened to a support or otherwise secured.

2.1.108 *Flameproof Enclosure* — An enclosure which will withstand without injury any explosion of inflammable gas that may occur within it under practical conditions of operation within the rating of the apparatus (and recognized overloads, if any, associated therewith) and will prevent the transmission of flame which may ignite any inflammable gas that may be present in the surrounding atmosphere.

NOTES

1 Hazardous areas are classified into different zones, depending upon the extent to which an explosive atmosphere may exist at that place. In such areas, flame proof switchgear, fittings, accessories have to be used/installed in flameproof enclosure.

2 An electrical apparatus is not considered as flameproof unless it complies with the appropriate statutory regulations.

3 Other types of fittings are also in vogue in wiring installations, for example, 'increased safety'.

2.1.109 *Functional Earthing* — Connection to earth necessary for proper functioning of electrical equipment.

2.1.110 *Hand-Held Equipment* — Portable equipment intended to be held in the hand during normal use, in which the motor, if any, forms an integral part of the equipment.

NOTE — A hand held equipment is an item of equipment, the functioning of which requires constant manual support or guidance.

2.1.111 *Harmonics* (*Current and Voltage*) — All alternating current which is not absolutely sinusoidal is made up of a fundamental and a certain number of current and voltage harmonics [multiples of 50 Hz (basic frequency)] which are the cause of its deformation (distortion) when compared to the theoretical sine-wave.

2.1.112 *Hazardous Live-Part* — A live part which can give, under certain condition of external influence, an electric shock.

2.1.113 *Impulse Current* — A parameter used for the classification test for SPDs (*see* **2.1.177**); it is defined by three elements, a current peak value, a charge Q and a specific energy W/R.

2.1.114 *Impulse Withstand Voltage* — The highest peak value of impulse voltage of prescribed form and polarity which does not cause breakdown of insulation under specified condition.

2.1.115 *Indirect Contact* — Contact of persons or livestock with exposed conductive parts made live by a fault and which may result in electric shock.

2.1.116 *Industrial Plugs and Sockets* — Plugs and socket-outlets, cable couplers and appliance couplers, primarily intended for industrial use, either indoors or outdoors.

NOTE — For the purpose of this NBCS, industrial plugs and sockets conforming to accepted standards [D-2(9)] shall be used for industrial purpose.

2.1.117 *Inflammable Material* — A material capable of being easily ignited.

2.1.118 *Installation* (*Electrical*) — An assembly of associated electrical equipment to fulfil a specific purpose or purposes and having coordinated characteristics.

2.1.119 *Insulated* — Insulated shall mean separated from adjacent conducting material or protected from personal contact by a non-conducting substance or an air space, in either case offering permanently sufficient resistance to the passage of current or to disruptive discharges through or over the surface of the substance or space, to obviate danger or shock or injurious leakage of current.

2.1.120 *Insulation* — Suitable non-conducting material, enclosing, surrounding or supporting a conductor.

2.1.120.1 *Insulation*, *basic* — Insulation applied to live parts to provide basic protection against electric shock and which does not necessarily include insulation used exclusively for functional purposes.

2.1.120.2 *Insulation*, *double* — Insulation comprising both basic and supplementary insulation.

NOTE — Double insulation for small hand held equipment allows them to be used without a safety earth connection, without shock risk of such hand held equipment.

2.1.120.3 *Insulation*, *reinforced* — Single insulation applied to live parts, which provides a degree of protection against electric shock equivalent to double insulation under the conditions specified in the relevant standard.

NOTE — The term ‘single insulation’ does not imply that the insulation is a homogeneous piece. It may comprise several layers which cannot be tested singly as supplementary or basic insulation.

2.1.120.4 *Insulation*, *supplementary* — Independent insulation applied in addition to basic insulation in order to provide protection against electric shock in the event of a failure of basic insulation.

2.1.121 *Inverter* — Electric energy converter that changes direct electric current to single-phase or polyphase alternating currents.

2.1.122 *Isolation* — Cutting off an electrical installation, a circuit, or an item of equipment from every source of electrical energy.

2.1.123 *Isolator* — A mechanical switching device which, in the open position, complies with the requirements specified for the isolating function. An isolator is otherwise known as a disconnector.

2.1.124 *Junction Box* — A box forming a part of wiring installation, intended to conceal electrical connections and joints of conductors/cables in order to protect the connection from external influences such as direct contact, dust, water, moisture, UV radiation, etc depending upon the protection requirement of the space or utility.

2.1.125 *Leakage Current* — Electric current in an unwanted conductive path under normal operating conditions.

2.1.126 *LEMP Protection Measures* (*SPM*) — Measures taken to protect internal systems against the effects of LEMP.

2.1.127 *Lightning Electromagnetic Impulse* (*LEMP*) — All electromagnetic effects of lightning current *via* resistive, inductive and capacitive coupling that create surges and radiated electromagnetic fields.

2.1.128 *Lightning Protection* — Complete system for protection of structures against lightning, including their internal systems and contents, as well as persons, in general consisting of an LPS and SPM.

2.1.129 *Lightning Protection Level* (*LPL*) — A number related to a set of lightning current parameters values relevant to the probability that the associated maximum and minimum design values will not be exceeded in naturally occurring lightning.

NOTE — Lightning protection level is used to design protection measures according to the relevant set of lightning current parameters.

2.1.130 *Lightning Protection System* (*LPS*) — Complete system used to reduce physical damage due to lightning flashes to a structure.

2.1.130.1 *Lightning protection system*, *External* — Part of the LPS consisting of an air-termination system, a down-conductor system and an earth-termination system.

2.1.130.2 *Lightning protection system, Internal* — Part of the LPS consisting of lightning equipotential bonding and/or electrical insulation of external LPS.

2.1.131 *Lightning Protection Zone* — Zone where the lightning electromagnetic environment is defined.

2.1.132 *Line Conductor* — A conductor of an a.c. system for the transmission of electrical energy other than a neutral conductor or a PEN conductor. This also means the equivalent conductor of a d.c. system unless otherwise specified in this NBCS.

2.1.133 *Live Part* — A conductor or conductive part intended to be energised in normal use including a neutral conductor but, by convention, not a PEN conductor.

2.1.134 *Live or Alive* — Electrically charged so as to have a potential different from that of earth.

2.1.135 *Locations*, *Industrial* — Locations where tools and machinery requiring electrical wiring are installed for manufacture or repair.

2.1.136 *Locations*, *Non-Industrial* — Locations other than industrial locations, and shall include residences, offices, shops, showrooms, stores and similar premises requiring electrical wiring for lighting, or similar purposes.

2.1.137 *Low-Voltage Switchgear and Controlgear Assembly* — A combination of one or more low voltage switching devices together with associated control, measuring, signalling, protective, regulating equipment, etc, completely assembled under the responsibility of the manufacturer with all the internal electrical and mechanical interconnections and structural parts. The components of the assembly may be electromechanical or electronic.

2.1.138 *Luminaire* — Equipment which distributes, filters or transforms the light from one or more lamps and which includes any parts necessary for supporting, fixing and protecting the lamps, but not the lamps themselves, and, where necessary, circuit auxiliaries together with the means for connecting them to the supply.

NOTE — For the purposes of this NBCS a batten lamp holder, or a lamp holder suspended by flexible cord, is a luminaire.

2.1.139 *Main Earthing Terminal* — The terminal or bar which is the equipotential bonding conductor of protective conductors and conductors for functional earthing, if any, to the means of earthing.

2.1.140 *Meshed Bonding Network* (*MESH-BN*) — Bonding network in which all associated equipment frames, racks and cabinets and usually the d.c. power return conductor are bonded together as well as at multiple points to the CBN and may have the form of a mesh.

2.1.141 *Mobile Equipment* — Electrical equipment which is moved while in operation or which can be easily moved from one place to another while connected to the supply.

2.1.142 *Monitoring* — Observation of the operation of a system or part of a system to verify correct functioning or detect incorrect functioning by measuring system variables and comparing the measured value with the specified value.

2.1.143 *Multiple Earthed Neutral System* — A system of earthing in which the parts of an installation specified to be earthed are connected to the general mass of earth and, in addition, are connected within the installation to the neutral conductor of the supply system.

2.1.144 *Neutral Conductor* — Includes the conductor of a three-phase four-wire system; the conductor of a single-phase or d.c. installation, which is earthed by the supply undertaking (or otherwise at the source of the supply), and the middle wire or common return conductor of a three-wire d.c. or single-phase a.c. system.

2.1.145 *Origin of an Electrical Installation* — The point at which electrical energy is delivered to an installation.

NOTE — An electrical installation may have more than one origin.

2.1.146 *Overcurrent* — A current exceeding the rated value. For conductors the rated value is the current carrying capacity.

2.1.147 *Overload Current* (*of a Circuit*) — An overcurrent occurring in a circuit in the absence of an electrical fault.

2.1.148 *PEN Conductor* — A conductor combining the functions of both protective conductor and neutral conductor.

2.1.149 *Phase Conductor* — *See* **2.1.132**.

2.1.150 *Plug* — A device, provided with contact pins, which is intended to be attached to a flexible cable and which can be engaged with a socket-outlet or with a connector.

2.1.151 *Point* (*in Wiring*) — A termination of the fixed wiring intended for the connection of current using equipment.

2.1.152 *Portable Equipment* — Equipment which is moved while in operation or which can easily be moved from one place to another while connected to the supply.

2.1.153 *Protection*, *Ingress* — The degree of protection against intrusions (body parts such as hands and fingers), dust, accidental contact and water.

NOTE — The classification of degrees of ingress protection provided by enclosures for electrical equipment shall be as per the accepted standard [D-2(10)].

2.1.154 *Protection*, *Mechanical Impact* — The degrees of protection provided by enclosures for electrical equipment against external mechanical impacts.

NOTE — The classification of degrees of protection against mechanical impact provided by enclosures for electrical equipment shall be as per accepted standard [D-2(10)]

2.1.155 *Prospective Fault Current* (I_{pf}) — The value of overcurrent at a given point in a circuit resulting from a fault of negligible impedance between live conductor having a difference of potential under normal operating conditions, or between a live conductor and an exposed-conductive part.

2.1.156 *Protective Conductor* — A conductor used for some measures of protection against electric shock and intended for connecting together any of the following parts:

a) Exposed conductive parts;

b) Extraneous conductive parts;

c) Main earthing terminal; and

d) Earthed point of the source, or an artificial neutral.

2.1.157 *Protective Conductor Current* — Electric current appearing in a protective conductor, such as leakage current or electric current resulting from an insulation fault.

2.1.158 *Protective Earthing* — Earthing of a point or points in a system or in equivalent, for the purpose of safety.

2.1.159 *Protective Separation* — Separation of one electric circuit from another by means of:

a) double insulation;

b) basic insulation and electrically protective screening (shielding); or

c) reinforced insulation.

2.1.160 *Rated Current* — Value of current used for specification purposes, established for a specified set of operating conditions of a component, device, equipment or system.

2.1.161 *Rated Impulse Withstand Voltage Level* (U_w) — The level of impulse withstand voltage assigned by the manufacturer to the equipment, or to part of it, characterizing the specified withstand capability of its insulation against overvoltage.

2.1.162 *Residual Current* — The algebraic sum of the instantaneous values of current flowing through all live conductors of a circuit at a point of the electrical installation.

2.1.163 *Residual Current Device* (*RCD*) — Mechanical switching device or association of devices designed to make, carry and break currents under normal service conditions and to cause the opening of the contacts when the residual current attains a given value under specified conditions.

2.1.164 *Residual Current Operated Circuit Breaker with Integral Overcurrent Protection* (*RCBO*) — A residual current operated circuit breaker designed to perform the functions of protection against overload and/or short-circuit.

2.1.165 *Residual Current Operated Circuit-Breaker without Integral Overcurrent Protection* (*RCCB*) — A residual current operated circuit breaker not designed to perform the functions of protection against overload and/or short-circuits.

2.1.166 *Residual Operating Current* — Residual current which causes the residual current device to operate under specified conditions.

2.1.167 *Service* — The conductors and equipment required for delivering energy from the electric supply system to the wiring system of the premises served.

2.1.168 *Shock Current* — A current passing through the body of a person or an animal and having characteristics likely to cause dangerous patho-physiological effects.

2.1.169 *Short-Circuit Current* — An overcurrent resulting from a fault of negligible impedance between live conductors having a difference in potential under normal operating conditions.

2.1.170 *Space Factor* — The ratio (expressed as a percentage) of the sum of the overall cross-sectional areas of cables (including insulation and sheath) to the internal cross-sectional area of the conduit or other cable enclosure in which they are installed. The effective overall cross-sectional area of a non-circular cable is taken as that of a circle of diameter equal to the major axis of the cable.

2.1.171 *Standby Supply System* — A system intended to maintain supply to the installation or part thereof, in case of interruption of the normal supply, for reasons other than safety of persons.

NOTE — Standby supplies are necessary, for example, to avoid interruption of continuous industrial processes or data processing.

2.1.172 *Stationary Equipment* — Either fixed equipment or equipment not provided with a carrying handle and having such a mass that it cannot easily be moved.

2.1.173 *Step Voltage* — The potential difference between two points on the earth's surface, separated by distance of one pace, that will be assumed to be one metre in the direction of maximum potential gradient.

2.1.174 *Socket-Outlet* — A device, provided with female contacts, which is intended to be installed with the fixed wiring and intended to receive a plug.

NOTE — A luminaire track system is not regarded as a socket-outlet system.

2.1.175 *Substation* — A facility containing power/distribution transformers interconnecting two or more networks of different voltages.

2.1.176 *Surge* — A transient created by LEMP (*see* **2.1.127**) that appears as an overvoltage and/or an overcurrent.

2.1.177 *Surge Protective Devices* (*SPD*) — A device intended to limit transient overvoltages and divert surge currents. It contains at least one non-linear component. Types of SPDs are as follows:

a) *Type* 1 *SPDs* (*Surge Arresters*) — For protection of high-energy surges, caused by direct lightning strikes or switching surges from utility grid, installed at the service entrance near the main distribution board;

b) *Type* 2 *SPDs* (*Transient Voltage Surge Suppressors or TVSS*) — For protection against secondary surges caused by utility grid switching or internal electrical faults. Installed in electrical distribution panel/sub-distribution board; and

c) *Type* 3 *SPDs* (*Plug-in Surge Protectors*) — For providing localized protection for sensitive electronic equipment like computers and TVs installed near the point of use.

2.1.178 *Sustainability* — Under electrical this refers to the generation of electricity using renewable sources such as solar, wind, hydro, geothermal and bioenergy that are naturally replenished and have minimal negative impact on the environment and to meet present energy needs without compromising the ability of future generations to meet their own, promoting long-term energy security and environmental protection.

2.1.179 *Switch* — A mechanical switching device capable of making, carrying and breaking current under normal circuit conditions, which may include specified operating overload conditions; and also of carrying for a specified time currents under specified abnormal circuit conditions, such as those of short circuit.

NOTE — A switch may also be capable of making, but not breaking, short-circuit currents.

2.1.180 *Switchboard* — An assembly of switchgear with or without instruments, but the term does not apply to a group of local switches in a final circuit.

NOTE — The term 'switchboard' includes a distribution board.

2.1.181 *Switch Disconnector* — A switch which, in the open position, satisfies the isolating requirements specified for a disconnector.

NOTE — A switch disconnector is otherwise known as an isolating switch.

2.1.182 *Switch Disconnector Fuse* — A composite unit, comprising a switch with the fuse contained in or mounted on the moving member of the switch.

2.1.183 *Switch*, *Linked* — A switch, the contacts of which are so arranged as to make or break all poles simultaneously or in a definite sequence.

2.1.184 *Switchgear* — An assembly of main and auxiliary switching apparatus for operation, regulation, protection or other control of electrical installations.

2.1.185 *Systems*, *Earthing* — An electrical system consisting of a single source or multiple sources running in parallel of electrical energy and an installation. Types of system are identified as follows, depending upon the relationship of the source and of exposed-conductive parts of the installation, to earth:

a) *TN system* — A system having one or more points of the source of energy directly earthed, the exposed conductive-parts of the installation being connected to that point by protective conductors;

b) *TN-C system* — A system in which neutral and protective conductor functions are combined in a single conductor throughout the system;

c) *TN-S system* — A system having separate protective conductor throughout the system;

d) *TN-C-S system* — A system in which neutral and protective conductor functions are combined in a single conductor in part of the system;

e) *TT system* — A system having one point of the source of energy directly earthed, the exposed-conductive-parts of the installation being connected to the earth electrodes electrically independent of the earth electrodes of the source. This is also known as direct earthing system; and

f) *IT system* — A system in which all live parts are isolated from earth or one point connected to earth through an impedance. The exposed-conductive-parts of the electrical installation are earthed independently or collectively or to the earthing of the system.

NOTE — The types of systems depending upon the relationship to the source and of the exposed conductive parts of the insulations to earth are defined in good practice [D-2(11)].

2.1.186 *Thermal Runaway* — An unstable condition arising during constant voltage charging in which the rate of heat generation exceeds the heat dissipation capability, causing a continuous temperature increase and a further rise in charging current, which can lead to battery destruction.

2.1.187 *Touch Voltage* — The potential difference between the ground potential rise (GPR) of a grounded metallic structure and the surface potential at the point where a person could be standing while at the same time having a hand in contact with the grounded metallic structure. Touch voltage measurements can be 'open circuit' (without the equivalent body resistance included in the measurement circuit) or 'closed circuit' (with the equivalent body resistance included in the measurement circuit) voltage by which an installation or part of an installation is designated.

2.1.188 *Usable Wall Space* — All portions of a wall, except that occupied by a door in its normal open position, or occupied by a fire place opening, but excluding wall spaces which are less than 1 m in extent measured along the wall at the floor line.

2.1.189 *Utility Building* — A standalone separate single or two storied service building structure outside the main building structure meant for only accommodating services' spaces, such as electric substation, diesel generator plant room, a.c. plant room, plumbing plant room, sewerage treatment plant, medical gases, electrical and mechanical maintenance rooms. Such buildings do not have any permanent occupancy other than by personnel on duty.

2.1.190 *Voltage Nominal* (*of an Installation*) — Voltage by which an installation or part of an installation is designated.

2.1.191 *Voltage*, *Extra Low* (*ELV*) — The voltage which does not normally exceed 50 V.

2.1.192 *Voltage*, *Low* (*LV*) — The voltage which normally exceeds 50 V but does not normally exceed 1 000 V in a.c. (alternating current) and 1 500 V in d.c. (direct current).

2.1.193 *Voltage*, *High* (*HV*) — The voltage which normally exceeds 1 000 V a.c. but less than or equal to 33 kV.

2.1.194 *Voltage*, *Extra High* (*EHV*) — The voltage, which normally exceeds 33 kV.

NOTE – The Central Electricity Authority and the Bureau of Indian Standards introduced norms for different voltages during 2017-2018, which have been adopted in good practice [D-2(1)]. These norms may differ from those adopted by various State Governments in India. In buildings across India over the past 75 years, 11 kV and 33 kV have been termed as high tension/high voltage. Electrical control switchgears available for 11 kV/33 kV are known as high voltage switchgears. Accordingly, the voltage norms specified in **2.1.191** to **2.1.194** are adopted for buildings in relation to this NBCS.

2.1.195 *Weatherproof* — Accessories, lighting fittings, current-using appliances and cables are said to be of the weatherproof type with ingress protection according to the application, if they are so constructed that when installed in open situation they will withstand the effects of rain, snow, dust and temperature variations.

2.2 Conventional Symbols

The architectural symbols that are to be used in all drawings, wiring plans, etc, for electrical installations in buildings shall be as given in Annex A.

For other graphical symbols used in electrotechnology, reference may be made to good practice [D-2(1)].

3 GENERAL REQUIREMENTS

3.1 Statutory Requirements

All electrical installations that are in use/being executed shall conform to *The Indian Electricity Act*, 2003 and *Central Electricity Authority* (*Measures Relating to Safety and Electric Supply*) *Regulations*, 2023 as amended up to date; and rules if any made there under. This NBCS covers brief information about the statutory requirements.

NOTE — After India's independence, India formulated *The IE Rules*, 1956 based on *The IE Act*, 1910. Thereafter in 2003, Government of India adopted *The Electricity Act*, 2003 and nominated CEA to adopt necessary regulations for electrical supply, safety, generation and distribution. Based on these directions, CEA issued *Central Electricity Authority* (*Measures Relating to Safety and Electric Supply*) *Regulations* in 2010 which is superseded with *CEA Regulations*, 2023. Consequent to this, *The IE Act*, 1910 and *IE Rules*, 1956 have been repealed. The norms for voltages under regulations were established by CEA during 2017-18 and based on the same good practice [D-2(12)] was issued in 2018 which has been adopted by good practice [D-2(1)]. Under this, good practice [D-2(1)] has categorized up to 33 kV as medium voltage. However, all State Electricity Boards have fixed voltage norms which are different from CEA/NEC norms. It has been the practice for over 75 years to refer to 11 kV and 33 kV as high tension or high voltage in buildings. Hence, it has been decided to give separate voltage norms for buildings in this NBCS.

3.1.1 *The Electricity Act*, 2003

Section 53 of *The Electricity Act*, 2003, states requirements relating to 'Provisions relating to safety and electrical supply'. Some of the important points included in this NBCS are protecting the public from the dangers arising out of electricity, reducing the risk of personal injury, and damage to property. In accordance, Central Electricity

Authority under Section 70 of the Act, has been empowered to specify suitable measures. Such measures are updated and notified from time to time in the form of regulations. It may be noted that any failure to comply with any order, or any attempt or abetment that contravenes the rules and regulations framed under the act, may attract appropriate action as per the provisions therein.

NOTE — It may be noted that any failure to comply with any order, or any attempt or abetment that contravenes the rules and regulations framed under the Act, may attract appropriate action as per Section 146 of the Act. Section 149 decides responsibility and Section 150 stipulates that any act of abetment in relation to an offence may invite appropriate consequences. It means that the persons who is not directly involved in construction of electrical installation but indirectly relate to integrated part of electrical installation, such as architectural or civil construction, such as keeping provision of spaces, reserving routes, maintaining clearances, civil construction with required fire rating, etc come under the ambit of these sections. Accepted standard [D-2(13)] provides list of such stakeholders involved in electrical installation.

3.1.2 *Central Electricity Authority*

The Central Electricity Authority, formed under Section 70, is empowered to make regulations as directed under Section 53 and Section 177 of the *Indian Electricity Act*, 2003. In accordance, the following regulations have been notified and are in force. However, reference shall always be made to the latest versions/amendments.

3.1.2.1 *Central Electricity Authority* (*Measures relating to Safety and Electric Supply*) *Regulations*, 2023

These regulations state various requirements to be observed in the following activities:

a) Design;

b) Construction;

c) Verification and testing;

d) Maintenance;

e) Use;

f) Electric supply; and

g) Various activities integrated with the work of electrical installation.

NOTE — Regulation No. 14 (2) requires electrical installations to follow relevant standards, including this NBCS, the National Electrical Code of India, or the International Standards, where Indian Standards are unavailable. So, though the BIS Standards and Codes of practice are guidelines, their observance is no longer optional but mandatory when read with Section 146 of the Act.

3.1.2.2 *Central Electricity Authority* (*Technical Standards for the Construction of Electrical Plants and Electrical Lines*) *Regulations*, 2022

From the perspective of this NBCS, these regulations apply to transmission and distribution licensees. That is, whenever any electrical line, whether overhead or underground, passes through the plot area of the building/building-complex, observance of these provisions, which are in the scope of the respective owner of the line, may require verification.

NOTE — Important sections of the above regulations are given in Annex B.

3.2 Project Management of Electrical Works

3.2.1 From the perspective of project management, electrical work activities shall broadly be divided into the following stages:

a) Planning;

b) Designing;

c) Construction;

d) Verification and testing; and

e) Maintenance.

NOTE — For existing buildings, (a) to (c) may not apply unless there is a major change or complete renovation.

3.2.2 *Coordination*

At all work stages and the activities within these stages, different persons/agencies concerning planning, civil construction and building services are involved. Mutual coordination between the stakeholders involved, directly or indirectly, is very important to avoid conflicts.

3.3 Stakeholders and their Responsibility

The role of stakeholders is very important in streamlining electrical work. Accepted standard [D-2(13)] identifies stakeholders as below:

a) Owner/developer;

b) Architect;

c) Civil contractor;

d) Other service providers;

e) Electrical consultant;

f) Electrical contractor;

g) Electrical inspector; and

h) Electricity supplier.

The standard states the responsibility of each stakeholder as per the related statutory compliances, quoting the clauses from related regulations, standards and codes. While assuming responsibility, each stakeholder shall have the required qualifications and experience in the respective field as set out in rules, regulations, bylaws, or any government notification. Where such eligibility criteria are not mandated, it will be the responsibility of the employer to appoint a person with qualifications and experience comparable to similar/correlating tasks. In addition, the provisions given in accepted standard [D-2(13)] may also be complied with.

NOTE — Most of the time, the electrical contractor who executes the work follows the design received from the consultant. But, for an electrical consultant who plays a key role of electrical design, there are no set rules or regulations to determine eligibility or accreditation procedures. Under the circumstances, until such rules come into force, reference to **3.5** from accepted standard [D-2(13)] may be taken, or the qualification and experience of such a person may be considered on par with the Chartered Electrical Safety Engineer as stated in regulation 6 of the *CEA* (*Measures Relating to Safety and Electric Supply*) *Regulations*, 2023 (*see* Annex B).

It should be noted that appointing technical experts like consultants/contractors from respective fields and assigning them responsibility are inherent parts of project management and need to be observed at the planning stage.

3.4 Appointment of Technical Professionals Concerning Electrical Installation

In addition to the requirements stated in accepted standard [D-2(13)], an electrical engineer shall be appointed on site as a registered building professional to streamline, monitor and certify, jointly with the consultant and the electrical contractor, all works relating to electrical services.

3.5 Roles and Responsibilities of the Persons Appointed for Electrical Work

There shall be a written agreement between the developer and the appointee deciding the scope of work and the responsibilities to be undertaken. Such an agreement shall include a declaration concerning the work the appointee will undertake (*see* Annex G).

3.5.1 *Electrical Engineer on Site*

To monitor the coordination of work between all stakeholders, from planning to completion, the electrical engineer on site has an important role. In the team of technical persons often referred to as 'Registered building professional' or 'Licensed technical professional/person', with different nomenclature in various building rules/regulations/byelaws, the inclusion of an electrical engineer shall be treated as an important requirement for controlling and monitoring electrical work activities. His duties and functions shall be:

a) observe all regulatory requirements;

b) maintain coordination between all stakeholders;

c) check electrical requirements from the perspective of location and spaces in the architectural plans;

d) check the electrical design prepared by the design consultant;

e) check specifications related to material and method of construction;

f) participate in preparing the activities chart, considering the smooth and coordinated work progress;

g) monitor and maintain surveillance from planning to completion and handing over, with special attention to the work that will be concealed;

h) check and jointly sign certificates/declarations and checklists as recommended in accepted standard [D-2(13)];

j) check required NOCs/Permissions from respective authorities; and

k) maintain a record of all documents.

3.5.2 *Electrical Consultant*

To perform the desired role as an electrical consultant, he shall have the necessary qualifications and experience. Reference may be taken from the note under **3.3**. Such a person shall have an updated knowledge of all regulatory requirements, standards and codes of practice related to the design, construction, verification, testing, and maintenance of electrical work. He shall be responsible for preparing designs with drawings and specifications that adhere to quality standards. He shall consult the architect regarding necessary points to consider at the planning and construction stage. Table 1 from accepted standard [D-2(13)] provides a list of activities and responsibilities. Some important points in this regard are given below:

a) Identify the existing overhead and underground electrical lines on the proposed development plot and the mandatory requirements, compliances, and NOCs related to clearances;

b) Spaces, locations and routes of the distribution network required for electrical installation;

c) Specific requirements related to RCC structure (static/dynamic load of electrical equipment, requirement of recess within RCC structure to avoid core cutting, required height between finished floor level and soffit of the beam);

d) Specific requirement related to wall thickness to accommodate concealed electric boxes, raised floor (false flooring) to accommodate cable work below;

e) Specific requirements where an aluminium formwork system is used to cast concrete for building elements like walls, floors, columns, beams and slabs. Similar provisions have to be used in case of prefabricated concrete works;

f) Specific requirements related to ventilation and avoiding the accumulation of heat;

g) Assessment of electrical load including future expansion (while assessing load, other service providers shall be consulted for their requirements);

h) Space requirement for the electrical sub-station as per the assessment of the required load. *See* Annex D for suggested space provision as per the substation's capacity;

j) Consult with the electric supply company for load sanction and requirements, if any, such as space/room (*see* Note), etc;

NOTE — The supply company may state the requirement for space within the consumer's premises for substation/equipment. There may also be a case where there is no spare capacity or possibility to augment the existing electrical distribution. The consultant shall be well aware of the conditions of the Supply Code approved by the respective State Electricity Regulatory Commission and, in accordance, give the architect the requirements related to space. All related correspondence shall be documented.

k) Prepare drawings showing the electrical equipment locations and the electric supply distribution network on site plans. Supplier and consumer distribution networks shall be segregated;

m) Prepare drawings of electrical equipment rooms of substation, switch rooms and consult with the architect and civil engineer about the requirements related to technical specifications of civil construction like fire rating, ventilation facilities, doors/openings, ducts, floor level, clear ceiling height below beam soffit, access facility, dust-free areas, etc. Some of such requirements may be:

   1) *Transformer sub-station* — Oil draining arrangement, oil soak pit, curb to prevent the spread of spillage/leaked/drained oil, the required clearances around apparatus considering the type of transformer dry/oil-cooled (O class)/liquid-cooled (K class), adjacent structure whether combustible/non-combustible, provision of baffle wall, etc;

   2) *Standby power supply* — Genset, PUC norms, stack height and the building in the vicinity, safe location; and

   3) *Standby power supply* — UPS system, location and specific requirements related to battery storage.

n) Drawings showing proposed internal routes and layouts of cables (mains, sub-mains, circuit mains, light, fan power outlet points, distribution boxes, boards with electrical accessories, outlet points and the required clearances between other services, accessibility, etc;

   NOTE — Where aluminium formwork technology is used to cast concrete for building elements like walls, floors, columns, beams, and slabs, drawings showing precise locations of points and boxes are most important. Similar provisions have to be provided in case of prefabricated concrete works.

p) Design electrical installation with due consideration for general characteristics that adhere to protection for safety;

q) Consider the related requirements stated under the Energy Conservation Building Code to qualify buildings under a certain class;

r) Prepare specifications for the selection and erection of electrical equipment with due consideration to the factors of external influences;

s) State requirements relating to fire prevention, specific to electrical installation as given under CEA Regulations, for example, placement of extinguishers, PPE, automatic fire suppression system, etc;

t) State design requirements related EV charging stations and the clearances around;

u) State if there are any specific requirements relating to the access;

   NOTE — In the event, the electric control panel room is being located in the basement there shall be at least two independent access to the ground floor to avoid any one access getting blocked leading to a serious situation in accessing, operating and controlling the electric supply of critical services in case of fire.

w) Provide technical support and guidance to site engineers/contractors during project execution to ensure material and installation quality, and assist in resolving issues arising during installation, verification, and commissioning;

y) State requirements related to verifying and testing of electrical installations; and

z) Maintain respective checklists updated as required under the accepted standard [D-2(13)].

3.5.3 *Electrical Contractor**

Electrical contractor shall have a licence issued by the appropriate government. It shall be valid at the time of agreement and renewed when necessary. He shall be aware of the obligations mandated as per the rules and regulations. The supervisor(s) appointed by him shall have competency and updated technical knowledge of all regulatory requirements and the codes of practice. The contractor shall be responsible for:

a) Resolving differences regarding the design, drawings, and specifications provided by the consultant, if any, and carrying out work as per the final design. In case of unresolved points, maintain the record;

   *NOTE — Where the electrical contractor is also performing the job of electrical consultant, he shall also be responsible for observing requirements stated under **3.5.2**.

b) Before commencing work, get the drawing approvals from the respective authority, where applicable;

c) Employ electrical supervisor and the workmen having permits of the appropriate class or designated as per regulation 3 of the *CEA* (*Measures Relating to Safety and Electric Supply*) *Regulations*, 2023 to carry out work on/for the electrical installation (*see* Annex B);

d) Weatherproof lockable storage space for materials at site to be arranged by the electrical contractor;

e) Observe workplace safety in respect of:

    1) temporary electrical installation on site; and

    2) provision of adequate tools and personal protective equipment (PPE) to workmen.

f) Check that requirements related to civil construction concerning electrical installation are satisfied;

g) Observe the activity chart based on a time schedule, which is mutually agreed upon between all concerned service providers and plan the work in coordination;

    NOTE — Where an aluminium formwork is used to cast concrete for building elements like walls, floors, columns, beams and slabs, the coordination with civil work needs to be observed precisely. Similar provisions have to be ensured in case of prefabricated concrete works.

h) Carry out electrical installation according to the plans and finalised design by the consultant or, where applicable, the design approved by the authority (electrical inspector);

j) The execution shall be according to the approved methods of construction stated under the National or International codes of practice, where the NBCS has not set any parameters;

k) All work should be executed under the strict supervision of a competent person with the necessary permit issued by the government;

m) A record of hidden work shall be maintained with certificates of required compliance, which shall be jointly signed with the engineer on site before concealing;

n) Maintain electrical installation safety throughout the construction period and the defect liability period;

p) Get the installation verified and tested, preferably through a third party, at the following stages:

    1) During construction; and

    2) After completion, before certifying for its beneficial use.

q) Help the electrical engineer on site in maintaining updated checklists as required under the accepted standards [D-2(13)]; and

r) Prepare handing-over documents for the respective owner, stating details of the electrical installation as given the checklist.

3.6 Materials

All materials, fittings, appliances, etc used in electrical and allied installations, shall conform to Part B ‘Building Materials’ of this NBCS and other concerned Indian Standards.

3.7 Coordination with Local Supply Authority

a) In all cases, that is, whether the proposed electrical work is a new installation or extension of an existing one, or a modification involving major changes, the electricity supply undertaking shall be consulted about the feasibility, etc, at an early date. The wattage per square metre and permissible diversity consideration shall be defined as per the type of building (residential, commercial, mercantile, industrial, retail, convention, exhibition, hotel, hospital, institution, flatted factory, group housing, etc). The wattage per square metre (W/m^2) shall be defined considering probable loads as per city grading such that future loading into the development is accounted; and

b) *Addition to an installation* — An addition, temporary or permanent, shall not be made to the authorized load of an existing installation, until it has been definitely ascertained that the current carrying capacity and the condition of existing accessories, conductors, switches, etc, affected, including those of the supply authority are adequate for the increased load. The size of the cable/conductor shall be suitably selected on the basis of the ratings of the protective devices. Ratings of protective devices and their types shall be based on the installed load, switching characteristics and power factor.

Load assessment and application of suitable diversity factor to estimate the full load current shall be made as a first step. This should be done for every circuit, submain and feeder. Power factor, harmonics (*see* **5.3.6.6**) and efficiency of loads shall also be considered. Diversity factor assumed shall be based on one's own experience or as per table under **4.2.2.2**. Allowance should be made for about 15 percent to 20 percent for extension in near future. The wiring system should be adopted taking into account the environmental requirements and hazards, if any in the building. The sizes of wiring cables are decided not merely to carry the load currents, but also to withstand thermal effects of likely overcurrents, short circuit and ensure acceptance level of voltage drop.

3.8 Power Factor Improvement in Consumers' Installation

3.8.1 Conditions of supply of electricity boards or licensees stipulate the lower-limit of power factor which is generally 0.95 lag or better.

3.8.2 Principal causes of low power factor are many. For guidance to the consumers of electric energy who take supply at low and medium voltages for improvement of power factor, reference shall be made to good practice [D-2(1)] and accepted standard [D-2(14)].

3.9 Execution of Work

Unless otherwise exempted under the appropriate regulation of the *CEA* (*Measures relating to Safety and Electric Supply*) *Regulations*, 2023 as amended from time to time, the work of electrical installations shall be carried out by a licensed electrical contractor and under the direct supervision of a person holding a certificate of competency and by persons holding a valid permit issued and recognized by the State government.

3.10 Safety procedures and practices shall be kept in view during execution of the work in accordance with accepted standard [D-2(15)].

3.11 Safety provisions given in Part F 'Fire and Life Safety' of this NBCS should be followed.

4 PLANNING OF ELECTRICAL INSTALLATIONS

4.1 General

The design and planning of an electrical wiring installation involve consideration of all prevailing conditions and is usually influenced by the type and requirements of the consumer. Various utility services including EV charging, ELV systems namely intercom, data cabling (*see* Part D 'Building Services, Section 6 Information and Communication Enabled Installations' of this NBCS), CCTV, fire detection, etc shall also be taken into account with anticipated future requirements. A competent electrical design engineer should be involved at the planning stage with a view to providing for an installation that will prove adequate for its intended purpose and ensure safety, reliability and energy efficiency in its use. The information/requirements given in **3** shall also be kept into consideration while designing and planning an electrical wiring installation. With the proliferation of the use of electrical and electronic devices in buildings as well as the increase in the generation/distribution capacities of power systems, the hazards of energy feed to a fault or defect in the electrical installation has increased. Reliability of power supply and continued supply even under abnormal conditions are becoming very important not only for the operation of services and activities in a building, but also for the life safety of occupants. . Electricity is linked to all services and addition of standby and emergency power supply systems adds to the complexity requiring proper coordinated design. Generally, it is not difficult to provide proper pathways and equipment installation spaces, if an integrated approach is taken from the beginning. The designs should also have to keep the availability of optimum access to installations to ensure proper maintenance. Considering various utility services and to avoid conflict amongst them, it is most important to estimate space requirement for electrical work including LV systems, at planning stage and allocate it in consultation with architect/civil engineer.

4.1.1 The design and planning of an electrical wiring installation shall take into consideration the following:

a) Type of supply, building utility, occupancy, envisaged load and the earthing arrangement available;

b) Provisioning and designing of circuits (circuit length, voltage drop and other aspects), cabling, equipment loads, selection of switchgears, protective devices, fittings and accessories, earthing system, electrical panel rooms, etc complete;

c) Climatic condition, such as cooling air temperature, moisture or such other conditions which are likely to affect the installation adversely including provisioning of air conditioning systems for present and/or future expansion;

d) Provisions for lightning protection system (LPS) based on risk assessment including using building structure for the purpose;

e) Possible presence of inflammable or explosive dust, vapour or gas;

f) Degree of electrical and mechanical protection necessary;

g) Importance of continuity of service including the possible need for standby supply;

h) Probability of need for modification or future extension;

j) Probable operation and maintenance cost taking into account the electricity supply tariffs available;

k) Relative cost of various alternative methods;

m) Need for radio and telecommunication interference suppression;

n) Ease of maintenance;

p) Safety aspects;

q) Energy conservation;

r) Importance of proper discrimination between protective devices for continuity of supply and limited isolation of only the affected portion;

s) Reliability of power supply and redundancy (of sources and distribution paths) to cater to the needs for emergency power and standby power for continued operation of systems as well as integration of alternate sources of energy such as diesel generation, solar energy, wind power, etc; and

t) Integration of different types of energy sources such as (single or multi) grid power, DG set power backup, battery storage energy system, on grid solar PV power, on grid other renewable energy sources such as wind power, micro wind wheel, etc.

NOTE — The design and planning of electrical installations shall also comply with relevant provisions of good practice [D-2(1)].

4.1.2 All electrical apparatus shall be suitable for the services these are intended for and shall confirm to relevant Indian Standards.

4.1.3 *Coordination*

Proper coordination and collaboration among the architect, civil engineer, electrical engineer and mechanical engineer shall be ensured from the planning stage of the installation. The electrical engineer shall be conversant with the needs of the electrical supply provider for making electrical supply arrangement. Electrical supplier's installation, as per regulations, needs to be segregated from consumer's installation. Wherever required, prior approval of drawings shall be taken from concerned electrical supplier/electrical inspector. Further, depending on load and regulation provisions, consumer will need to submit to the electrical supplier the details regarding the accommodation of substation including transformers, switch-rooms, standby power, solar photovoltaic panels, lighting and ventilation scheme for the approval. Additional information sought by the Authority regarding details of electrical safety apparatus, fire safety apparatus, cable ducts, rising mains and distribution cables, sub-distribution boards, openings in floors and walls, etc for all electrical installations shall be provided. Provisions as-given in accepted standard [D-2(13)] shall also be complied.

4.1.4 While planning wiring and installation of fittings and accessories, information should be exchanged between the owner of the building/architect/consultant/electrical contractor and the local supply authority in respect of tariffs applicable, types of apparatus that may be connected under each tariff, requirement of space for installing meters, switches, etc, and for total load requirements of lights, fans and power. Consideration should also be taken for the anticipated increase in the use of electricity for lighting, general purpose socket-outlet, kitchen equipment, air conditioning, utility sockets, heating, etc.

4.1.5 It is essential that adequate provision should be made for all the services which may be required immediately and during the intended useful life of the building. If not provided, the user may be tempted to carry out extension of the installation himself or to rely upon use of multi-plug adaptors and long flexible cords, both of which are not recommended.

4.2 Substation and Switchrooms

4.2.1 *Location and Other Requirements*

The location and other requirements of a substation and switchrooms shall be as given below:

a) Availability of power lines nearby may be kept in view while deciding the location of the substation.

b) The substation should preferably be located near the load centre in a separate utility building adjacent to the generator room, if any. Location of substation in the basement should be avoided, as far as possible. If it is unavoidable, the floor level of substation shall be at least 0.6 m above the lowest point of the basement.

c) In case of more than 2 basements in a building/buildings, the substation/switchroom shall be provided in either first or second basement with floor of the substation not more than 10 m below the adjoining (site) ground level.

d) In places where flooding can occur and water level may go above 1 000 mm, the base substation may be located on one level above the ground level of a utility building or of main building. In such cases, only one feeder should feed ground level and levels below with automatic tripping of the feeder to avoid electrocution in case of live electricity coming in contact with water. Designers shall use their discretion in special cases depending on the degree of reliability, redundancy and the category of load and make suitable provisions.

NOTE — In cases, where the substation is located one level above ground level of utility building or main building, this should be after due evaluation of the other risks posed by such a location combined with the concurrence for such a decision from State Electricity Authority comprising the electrical inspectorate and the distribution licensee and the fire service. There should be direct access from outside the building for substation without entering building to substation.

e) Depending upon the topology of the area (in mountains/stepped terrain), location of substation and DG set should be such that flooding of the equipment area is avoided, with substation and DG set located at least 300 mm above maximum flood level with natural drainage of the substation/DG sets areas.

f) Ideal location for an electrical substation for a group of buildings will be at the electrical load centre. Generally, the load centre will be somewhere between the geometrical centre and the air conditioning plant room, as air conditioning plant room will normally be the largest load, if the building(s) are centrally air conditioned.

g) In order to prevent storm water entering the transformer and switch rooms, the floor level of the substation/switchroom shall be at least 300 mm above the highest flood water level that may be anticipated in the locality. Also, facility shall be provided for automatic removal of water.

h) Substation shall not be located immediately above or below plumbing water tanks or sewage treatment plant (STP) water tanks at the same location.

j) All door openings from substation, electrical rooms, etc, should open outwards. Vertical shutters (like fire rated rolling shutters) may also be acceptable provided they are combined with a single leaf door opening outwards for exit in case of emergency. For large substation room/electrical room having multiple equipment, two or more doors shall be provided which shall be remotely located from each other.

k) If substation is located at a height 1 000 m above MSL, then adequate derating of equipment shall be considered.

m) HV panel room and transformers should have direct access and located as near as possible. In case HV panel and transformers are located at different floors or at a distance of more than 20 m, HV isolator shall be provided nearer to the transformer.

n) In case transformer and main HV/LV panel room are located at different floors, the designer should also take care of the safety requirements caused by lack of direct visibility of the status of the controlling switch. To cater to the safety requirements under different conditions of operation as well as maintenance, it may be necessary to provide additional isolator or an emergency push button in the vicinity to trip the supply. Decision has to be taken based on the possible risks.

p) No services or ventilation shafts shall open into substation or switch room unless specific to substation or switch room.

q) *Oil-filled installation* — Substations with oil-filled equipment require great consideration for the fire detection, protection and suppression. Oil-filled transformers require a suitable soak pit with gravity flow to contain the oil in the event of the possibility of oil spillage from the transformer on its failure. Installation of oil-filled equipment shall meet the following requirements:

    1) Substations with oil-filled equipment/apparatus (transformers and high voltage panels) shall be either located in open or in a utility building. They shall not be located in any floor other than the ground floor or the first basement of a utility building. They shall not be located below first basement slab of utility building. They shall have direct access from outside the building for operation and maintenance of the equipment.

    2) Substations/utility buildings (where the substation or oil-filled transformer is located) shall be separated from the adjoining buildings including the main building by at least 6 m clear distance to allow passage of fire tender between the substation/utility building and adjoining building/main building.

    3) There shall be no interconnecting basement with the main building underneath the oil-filled transformers.

    4) Provisions for oil drainage to a tank (from which oil can be decanted and reused) at a lower level and separated by adequate fire barrier shall be provided. If there is a floor directly below the ground floor level or first basement where the oil-filled transformers and oil-filled circuit breakers are placed, then they should be separated by a fire barrier of appropriate fire rating as per Part F 'Fire and Life Safety' of this NBCS and proper oil drainage system shall be provided to avoid possible leakage of oil into the lower floor.

    5) Substation equipment having more than 2 000 of oil whether located indoors in the utility building or outdoors shall have baffle walls of 4 h fire rating between apparatus (*see also* Part F 'Fire and Life Safety' of this NBCS for fire safety related requirements).

    6) Provisions shall be made for suitable oil tank, and where use of more than 9 000 litre of oil in any one oil tank, receptacle or chamber is involved, provision shall be made for the draining away or removal of any oil which may leak or escape from the tank, receptacle or chamber containing the same. Special precautions shall be taken to prevent the spread of any fire resulting from the ignition of the oil from any cause and adequate provision shall be made for extinguishing any fire which may occur.

    7) Oil filled transformers/stabilizers/auto transformers (with oil capacity more than 50 litre) or any equivalent electrical equipment shall not be used within the buildings other than utility buildings. Utility building should not be used for any other activity other than services. In case of less than 50 litre equipment placed in building, it should be kept in naturally ventilated areas and fire segregated from occupied areas and other areas prone to accidental fires.

    8) Adequate fire barriers or deflectors shall be provided to avoid flames from the substation reaching or affecting the adjacent areas including upper floors (*see also* Part F 'Fire and Life Safety' of this NBCS).

    9) Transformer, HV panel, LV isolator shall not be kept one above the other in a way that in case of oil leakage or fire in an equipment the other becomes unapproachable. Stacking of electrical equipment should not be done.

    10) For transformers having large oil content (more than 2 000 litre), *Rule* 46(2) of the *Central Electricity Authority* (*MRSES*) *Regulations*, 2023 shall apply (*see* Annex B).

r) *Dry-type installation* — In case electric substation has to be located within the main multi-storeyed building itself for unavoidable reasons, it shall be a dry-type installation with very little combustible material, such as, a dry type transformer with vacuum breakers as HT switchgear and ACB or MCCB as low voltage (LV) switchgear. Such substations shall be located on the ground level or on first basement and shall have direct access from the outside of the building for operation and maintenance of the equipment.

Exceptionally, in case of functional buildings, such as air traffic control towers, high rise non – residential buildings, data centres and mixed use buildings of height more than 150 m having high electrical load requirement, dry-type installations/substations may also be provided at upper level without emergency backup systems requiring diesel or any inflammable material storage. This measure will decrease the current flow and short-circuit rating at various points, thereby reducing vulnerability to fire. In such cases, a base substation shall be located at ground floor/first basement to cater to the main HV/LV panel which feeds life and safety services loads as defined in **4.2.1**(h). The base substation shall be located in such a way to provide direct access to the firemen in case of any emergency. The power supply control to any substation or transformer located at upper floors shall be from the base substation so that in case of fire, the electrical supply can be easily disconnected to avoid additional losses.

s) The power supply HV cables voltage shall not be more than 36 kV and a separate dedicated and fire compartmented shaft should be provided for carrying such high voltage cables to upper floors in a building. These shall not be mixed with any other shaft and suitable fire detection and suppression measures shall be provided throughout the length of the cable on each floor.

t) The provision for installation and removal of substation equipment should be provided from inside or outside the building without disturbing the associate major equipment in the substation. In case of inside building path a designated elevator should be installed which is capable of handling weight and size of transformer parts being transported to designated floor for installation, maintenance and removal from the floor.

u) In case of compact substation {*see* accepted standard [D-2(7)]}, design and location of the substation shall ensure safety of the people around the compact substation installed along walkways, playgrounds, etc. Compact substation with incomer voltage of 12 kV or less, when located in open areas shall have fencing or barrier (of any metal based protection, such as wire mesh or chain link, which is duly earthed) against unauthorized contact possibility around it at a minimum distance of 750 mm around it with access for maintenance from all four sides. For incomer voltage more than 12 kV and less than 24 kV the fencing distance from substation may be 1 000 mm minimum. In case of more than 24 kV incomer, the distance may be further increased accordingly. The fencing design should take care of the servicing and maintenance requirements of the substation equipment.

w) In case of two transformers (dry type or transformers with cumulative oil quantity less than 2 000 litre) located next to each other without intermittent wall, the distance between the two shall be minimum 1 500 mm for 11 kV, minimum 2 000 mm for 22 kV and 33 kV. Beyond 33 kV, two transformers shall be separated by baffle wall of 4 h fire rating.

y) Horizontal routing of HT cable through functional/occupied areas should be avoided in view of safety.

z) If dry type transformer is used, it may be located adjacent to high voltage switchgear in the form of unit type substation. In such a case, no separate room or fire barrier for the transformer is required either between transformers or between transformer and the switchgear, thereby decreasing the room space requirement. however, minimum distances as specified in **4.2.1**(w) shall be maintained between the apparatus depending upon voltage ratings. Layout of equipment should take care of the need that any one piece of equipment or sub-assembly can be taken out of service and out of the installed location, while keeping the remaining system in service. Working space for access for maintenance of equipment, while keeping an adjoining section of the substation live to maintain power supply to essential loads, may require additional space between such sections of equipment.

aa) For acoustical enclosures/treatment, reference may be made to Part D 'Building Services, Section 4 Acoustics, Sound Insulation and Noise Control' of this NBCS and CPCB norms requirements.

bb) The minimum recommended spacing between the walls and the transformer periphery from the point of proper ventilation shall be in accordance with good practice [D-2(16)] (*see also* Fig. 1A). The actual spacing may be more than those given in the figure, depending on the circumstances, such as access to the accessories. Other requirements relating to installation of transformers shall also be in accordance with good practice [D-2(16)].

cc) *High voltage switch room/space* — The design should take care of HV equipment space and clearance required around for maintenance and personnel safety as given in **5.3.6.8**. This room may preferably have direct access from outside. In case of substation having one transformer and one source of supply, the owner shall provide one high voltage switch. In case of single point supply with two or more transformers, the number of switch required will be one for incoming supply and one for each transformer. Additional space may be provided keeping in mind future extension, if any. In case of dual supply, two switches shall be provided with mechanical/electrical inter locking arrangement. In case the number of incoming and outgoing switches exceed five, bus coupler of suitable capacity should invariably be provided.

dd) *Low voltage switch room/space* — The floor area required in respect of low voltage switchgear room may be determined keeping in view the number and type of incoming, outgoing, bus coupler switches including likely expansion in future, space requirement as given in **5.3.6.8**. The additional requirements of LV switchroom when located separate from the substation shall be as per **4.4**.

ee) Other requirements relating to installation of switchgears and controlgears as given in good practice [D-2(17)] shall also be complied with.

ff) The minimum height of substation room/HV switch room/LV switch room shall be arrived at considering 1 200 mm clearance requirement from top of the equipment to below the soffit of the beam (*see also* Annex C). In case cable entry/exit is from above the equipment (transformer, HV switchgear, LV switchgear), height of substation room/HV switch room/LV switch room shall also take into account requirement of space for turning radius of cable above the equipment height.

gg) All the rooms shall be provided with partitions up to the ceiling and shall have proper ventilation. Special care should be taken to dissipate transformer heat and where necessary fresh air louvers at lower level and exhaust fans at higher level shall be provided at suitable locations.

hh) In case of cable trench in substation/HV switch room/LV switch room, the same shall be adequately drained to ensure no water is stagnated at any time with live cables.

jj) *Power supply to emergency fire and life safety systems* — Emergency power supply of distribution system for critical requirement for functioning of fire and life safety system and equipment, shall be planned for efficient and reliable power and control supply to the following systems and equipment where provided:

  1) Fire pumps;
  2) Pressurization and smoke venting; including its ancillary systems such as dampers and actuators;
  3) Fireman's lifts (including all lifts).
  4) Exit signage lighting;
  5) Emergency lighting;
  6) Fire alarm system;
  7) Public address (PA) system (relating to emergency voice evacuation and annunciation);
  8) Magnetic door hold open devices; and
  9) Lighting in fire command control and security room.

Power supply to these systems and equipment shall be from normal and emergency (standby generator) power sources with change over facility. It shall be ensured that in case the power supply is from HT source/HT generation, transformers should be planned in stand-by capacity to ensure continuity of power to such systems. Wherever transformers are installed at higher levels in buildings and backup DG sets are of higher voltage rating, then dual redundant cables shall be taken to all transformers. The generator shall be capable of taking starting current of all the fire and life safety systems and equipment as above. Where parallel HV/LV supply from a separate substation fed from different grid is provided with appropriate transformer for emergency, the provision of generator may be waived in consultation with the Authority.

NOTE — Standby generator shall not be kept at upper levels, *see* **4.3.1**.

The power supply to the panel/distribution board of these fire and life safety systems shall be through fire proof enclosures or fire survival cables or through alternate route in the adjoining fire compartment to ensure that supply of power is reliable to these systems and equipment. It is to be ensured that the cabling from the adjoining fire compartment is to be protected within the compartment of vulnerability.

The location of the panel/distribution board feeding the fire and life safety system shall be in fire safe zone ensuring supply of power to these systems. The cable used shall as far as possible be fire survival cable as per the accepted standard [D-2(3)].

Cables for fire alarm and PA system shall be laid in metal conduits or armoured to provide physical segregation from the power cables.

NOTE — Fire control room to be located at or near the main entrance of the building which shall be treated as fire safe zone for all purposes.

kk) Other requirements as given in *Central Electricity Authority* (*Measures relating to Safety and Electric Supply*) *Regulations*, 2023 shall also be complied with. The fire safety requirements for substation and electrical rooms, including fire rating requirements of substations enclosure, that is, walls, floor, ceiling, openings, doors, etc, as given in Part F 'Fire and Life Safety' of this NBCS should also be complied with.

4.2.2 *Layout of Substation*

4.2.2.1 In allocating the area of substation, it is to be noted that the flow of electric power is from supply company's meter room to HV room, then to transformer and finally to the LV switchgear room. The layout of the room and trenches of required depth shall be in accordance with this flow, so as to optimize the cables, bus-trunking, etc. Visibility of equipment controlled from the operating point of the controlling switchgear is also a desirable feature, though it may not be achievable in case of large substations. Substations shall not be located at or across expansion joints. The rooms/spaces required in a substation shall be provided as below (*see also* Fig. 1):

a) *Supply company's meter room*, generally at the periphery of the premise with direct access from the road/outside;

b) *HV isolation room*, required in case the substation is away from the meter room and is planned adjacent to meter room for disconnecting supply in case of any repair required between meter room and substation;

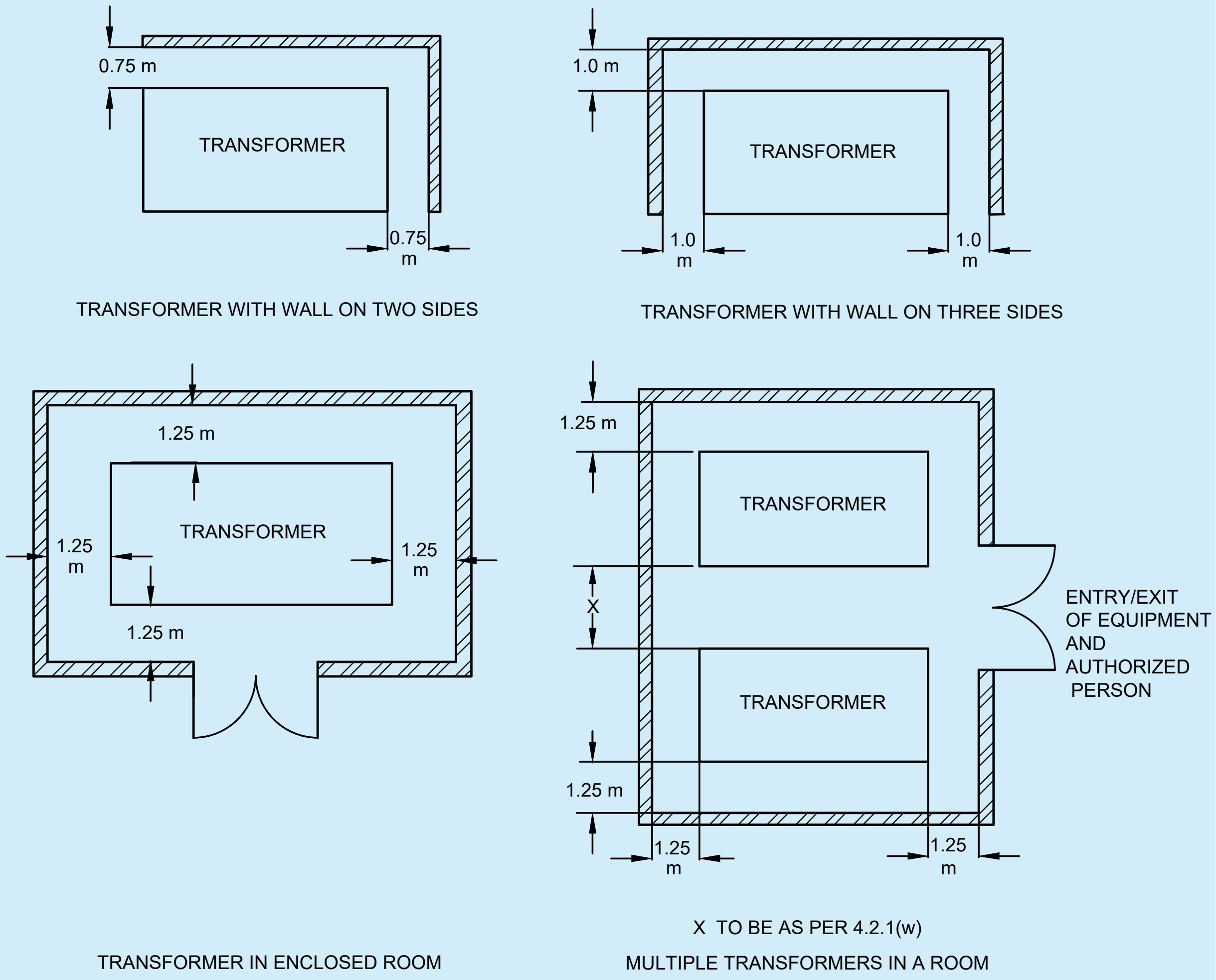
c) *HV panel room/space*, located adjacent to transformer;

d) *Transformer room/space*, separate space in case of oil-filled transformer and combined space in case of dry type transformer;

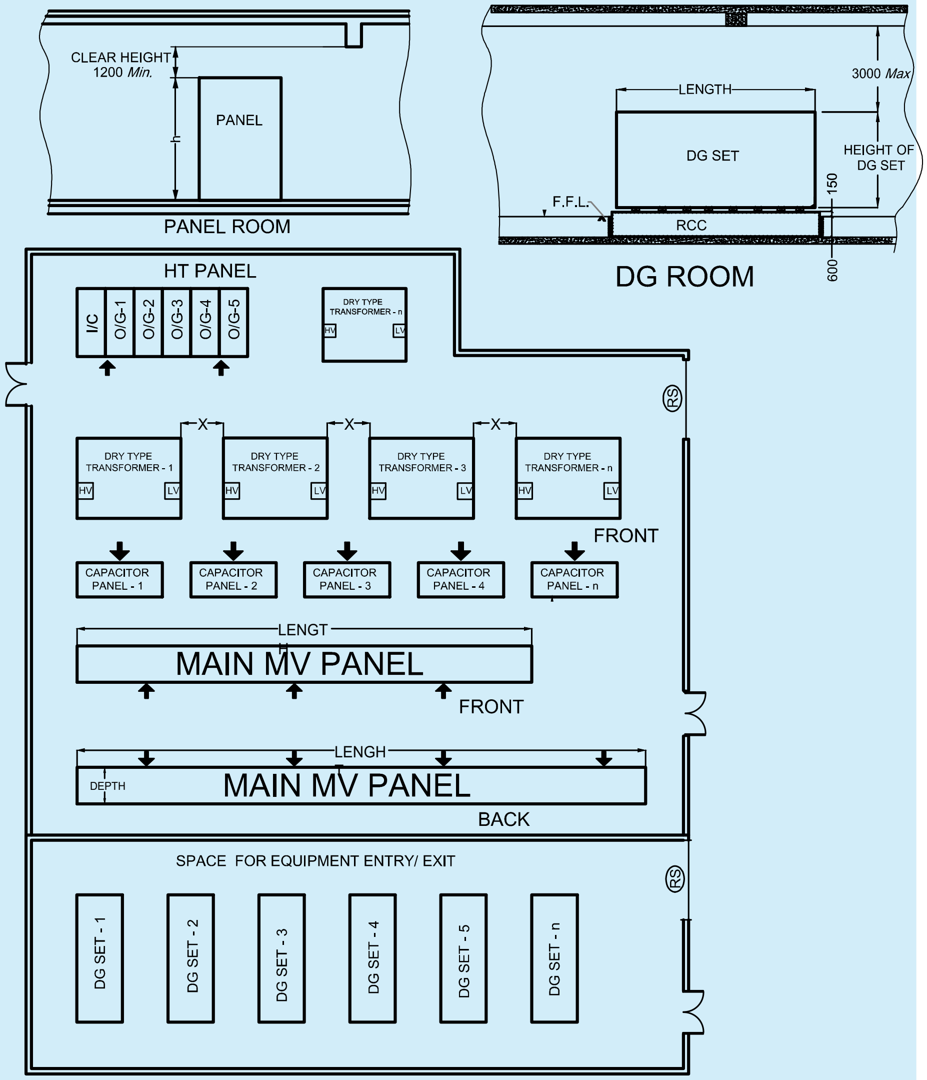
e) *LV isolation room/space* required, in case LV panel is away from transformer or on a different level for isolating supply in case of any repair required between transformer and LV switchgear; and

f) *Main LV panel room/space*, required for distribution to different facility/utility in a building.

A typical layout of a substation is shown in Fig. 1B.


0.75 m
TRANSFORMER
0.75 m
TRANSFORMER WITH WALL ON TWO SIDES
1.0 m
TRANSFORMER
1.0 m
1.0 m
TRANSFORMER WITH WALL ON THREE SIDES
1.25 m
TRANSFORMER
1.25 m
1.25 m
1.25 m
TRANSFORMER IN ENCLOSED ROOM
1.25 m
TRANSFORMER
X
TRANSFORMER
ENTRY/EXIT OF EQUIPMENT AND AUTHORIZED PERSON
1.25 m
1.25 m
1.25 m
X TO BE AS PER 4.2.1(w)
MULTIPLE TRANSFORMERS IN A ROOM

1A MINIMUM RECOMMENDED SPACING BETWEEN THE TRANSFORMER PERIPHERY AND WALLS


CLEAR HEIGHT 1200 *Min.*
h
PANEL
PANEL ROOM
LENGTH
3000 *Max*
DG SET
HEIGHT OF DG SET
150
F.F.L.
RCC
600
DG ROOM
HT PANEL
I/C
O/G-1
O/G-2
O/G-3
O/G-4
O/G-5
DRY TYPE TRANSFORMER - n
HV
LV
RS
X
DRY TYPE TRANSFORMER - 1
DRY TYPE TRANSFORMER - 2
DRY TYPE TRANSFORMER - 3
DRY TYPE TRANSFORMER - n
FRONT
CAPACITOR PANEL - 1
CAPACITOR PANEL - 2
CAPACITOR PANEL - 3
CAPACITOR PANEL - 4
CAPACITOR PANEL - n
LENGTH
MAIN MV PANEL
FRONT
LENGH
DEPTH
MAIN MV PANEL
BACK
SPACE FOR EQUIPMENT ENTRY/ EXIT
DG SET - 1
DG SET - 2
DG SET - 3
DG SET - 4
DG SET - 5
DG SET - n

X TO BE AS PER 4.2.1(w)

ALL DIMENSIONS IN MILLIMETRES.

1B TYPICAL LAYOUT OF SUBSTATION WITH DRY TYPE EQUIPMENT IN A SINGLE ROOM

FIG. 1 TYPICAL LAYOUT OF SUBSTATION INCLUDING MINIMUM RECOMMENDED SPACING OF TRANSFORMER PERIPHERY FROM WALLS

4.2.2.2 *Capacity and size of substation*

The capacity of a substation depends upon the area of the building and its type. The capacity of substation may be determined based on the load requirements [*see also* 3.5.2 (g)]. The Annex F of **6.5.1** under Part 1 'General and Common Aspects, Section 9 Wiring Installations' of good practice [D-2(1)] gives broad values for different types of loads. Ratings of some electrical equipment are given in **6.1**. The Table given below provides broad values for different types of electrical loads. All these aspects shall be considered while calculating the load assessment for the building.

Sl No.	*Purpose of Final Circuit Fed from Conductors or Switchgear to which Diversity Applies*	*Typical Allowances for Diversity Based on*: *Type of Building*		
		Individual House-Hold Installations, Including Individual Dwelling of a Block	Small Shops, Stores, Offices and Business Premises	Small Hotels, Boarding Houses, etc
(1)	(2)	(3)	(4)	(5)
i)	Lighting and convenience power	66 percent of total current demand	90 percent of total current demand	75 percent of total current demand
ii)	Heating and power [*see also* Sl No. (iii) to (iv)]	100 percent of total current demand up to 10 A + 50 percent of any current demand in excess of 10 A	100 percent of full load of largest appliance + 75 percent of remaining appliances	100 percent of full load of largest appliance + 60 percent of second largest appliance + 40 percent of remaining appliances
iii)	Air-conditioning (non-centralized)	100 percent of connected AC load for spaces up to 100 m^2 and 60 percent to 75 percent of connected AC load beyond 100 m^2	100 percent of connected AC load for spaces up to 200 m^2 and 80 percent to 85 percent of connected AC load beyond 200 m^2	90 percent of full load for public spaces and FOTH/BOTH spaces + 60 percent – 75 percent of rooms
iv)	Air-conditioning (centralized)	70 percent of high side equipment and 80 percentage of low side equipment	80 percent of high side equipment and 90 percentage of low side equipment	80 percent of high side equipment and 90 percentage of low side equipment
v)	Cooking appliances	10 A + 30 percent full load of connected cooking appliances in excess of 10 A + 6 A if socket-outlet incorporated in the unit	100 percent of full load of largest appliance + 80 percent of full load of second largest appliance + 60 percent of full load of remaining appliances	70 percent to 60 percent of full load of kitchen equipment and its corresponding ventilation equipment
vi)	Laundry equipment’s	100 percent of full load of largest motor + 50 percent of full load of remaining motors	100 percent of full load of largest motor + 50 percent of full load of remaining motors	100 percent of full load of largest motor + 50 percent of full load of remaining motors
vii)	Motors (other than lift, escalators and travellators motors which are subject to special consideration)	100 percent of full load of largest motor + 50 percent of full load of remaining motors	100 percent of full load of largest motor + 80 percent of full load of second largest motor + 60 percent of full load of remaining motors	100 percent of full load of largest motor + 50 percent of full load of remaining motors

Table (*Concluded*)

Sl No.	*Purpose of Final Circuit Fed from Conductors or Switchgear to which Diversity Applies*	*Typical Allowances for Diversity Based on*: *Type of Building*		
		Individual House-Hold Installations, Including Individual Dwelling of a Block	Small Shops, Stores, Offices and Business Premises	Small Hotels, Boarding Houses, etc
(1)	(2)	(3)	(4)	(5)
viii)	Lift, escalators and travellators	100 percentage of cumulative loads	100 percentage of cumulative loads	100 percentage of cumulative loads
ix)	Water heater/heat pump (instantaneous type[1])	100 percent of full load of largest appliance + 100 percent of full load of second largest appliance + 25 percent of full load of remaining appliances	100 percent of full load of largest appliance + 100 percent of full load of second largest appliance + 25 percent of full load of remaining appliances	100 percent of full load of largest appliance + 100 percent of full load of second largest appliance + 25 percent of full load of remaining appliances
x)	Water heater (thermostatically controlled)	No diversity allowable[2]	–	–
xi)	Floor warming installations	No diversity allowable[2]	–	–
xii)	Water heaters thermal storage space heating installations	No diversity allowable[2]	–	–
xiii)	Standard arrangements of final circuits in accordance with good practice [D-2(18)]	100 percent of the current demand of the largest circuit + 40 percent of the current demand of every other circuit	100 percent of the current demand of the largest circuit + 50 percent of the current demand of every other circuit	100 percent of the current demand of the largest circuit + 40 percent of the current demand of every other circuit
xiv)	Socket-outlets other than those included in Sl No. (ix) and stationary equipment other than those listed above	100 percent of the current demand of the largest point + 40 percent of the current demand of every other point	100 percent of the current demand of the largest point + 75 percent of the current demand of every other point	100 percent of the current demand of the largest point + 75 percent of the current demand of every point in main rooms (dining rooms, etc) + 40 percent of the current demand of every other point

NOTE — Diversity may be considered if multiple units of water heater are there in an individual house-hold installation, including individual dwelling of a block.

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[1] For the purpose of the table, an instantaneous water heater is deemed to be a water heater of any loading which heats water only while the tap is turned on and therefore uses electricity intermittently.

[2] It is important to ensure that the distribution boards are of sufficient rating to take the total load connected to them without the application of any diversity.

After calculating the electrical load on the above basis, an overall load factor of 50 percent to 90 percent is to be applied to arrive at the minimum capacity of substation. A future load may also be considered for substation sizing [*see* **3.5.2** (g)]. The area required for substation and transformer room for different capacities is given in Annex C for general guidance. For reliability, it is recommended to split the load into more than one transformer and also provide for standby transformer as well as multiple sources, bus-section, etc.

4.3 Emergency Power Backup System (DG Sets/Gas Generators)

4.3.1 *Location*

The emergency power supply (such as generating sets) should not be allowed to be installed above ground floor or below the first basement level of the building in case of multiple basements. However, if necessary DG set can be installed in first floor with dedicated approach and in separate fire compartment. In case of DG set located in basement, facilities for forced ventilation shall be provided such that there is minimum derating of the equipment. The generating set should preferably be housed adjacent to LV switchgear in the substation building to enable transfer of electrical load efficiently and also to avoid transfer of vibration and noise to the main building.

4.3.2 *Room for Emergency Power Backup System*

The capacity of standby generating set shall be chosen on the basis of essential light load, essential air conditioning load, essential life and safety services load [*see* **4.2.1**(jj)], essential equipment load and essential services load, such as minimum one lift out of the bank of lifts and minimum one or all water pumps. In certain cases, more than one generating set is provided based on the type of essential and sensitive loads that are to be operational during power breakdowns. Hence depending on the change over time, the connected switchgears/automatic mains failure (AMF) panels are to be selected. Having chosen the capacity and number of generating sets, required space may be provided for their installation (*see* Annex D for general guidance). There shall be provision of separate direct escape and entry from outside so that in case of fire, electrical supplies can be disconnected to avoid additional losses which may be caused due to electrical supply, present at the time of fire. The height of diesel generating (DG) set rooms shall however be not more than 3 000 mm above the DG set height, unless required due to DG room ventilation requirements. Adequate space shall be provided for storing of fuel. Facilities including space at appropriate positions, relative to the location of the installed equipment has to be kept in the layout design for removal of equipment or sub-assemblies for repair or maintenance. When it is located at a place, other than the ground level with direct equipment access, a hatch or ramp shall be provided.

4.3.3 *Installation and Other Requirements*

Following installation and other requirements shall also be complied with:

a) Day-oil tanks for the DG sets shall be in compliance with *The Petroleum Act*, 1934. It is desirable to have day oil tanks of capacity less than 1 000 litre of diesel/high speed diesel (HSD) with the DG set and not exceeding 1 500 litre of HSD in separate rooms adjacent to DG sets/DG room. Additional quantities required should be kept in underground tanks as per provisions of *The Petroleum Act*, 1934 after taking necessary license;

b) The emergency installation shall comply with the norms laid down by the Central Pollution Control Board (CPCB) and shall also be in compliance with *The Petroleum Act*, 1934 and guidelines of Oil Industry Safety Directorate (OISD). Compartmentation for fire protection with detection and first-aid protection measures is essential;

   NOTE — Different type of fire safety requirements exists for the DG set, for the oil storage area and for the switchgear (*see also* Part F 'Fire and Life Safety' of this NBCS).

c) Acoustic enclosure for DG sets/acoustic lining of the DG room and ventilation system for DG room shall be in line with the requirements of CPCB. If DG set is located outdoor, it shall be housed in acoustics enclosure as per the requirements of CPCB norms. For acoustical enclosures/treatment, reference shall also be made to Part D 'Building Services, Section 4 Acoustics, Sound Insulation and Noise Control' of this NBCS;

d) Vertical stacking of DG Sets should not be done to ensure at least one DG set is in operation when the other set is on fire or under maintenance. In case stacking of DG sets is unavoidable on ground, a proper fire barrier of 120 min fire rating between the two DG sets should be ensured. Both DG sets should be kept on free standing civil structure with independent access for each generating set and fire barriers in between, such that fire in one does not jump/drip to other. Also, both should be available independently for repair and maintenance. In case of horizontal stacking of DG sets not less than 1.2 m space between the DG sets shall be maintained. Proper ventilation arrangement within the space shall be provided where stacking of DG sets is done;

e) The DG set room should have proper ventilation for engine combustion requirements, heat produced by the body of DG set and the heat removal from radiator or cooling tower, etc to maintain ambient temperature inside the room. The other requirements given in Part F 'Fire and Life Safety' of this NBCS for room for emergency power backup system including DG set room should also be complied with;

f) Other environmental requirements under the provisions of *The Petroleum Act/Rules*, 2002 and norms laid down by CPCB, as amended from time to time, shall be taken into account particularly from the aspect of engine emissions including the height of exhaust pipe and permitted noise levels/controls; and

g) Provisions contained in the *CEA* (*Measures relating to Safety and Electric Supply*) *Regulations*, 2023, as amended up to date, good practice [D-2(1)] and relevant Indian Standards shall also be complied with.

4.4 Battery Storage Energy Power Backup System (Li-ion or Similar)

Bulk storage of batteries for power backup supply shall be allowed to be installed in rooms which are properly ventilated to avoid fire accidents (18 air changes per hour). The system shall comply with provisions under relevant IEC standards for storage batteries. There shall be proper space around the container having storage batteries. Necessary gas monitoring system with automatic ventilation arrangement shall be provided for the space. No other material shall be stored in the battery storage area. These batteries should be properly maintained and connected to avoid any sparking/flashing leading to fire. Protection measures shall be taken to avoid thermal runaway, short circuiting, overheating of connecting cables, etc. Container should be air-conditioned/air cooled/liquid cooled and kept as per OEM guidelines. All protection and safety measures as given in the relevant Indian Standards shall be complied. Only a.c. wiring should be taken out of the container for synchronizing with other emergency sources or feeding solar power to premise as individual supply.

4.5 Multiple Energy Sources

When multiple energy sources such as grid, DG set power backup with AMF panel, battery storage energy system, on grid solar PV power, on grid other renewable energy sources such as wind power, micro wind wheel, etc are to be used in the same project simultaneously, synchronization of voltage and frequency of each source is required for energies to be used optimally including setting priorities of source utilization. All protection and safety measures as given in the relevant Indian Standards for each of the energy sources shall also be complied with.

4.6 Location of LV Switch Room Other Than in Substation

In large installations other than where a substation is provided, a separate switch room shall be provided. This shall be located as close to the electrical load centre as possible, on the ground floor or on the first basement level of the building, preferably on the same floor as Transformers. In case LT panel and transformer and DG sets are on different floors then LT isolators shall be proposed adjacent to transformer and DG sets.

Suitable cable trays/busducts shall be laid with minimum number of bends from the points of entry of the main supply cable to the position of the main switchgear. The switch room shall also be placed in such a position that riser shafts may readily be provided therefrom to the upper floors of the building in one straight vertical run. In larger buildings, more than one riser shaft may be required and then horizontal cable trays/bus ducts may also be required for running cables from the switch room to the foot of each rising main. The support system shall be sufficient to take into account the load of the cables to be carried with seismic considerations.

Such cable trays shall either be reserved for specific voltage grades or provided with a means of segregation for low and extra low voltage installations, such as nurses call-bell systems in hospitals, intercom telephone installations, fire detection and alarm system, security systems, data cables and announcement or public address system. Cables/wires for emergency fire and life safety services and their routing should be in accordance with **4.2.1**(jj) and Part F 'Fire and Life Safety' of this NBCS so that these services are maintained even in the event of fire.

Clear space around panels should be kept for access and maintenance depending on circuit breaker type as required. In case of ACB/MCCB front and back access should be planned with all sides movement clearance with 1 000 mm access on back and sides and 2 000 mm access in front of panel. However, space of less than or up to 200 mm is permitted on the back of the panel where there is no access or sufficient space.

4.7 Location and Requirements of Distribution Panels

All distribution panels including switchgears shall be installed in readily accessible position. The electrical controlgear distribution panels and other apparatus, which are required on each floor may conveniently be mounted adjacent to the rising mains, and adequate space considering clearances required as per **5.3.6.8** shall be provided at each floor for this purpose.

4.8 Substation Safety

The owner and the operator of any substation shall be collectively and severally be responsible for any lapse or neglect leading to an accident or an incidence of an avoidable abnormality and shall take care of the following safety requirements:

a) Enclose the substation or similar equipment where necessary to prevent, so far as is reasonably practicable, danger of electric shock or unauthorized access.

b) All equipment, entry and exit shall be always kept accessible.

c) Substation should be a separate fire compartment and its ventilation should be independent of any other fire compartment.

d) All substation rooms shall have two doors at opposite ends. Distance between all equipment such that exit/entry of equipment is feasible without removing of any equipment, light, cable or bus duct, etc.

e) Any part of the substation which is open to the air shall be enclosed, with a fence (earthed efficiently at both ends) or wall at least 600 mm above the height of tallest equipment; to prevent, so far as is reasonably practicable, danger of electric shock or unauthorized access.

f) Transformers (oil filled) when placed in open shall have fencing/wall at least 600 mm above the height of transformer. If trees are there around the substation, then a temporary cover should be provided to avoid leaves falling on the terminals of HT/LT terminations.

g) It shall be ensured that the following are displayed at all times in the substation:

    1) Sufficient safety signs of such size and placed in such positions as are necessary to give due warning of such danger as is reasonably foreseeable in the circumstances;

    2) A notice which is placed in a conspicuous position and which gives the location or identification of the substation, the name of each owner/operator who owns or operates the substation equipment making up the substation and the telephone number where a suitably qualified person appointed for this purpose by the owner/operator will be in constant attendance; and

    3) Such other signs, which are of such size and placed in such positions, as are necessary to give due warning of danger having regard to the siting of, the nature of, and the measures taken to ensure the physical security of, the substation equipment;

h) All reasonable precautions are taken to minimize the risk of fire associated with the equipment.

j) In addition to provisions mentioned in (c), name and emergency telephone number of the authorized personnel shall also be displayed at the substation and instructions covering schematic diagram; requirements of switchgear interlocking, if any; and permission requirements, if any, for load limitations on (incoming) feeders; be also prominently displayed.

4.9 Overhead Lines, Wires and Cables

All erections/alterations having relation to overhead lines, wires and cables shall comply with *Central Electricity Authority* (*Measures relating to Safety and Electric Supply*) *Regulations*, 2023 with special reference to regulation number 62 and 63 and the following points. However, in case of any conflict, the regulations shall prevail (*see* Annex B).

4.9.1 *Height Requirement*

4.9.1.1 While overhead lines may not be relevant within buildings, regulations related to overhead lines are of concern from different angles as follows:

a) Overhead lines may be required in building complexes, though use of underground cables is the preferred alternative; and

b) Overhead lines may be passing through the site of a building. In such a case the safety aspects are important for the construction activity in the vicinity of the overhead line as well as portions of low height buildings that may have to be constructed below the overhead lines. Overhead lines running adjacent to buildings pose hazard from the aspect of certain maintenance activity (such as use of a ladder on external face of a building) causing temporary compromise of the minimum safety clearance.

4.9.1.2 If at any time subsequent to the erection of an overhead line, whether covered with insulating material or not, or underground cable, any person who proposes to erect a new building or structure or to raise any road level or to carry out any other type of work whether permanent or temporary or to make in or upon any building, or structure or road, any permanent or temporary addition or alteration, in proximity to an overhead line or underground cable, such person and the contractor whom he employs to carry out the erection, addition or alteration, shall give intimation in writing of his intention to do so to the supplier or owner and to the Electrical Inspector and shall furnish therewith a scale drawing showing the proposed building, structure, road or any addition or alteration and scaffolding thereof required during the construction. In this connection, Regulation 63 of *Central Electricity Authority* (*Measures relating to Safety and Electric Supply*) *Regulations*, 2023, shall also be complied with (*see* Annex B).

4.9.1.3 Any person responsible for erecting an overhead line will keep informed the authority(s) responsible for services in that area for telecommunication, gas distribution, water and sewage network; roads and so as to have proper coordination to ensure safety. He shall also publish the testing, energizing programme for the line in the interest of safety.

4.9.1.4 For minimum distance (vertical and horizontal) of electric lines/wires/cables from buildings, Regulations 60, 62, 63, and 67 of *Central Electricity Authority* (*Measures relating to Safety and Electric Supply*) *Regulations*, 2023, shall be complied with (*see* Annex B).

4.9.1.5 Regulation 66 of *Central Electricity Authority* (*Measures relating to Safety and Electric Supply*) *Regulations*, 2023, which govern conditions related to the storage of material including storage of construction material at a construction site, or other materials in a building in vicinity of overhead lines and underground cables, shall also be complied with (*see* Annex B).

4.9.2 *Position, Insulation and Protection of Overhead Lines*

4.9.2.1 Any part of an overhead line which is not connected with earth and which is not ordinarily accessible shall be supported on insulators or surrounded by insulation. Any part of an overhead line which is not connected with earth and which is ordinarily accessible shall be:

a) made dead; or

b) so insulated that it is protected, so far it is reasonably practicable, against mechanical damage or interference; or

c) adequately protected to prevent danger.

4.9.2.2 Any person responsible for erecting a building or structure which will cause any part of an overhead line which is not connected with earth to become ordinarily accessible shall give reasonable notice to the licensee or distributor who owns or operates the overhead line of his intention to erect that building or structure.

The expression ‘ordinarily accessible’ means the overhead line might be reachable by hand if any scaffolding, ladder or other construction was erected or placed on/in, against or near to a building or structure.

4.9.2.3 Any bare conductor not connected with earth, which is part of a low voltage overhead line, shall be situated throughout its length directly above a bare conductor which is connected with earth.

4.9.3 *Precautions against Access and Warnings of Dangers*

4.9.3.1 Every support carrying a high voltage overhead line shall be fitted with anti-climbing devices to prevent any unauthorized person from reaching a position at which any such line will be a source of danger. In this connection, Regulation 76 of *Central Electricity Authority* (*Measures Relating to Safety and Electric Supply*) *Regulations*, 2023, shall also be complied with (*see* Annex B).

4.9.3.2 Every support carrying a high voltage overhead line, and every support carrying a low voltage overhead line incorporating bare phase conductors, shall have attached to it sufficient safety signs and placed in such positions as are necessary to give due warning of such danger as is reasonably foreseeable in the circumstances.

4.9.3.3 Poles supporting overhead lines near the road junctions and turnings shall be protected by a masonry or earth fill structure or metal barricade, to prevent a vehicle from directly hitting the pole, so that the vehicle, if out of control, is restrained from causing total damage to the live conductor system and lead to a hazardous condition on the road or footpath or building.

4.9.4 *Fitting of Insulators to Stay Wires*

Every stay wire which forms part of, or is attached to, any support carrying an overhead line incorporating bare phase conductors (except where the support is a lattice steel structure or other structure entirely of metal and connected to earth) shall be fitted with an insulator, no part of which shall be less than 3 m above ground or above the normal height of any such line attached to that support.

4.10 Maps of Underground Networks

4.10.1 Any person or organization or authority laying cables shall contact the local authority in charge of that area and find out the layout of:

a) water distribution pipe lines in the area;
b) sewage distribution network;
c) telecommunication network;
d) gas pipeline network; and
e) existing power cable network;

and plan the cable network in such a manner that the system is compatible, safe and non-interfering either during its installation or during its operation and maintenance. Plan of the proposed cable installation shall be brought to the notice of the other authorities referred above.

4.10.2 Suitable cable markers and danger sign as will be appropriate for the safety of the workmen of any of the systems shall be installed along with the cable installation. Cable route markers shall be provided at every 20 m and also at turnings and/or crossings.

4.10.3 Notification of testing and energization of the system shall also be suitably publicized for ensuring safety.

4.10.4 Any person or organization or authority associated with the operation and maintenance of services in a complex is required to have a complete integrated diagram or drawings of all services with particular emphasis on the hidden pipes, cables, etc, duly kept up-to-date by frequent interaction with all agencies associated with the maintenance work.

Organization or agency responsible for laying cables shall have and, so far it is reasonably practicable, keep up-to-date, a map or series of maps indicating the position and depth below surface level of all networks or parts thereof which he owns or operates. Where adequate mapping has not been done and the excavation for cable laying reveals lines pertaining to any of the other services, three dimensional location should be marked and recorded. Even where mapping exists, it may be examined if the records have become obsolete due to change such as, in road level. Any map prepared or kept shall be available for inspection by any authority, such as municipality, water supply, sewage, service providers and general public, provided they have a reasonable cause for requiring reference to any part of the map.

4.10.5 Any agency working on any one or more service (occupying the underground space for service pipes, cables, etc) should keep the other agencies informed of the work so that an inadvertent action will not cause a disruption of service. Each agency should be responsible for keeping the latest information with the central authority of such records and should be responsible to ensure that the modifications, if any, are duly updated and notified among the other agencies.

5 DISTRIBUTION OF SUPPLY AND CABLING

5.1 General

5.1.1 In the planning and design of an electrical wiring installation, due consideration shall be made of all the prevailing conditions. It is recommended that advice of a competent electrical engineer be sought at the initial stage itself with a view to providing an installation that will prove adequate for its intended purpose, be reliable, safe and efficient.

While planning of routing of cables and bus trunking it shall be ensured to avoid passing of cables and bus trunking from lift lobbies, staircase lobbies and fire exits. Proper ventilations or air-changes shall be provided for heat rejected from bus trunking and cables.

5.1.2 A certain redundancy in the electrical system is necessary and has to be built in from the initial design stage itself. The extent of redundancy will depend on the type of load, its criticality, normal hours of use, quality of power supply in that area, coordination with the standby power supply, capacity to meet the starting current requirements of large motors, etc.

5.1.3 In modern building technology, following high demands are made of the power distribution system and its individual components:

a) long life and good service quality;

b) safe protection in the event of fire;

c) low fire load;

d) flexibility in load location and connection, but critical in design;

e) low space requirement; and

f) minimum effort involved in carrying out retrofits.

5.1.4 The high load density in modern large buildings and high-rise buildings demands compact and safe solution for the supply of power. The use of busbar trunking system is ideal for such applications. Busbar trunking can be installed in vertical riser’s shafts or horizontally in passages for transmission and distribution of power. They allow electrical installations to be planned in a simple and neat manner. In the building complexes, additional safety demands with respect to fire barriers and fire load can also be met with the use of busbar trunking. Busbar trunking system also reduces the combustible material near the area with high energy in comparison with other distribution systems such as cables and makes the building safe from the aspect of vulnerability to fire of electrical origin. In addition, unlike cable systems the reliability of a busbar trunking system is very high. These systems also require very little periodic maintenance. Choice of busbar trunking for distribution in buildings can be made on the basis of:

a) reduced fire load (drastically reduced in comparison to the cable system);

NOTE — Insulation materials of cables are required to be fire resistant and an essential performance requirement is that the insulation material may burn or melt and flow when directly exposed to a temperature (or fire) higher than what it is class designated, but should not continue to burn after the flame or the source of heat or fire is extinguished. Even if the above fire resistant property is exhibited by the cable insulation, a large collection of cables will make the cable insulation fail to exhibit this retardant property. While specific guidelines for limiting number of cable and bunching is not available and in such cases the switch over to a busbar trunking system is the proper alternative.

b) reduced maintenance over its entire lifetime;

c) longer service lifetime in comparison with a cable distribution; and

d) enhanced reliability due to rigid bolted joints and terminations and extremely low possibility of insulation failure.

NOTE — Provisions contained in electric supply and cabling shall also comply with the provisions relating to *the CEA* (*Measures relating to Safety and Electric Supply*) *Regulations*, 2023, good practice [D-2(1)] and relevant Indian Standards as amended up to date.

5.2 System of Supply

5.2.1 All electrical apparatus shall be suitable for the voltage and frequency of supply.

5.2.2 In case of connected load of 100 kVA and above, the relative advantage of high voltage three-phase supply may be considered. Though the use of high voltage supply entails the provisions of space and the capital cost of providing suitable transformer substation at the consumer's premises, the following advantages are gained:

a) advantage in tariff;

b) more effective earth fault protection for heavy current circuits;

c) elimination of interference with supplies to other consumers permitting the use of large size motors, welding plant, etc; and

d) better control of voltage regulation and more constant supply voltage.

NOTE — Additional safety precautions required to be observed in HV installations shall also be kept in view.

In many cases there may be no choice available to the consumer, as most of the licensees have formulated their policy of correlating the supply voltage with the connected load or the contract demand. Generally, the supply is at 240 V single phase up to 5 kVA, 415/240 V 3 phase from 5 kVA to 100 kVA, 11 kV (or 22 kV) for loads up to 5 MVA and 33 kV for consumers of connected load or contract demand more than 5 MVA.

In case of load exceeding 10 MVA at 33 kV for building complex, designer may explore option of having a combination of power transformers and distribution transformers to reduce the numbers and long lengths of power cables. 33 kV/11 kV power substation at site level/utility building for stepping down at 11 kV and then having 11 kV/415 Volt distribution substation at basement/ground/first floor/usage floors, near load centres to avoid long lengths of 415 volt cables.

5.2.3 In very large industrial buildings where heavy electric demands occur at scattered locations, the economics of electrical distribution at high voltage from the main substation to other subsidiary transformer substations or to certain items of plant, such as large motors and furnaces, should be considered. The relative economy attainable by use of high voltage distribution and high voltage equipment is a matter for expert judgment and individual assessment in the light of experience by a professionally qualified electrical engineer. *See also* good practice [D-2(1)] and accepted standard [D-2(19)].

5.2.4 In case of complex buildings/mixed use buildings where individual load of usage category (such as commercial, mercantile, residential, hotels, hospitals, storage, industry, etc has cumulative load of 1 000 kVA, then for EV charging requiring more than 100 kVA power should be proposed with independent distribution transformer(s) (200 kVA or more) with separate meter to avoid mixing of different type of loads, harmonics, etc.

5.2.5 As far as possible, EV charging arrangement shall be provided with independent transformer to ensure that harmonics created during EV charging do not interfere with power supply to other system. It shall be ensured that EV charging is not fed from diesel generator sets or gas generators or similar fuel based power generating systems (*see* **10.7** for more details).

5.3 Substation Equipment and Accessories

Substations require an approval from the Electrical Inspectorate. Such approval is mandatory before energizing the substation. Therefore, it is essential to get the approval for the general layout, schematic layout, protection plan, etc, before the start of the work from the Inspectorate. All substation equipment and accessories and materials, etc, shall conform to relevant Indian Standards, wherever they exist, otherwise the consumer (or his consultant) shall specify the standards to which the equipment to be supplied and that shall be approved by the authority. Manufacturers of equipment have to furnish certificate of conformity as well as type test certificates for record, in addition to specified test certificates for acceptance tests and installation related tests for earthing, earth continuity, load tests and tests for performance of protective gear. All works under this, shall comply with the requirements of relevant Indian Standards and provisions of **5.1** of Part 1 'General and Common Aspects, Section 9 Wiring Installations' of good practice [D-2(1)].

5.3.1 *Supply Company's High Voltage Meter Board*

In case of single point high voltage metering, energy meters shall be installed in building premise as per **4.2.2.1**, at such a place which is readily accessible/provides unobstructed access to the electric supply company. The supplier or owner of the installation shall provide at the point of commencement of supply a suitable isolating device fixed in a conspicuous position at not more than 1.7 m above the ground so as to completely isolate the supply to the building in case of emergency.

In case of multipoint metering, main energy meter and reference meters shall be installed in building premises as per **4.2.2.1**, at a place which is readily accessible to the owner/operator of the building and the authority. These should be accompanied with smart metering system (with dual source pre-paid meters).

In this connection, the *Central Electricity Authority* (*Installation and Operation of Meters*) *Regulations*, 2006, as amended from time-to-time shall also be complied with.

5.3.2 *High Voltage Switchgear*

5.3.2.1 The selection of the type of high voltage switchgear for any installation inter alia depends upon the following:

a) voltage of the supply system;

b) prospective short-circuit current at the point of supply;

c) size and layout of electrical installation;

d) availability of space; and

e) nature of installation.

Making and breaking capacity of switchgear shall be commensurate with short-circuit potentialities of the supply system and the supply authority shall be consulted on this subject. The HV switchgear and controlgear shall conform to the relevant Indian Standards. For details see accepted standard [D-2(7)].

5.3.2.2 Guidelines on various types of switchgear equipment and their choice for a particular application shall be in accordance with good practice [D-2(20)].

5.3.2.3 In extensive installations of switchgear (having more than four incoming supply or having more than 12 circuit breakers), banks of switchgears shall be segregated from each other in order to prevent spreading of the risk of damage by fire or explosion arising from switch failure. Where a bus-bar section switch is installed, it shall also be segregated from adjoining banks in the same way {*see* good practice [D-2(21)]}.

5.3.2.4 It should be possible to isolate any section from the rest of the switchboards such that work might be undertaken on this section without the necessity of making the switchboard dead. Isolating switches used for the interconnection of sections or for the purpose of isolating circuit-breakers of other apparatus, shall also be segregated within its compartment so that no live part is accessible when work in a neighbouring section is in progress.

5.3.2.5 In the case of double or ring main supply, switchgears with interlocking arrangement shall be provided to prevent simultaneous switching of two different supply sources. Electrical and/or mechanical interlocks may preferably be provided.

5.3.2.6 The selection and erection shall also comply with the provisions of accepted standard [D-2(22)].

5.3.3 *HV Cables*

5.3.3.1 The sizing of the cable shall depend upon the method of laying cable, current to be carried, permissible maximum temperature it shall withstand, voltage drop over the length of the cable, the prospective short-circuit current to which the cable may be subjected, the characteristics of the overload protection gear installed, load cycle, thermal resistivity of the soil and the operating voltage {*see also* good practice [D-2(23)]}.

5.3.3.2 All HV cables shall be installed in accordance with good practice [D-2(23)]. The HV cables shall either be laid on the cable rack/built-up concrete trenches/tunnel/basement or directly buried in the ground depending upon the specific requirement. When HV cable is hanging/running below the basement ceiling slab, the cable shall be laid in a fire rated enclosure/cable tray. The advice of the cable manufacturer with regard to installation, jointing and sealing should also be followed.

5.3.4 *High Voltage Busbar Trunking/Ducting*

HV busbar system is used for transporting power between HV generators, transformers and the infeed main switchgear of the main HV switchgear.

Generally, three types of bus ducts, namely non-segregated, segregated and isolated phase bus ducts are used. The non-segregated bus ducts consist of three phase busbars running in a common enclosure made of steel or aluminium. The enclosure shall provide safety for the operational personnel and shall reduce chances of faults. HV interconnecting busbar trunking for a.c. voltage above 1 kV up to and including 36 kV shall conform to accepted standard [D-2(24)]. The enclosures shall be effectively grounded.

Segregated phase bus ducts are similar to non-segregated phase duct except that metal or isolation barriers are provided between phase conductors to reduce chances of phase to phase faults. However, it is preferable to use metal barriers.

In the case of isolated bus ducts, each phase conductor shall be housed in a separate non-magnetic enclosure. The bus duct shall be made of sections which are assembled together at site to make complete assembly. The enclosure shall be of either round or square shape and welded construction. The enclosures of all phases in general should be supported on a common steel structure.

Seismic supports shall be provided for busbar trunking having continuous straight lengths of more than 24 m at a single stretch in horizontal formation and 12 m in vertical formation in accordance with relevant standards.

The bus duct system shall be coordinated with connecting switchgear so as to provide adequate protection.

When busbar trunking is crossing different fire compartments, they shall have fire barriers of same rating as that of the compartment (*see also* Part F 'Fire and Life Safety' of this NBCS).

5.3.5 *Transformers*

5.3.5.1 General design objective while selecting the transformer(s) for a substation should be to provide at least two or more transformers, so that a certain amount of redundancy is built in, even if a standby system is provided. With growing emphasis on energy conservation, the system design should be made for both extremes of loading. During the periods of lowest load in the system, it would be desirable to operate only one transformer and subsequently switching on the additional transformers as the load increases during the day. Total transformer capacity is generally selected on the basis of present load, possible future load, operation and maintenance cost and other system conditions. The selection of the maximum size (capacity) of the transformer is guided by the short-circuit making and breaking capacity of the switchgear used in the high voltage distribution system. Maximum size limitation is important from the aspect of feed to a downstream fault. The transformers shall conform to accepted standards [D-2(25)].

5.3.5.2 For reasons of reliability and redundancy it is normal practice to provide at least two transformers (especially where electrical load is beyond 1 500 kVA) for functional buildings, hospitals, hotels, institutes, etc. Providing distribution transformers beyond 1 600 kVA/2 000 kVA is not recommended. Interlinking by tie lines is an alternative to enhance reliability/redundancy in areas where there are a number of substations in close vicinity, such as a campus with three or four multi-storeyed blocks, each with a substation. Ring main type of distribution is preferred for complexes having a number of substations.

5.3.6 *Low Voltage Switchgear*, *Controlgear and their Assemblies*

5.3.6.1 The selection of the type of low voltage switchgear for any installation inter alia depends upon the following:

a) voltage of the distribution system;

b) prospective circuit current at the point at which the switchgear is proposed;

c) prospective short-circuit current at which the switchgear is proposed;

d) availability of space; and

e) nature of installation.

The switchgear, controlgear and their assemblies so selected, shall comply with the accepted standards [D-2(26)].

5.3.6.2 Switchgear (and its protective device) shall have breaking capacity not less than the anticipated fault level in the system at that point. System fault level at a point in distribution systems is predominantly dependent on the transformer size and its reactance. Parallel operation of transformers increases the fault level.

5.3.6.3 Where two or more transformers are to be installed in a substation to supply a low voltage distribution system, the distribution system shall be divided into separate sections each of which shall be normally fed from one transformer only unless the low voltage switchgear has the requisite short-circuit capacity. Provision may, however, be made to interconnect separate sections, through a bus coupler in the event of failure or disconnection of one transformer. *See* **4.2** for details of location and requirements of substation.

5.3.6.4 Isolation and controlling circuit breaker shall be interlocked so that the isolator cannot be operated unless the corresponding breaker is in open condition. The choice between alternative types of equipment may be influenced by the following considerations:

a) In certain installations supplied with electric power from remote transformer substations, it may be necessary to protect main circuits with circuit-breakers operated by earth fault, in order to ensure effective earth fault protection;

b) Where large electric motors, furnaces or other heavy electrical equipment is installed, the main circuits shall be protected from short-circuits by switch disconnector fuse or circuit breakers. For motor protection, the combination of contactor overload device and fuse or circuit breakers shall have total co-ordination at least for motor ratings up to 10 kW and for ratings above 10 kW, it shall be Type 2 co-ordination in accordance with relevant part of accepted standards [D-2(26)]. Wherever necessary, back up protection and earth fault protection shall be provided to the main circuit; and

c) Where means of isolating main circuits is separately required, switch disconnector fuse or switch disconnector may form part of main switchboards.

5.3.6.5 It shall be mandatory to provide power factor improvement at the substation bus with suitable capacity of inductor-capacitor combination and relative switchgear in consultation with the respective manufacturers depending upon the nature of electrical load anticipated on the system. Necessary switchgear/feeder circuit breaker shall be provided for controlling of inductor-capacitor bank.

Power factor of individual motor may be improved by connecting individual capacitor banks in parallel. For higher range of motors, which are running continuously without much variation in load, individual power factor correction at load end is advisable.

NOTE — Care should be taken in deciding the kVAr rating of the capacitor in relation to the magnetizing kVA of the motor. Over rating of the capacitor may cause injury to the motor and capacitor bank. The motor still rotating after disconnection from the supply, may act as generator by self-excitation and produce a voltage higher than supply voltage. If the motor is again switched on before the speed has fallen to about 80 percent of the normal running speed, the high voltage will be superimposed on the supply circuits and will damage both the motor and the capacitor.

As a general rule, the kVAr rating of the capacitor should not exceed the no-load magnetizing kVA of the motor.

Generally, it will be necessary to provide an automatic control for switching on the capacitors matching the load power factor and the bus voltage. Such a scheme will be necessary as capacitors permanently switched in the circuit may cause overvoltage at times of light load. Capacitor panel shall be provided with adequate ventilation facility.

With the wide spread use of thyristor and rectifier based loads, there is a necessity of providing a full size neutral; but this requirement is generally limited to the 3-phase 4-wire distribution generally in the 415 V.

5.3.6.6 Harmonics on the supply systems are becoming a greater problem due to the increasing use of electronic equipment, computer, fluorescent lamps, LEDs and CFLs (both types have control/driver circuits operating in switch mode), mercury vapour and sodium vapour lighting, TV, microwave ovens, latest air conditioners, refrigerators, controlled rectifier and inverters for variable speed drives, power electronics and other non-linear loads. Harmonics may lead to almost as much current in the neutral as in the phases. This current is almost third, fifth, seventh and ninth harmonic. In such cases, phase rectification devices may be considered at the planning stage itself for the limits of harmonic voltage distortion. Use of active filters in combination/independent use with capacitor banks should be proposed with either 3-phase 3-wire or 3-phase 4 wire depending upon the equipment for which electricity is utilized. The active filters along with capacitor panel should be proposed to be located in controlled environment.

5.3.6.7 Sufficient clearances as below shall be provided for isolating the switchboard to allow access for servicing, testing and maintenance (*see* Fig. 2):

a) A clear space of not less than 1 m in width shall be provided in front of the switchboard;

NOTE — In case the board has a shutter in the front for aesthetic reasons, the opening of the shutter shall satisfy the requirement of working/safety space of 1 m in front of the switchgear.

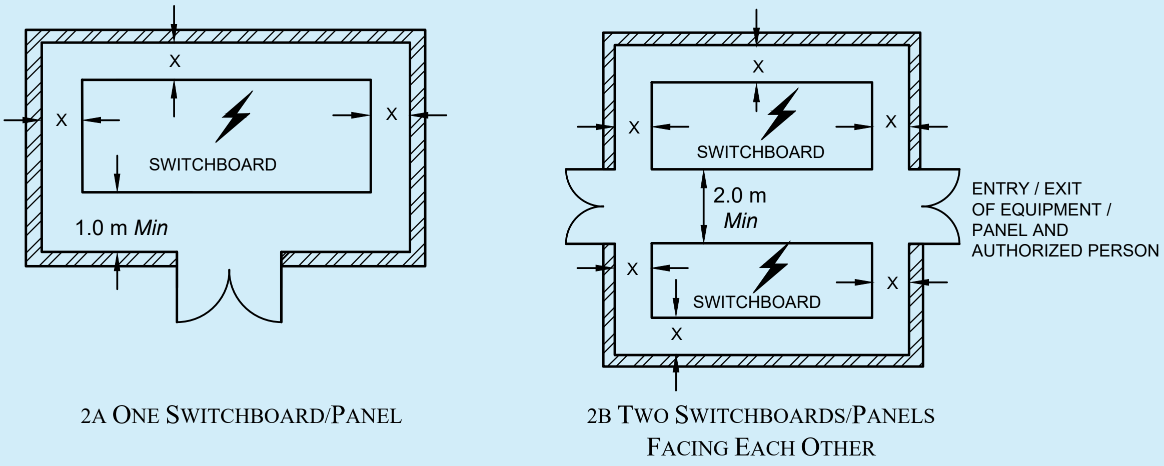
b) If access behind the switchboard is provided then it shall be either less than 200 mm or more than 750 mm in width, measured from the farthest protruding part of any attachment or conductor;

c) If the space behind the switchboard exceeds 750 mm in width, there shall be a passageway from either end of the switchboard, clear to a height of 1.8 m; and

d) If two switchboards are facing each other, a minimum distance of 2.0 m shall be maintained between them.

The connections between the switchgear mounting and the outgoing cable up to the wall shall be enclosed in a protection pipe.

There shall be a clear distance of not less than 250 mm between the board and the insulation cover, the distance being increased for larger boards in order that on closing of the cover, the insulation of the cables is not subjected to damage and no excessive twisting or bending in any case. The cable alley in the metal board should enable within prescribed limit, twisting or bending of cable such that insulation of the cables is not subjected to damage.



2A ONE SWITCHBOARD/PANEL

2B TWO SWITCHBOARDS/PANELS FACING EACH OTHER

X = LESS THAN 200 mm (IF SWITCHBOARD/PANEL IS NOT ACCESSIBLE FROM BEHIND)
= MORE THAN 750 mm (IF SWITCHBOARD/PANEL IS ACCESSIBLE FROM BEHIND)

NOTE — X TO BE MEASURED FROM THE FARTHEST PROTRUDING PART OF ANY ATTACHMENT OR CONDUCTOR.

FIG. 2 CLEARANCES AROUND SWITCHBOARD IN ENCLOSED ROOM

In this connection, for installation of voltages exceeding 250 V single phase, Regulation 37 of *Central Electricity Authority* (*Measures Relating to Safety and Electric Supply*) *Regulations*, 2023 shall also be complied with (*see* Annex B).

5.3.6.8 Sufficient additional space shall be allowed in substations and switch rooms to allow operation and maintenance. Sufficient additional space shall be allowed for temporary location and installation of standard servicing and testing equipment. Space should also be provided to allow for anticipated future extensions.

5.3.6.9 Panels in a room or cubicle, access to which is controlled by lock and key, shall be accessible to authorized persons only.

5.3.6.10 Except main LV panel, it will be preferable to locate the sub-panels/distribution boards/sub-meter boards near load centre. Further, it should be ensured that these panels are easily approachable. The panels should have clear access from common areas excluding staircase.

Where the switchboard is erected in a room of a building isolated from the source of supply or at a distance from it, adequate means of control and isolation shall be provided both near the boards and at the origin of supply. Sufficient clearances as per **5.3.6.8** shall be provided.

5.3.6.11 All switchboards shall be of metal clad totally enclosed type or any insulated enclosed pattern.

5.3.6.12 The selection and erection shall also comply with the provisions of accepted standard [D-2(22)].

5.3.7 *Medium/Low Voltage Cables*

5.3.7.1 The sizing of the cable shall depend upon the current to be carried, method of laying cable, permissible maximum temperature it shall withstand, voltage drop over the length of the cable, the prospective short-circuit current to which the cable may be subjected, the characteristics of the overload protection gear installed, load cycle, thermal resistivity of the soil and the operating voltage {*see also* good practice [D-2(18)]}.

It is desirable to use flame retardant/flame retardant low smoke and halogen free cables and wires in electrical distribution systems.

It is recommended to use four core cable in place of three and half core in respect of sizes below 50 mm^2 to minimize heating of neutral core due to harmonic content in the supply system and to also avoid overload failures. As far as possible, balancing of single phase system shall be done to ensure minimum unbalanced current in neutral of three phase system. Only four core cables shall be used for internal electrical installation. Also, all cable sizes up to 25 mm^2 shall be of copper conductor to prevent overheating and fire incidence in internal electrical installations and capacity/size considerations. All cables shall be installed in accordance with good practice [D-2(18)]. The advice of the cable manufacturer with regard to installation, jointing and sealing should also be followed.

5.3.7.2 *Colour identification of cores of non-flexible cables* {*see also* accepted standard [D-2(27)]}

The colour of cores of non-flexible cables shall be in accordance with the following:

Sl No. (1)	*Function* (2)	*Colour Identification of Core of Rubber of PVC Insulated Non-flexible Cable, or of Sleeve or Disc to be Applied to Conductor or Cable Code* (3)
i)	Protective or earthing	Green and yellow (*see* Note 1)
ii)	Phase of a.c. single-phase circuit	Red [or yellow or blue (*see* Note 2)]
iii)	Neutral of a.c. single or three-phase circuit	Black
iv)	Phase R of 3 phase a.c. circuit	Red
v)	Phase Y of 3 phase a.c. circuit	Yellow
vi)	Phase B of 3 phase a.c. circuit	Blue
vii)	Positive of d.c. 2 wire circuit	Red
viii)	Negative of d.c. 2 wire circuit	Black
ix)	Outer (positive or negative) of d.c. 2 wire circuit derived from 3 wire system	Red
x)	Positive of 3 wire system (positive of 3 wire d.c. circuit)	Red
xi)	Middle wire of 3 wire d.c. circuit	Black
xii)	Negative of 3 wire d.c. circuit	Blue
xiii)	Functional earth-telecommunication	Cream/grey

NOTES

1 Bare conductors are also used for earthing and earth continuity conductors. But it is preferable to use insulated conductors with green coloured insulation with yellow stripes.

2 As alternative to the use of red, if desired in large installations, up to the final distribution board.

3 For armoured PVC-insulated cables and paper-insulated cables, *see* relevant Indian Standard.

5.3.8 *LV Busbar Trunking/Rising Mains*

5.3.8.1 Where heavy loads and/or multiple distribution feeders are required to be supplied, busbar/rising main systems are preferred. The busbars are available for continuous run from point to point or with tap offs at standard intervals and have to be chosen as per specific requirement. Seismic supports shall be provided for busbar trunking having continuous straight lengths of more than 24 m at a single stretch in horizontal formation and 12 m in vertical formation in accordance with relevant standards. There are following two types of LV bus duct system for power distribution:

a) air insulated (conventional) type; and

b) compact and sandwich type.

5.3.8.1.1 *Air insulated* (*conventional*) *type bus duct*

These are used for large power handling between transformer and switchgear or between switchgear and large power loads such as compressor drive motor, etc. This type is generally used in plant rooms, riser shafts, substations, etc. These are generally air insulated with intermediate ceramic support insulators enclosed in a metallic enclosure, which should be earthed. They have the least amount of combustible material. However, when these are crossing different fire compartments, they shall have fire barriers of same rating as that of the compartment (*see also* Part F 'Fire and Life Safety' of this NBCS).

Air insulated (conventional) type bus ducts with non-metallic enclosures are also available. However, such bus ducts shall be used only if essential and with appropriate additional care.

5.3.8.1.2 *Compact and sandwich type bus duct*

Compact and sandwich type bus ducts are used within areas of the building which have space restrictions, functional reasons and for aesthetic considerations. The busbars shall be of copper considering the safety and longevity aspects. They may be used in false ceiling spaces or even in corridors and shafts for distribution without any false ceiling as they provide an aesthetically acceptable finish to merge with other building elements such as beams, ducts or pipes in functional buildings.

The insulation material in such ducts are generally glass fibre tape or epoxy encapsulation in combination with ceramic supports/spacers. These bus ducts should be duly enclosed by a metallic enclosure, which should be earthed.

5.3.8.1.3 The selection and erection shall also comply with the provisions of accepted standard [D-2(28)].

5.3.8.2 The bus duct system shall be coordinated with connecting switchgear so as to provide adequate protection.

5.3.8.3 When busbar trunking is crossing different fire compartments, they shall have fire barriers of same rating as that of the compartment (*see also* Part F 'Fire and Life Safety' of this NBCS).

5.3.8.4 The low voltage busbar trunking shall conform to accepted standard [D-2(28)].

5.4 Reception and Distribution of Main Supply (LV Connections)

5.4.1 *Control at Point of Commencement of Supply*

5.4.1.1 The supplier shall provide a suitable metering switchboard in which each meter units shall have its individual compartment housing meter, wiring, circuit breaker, etc within a consumer's premises, in an accessible position and such metering switchboard shall be contained within adequately enclosed fireproof receptacle. Where more than one consumer is supplied through a common service line, such consumer shall be provided with an independent metering unit in a switchboard housed in common area with an incoming breaker. Such meter switchboards should be housed in an enclosed and lockable space. Cables/wires from such switchboards connecting to individual consumers should terminate directly to consumer's distribution board without any interim termination or change of conductor. Such switchboards maybe located at ground floor or first basement, if building height is not exceeding 15 m. All metering panel/connection arrangements will have interconnection between circuit breakers, fuses, individual meters, etc should be using solid busbar instead of cables (where length of cables is less than 10 m).

However, for buildings above height of 15 m [Regulation 38 of the *Central Electricity Authority* (*Measures relating to Safety and Electric Supply*) *Regulations*, 2023] shall be having meters on individual floors. In case of commercial buildings/shopping malls/multi-use spaces where, combining of units maybe envisaged, meter switchboards should be placed on the floor where consumer unit is located (*see* Annex B).

In case of high rise buildings, the supplier or owner of the installation shall provide at the point of commencement of supply a suitable isolating device with cut-out or breaker to operate on all phases except neutral in the 3 phase, 4 wire circuit and fixed in a conspicuous position at not more than 1.7 m above the ground so as to completely isolate the supply to the building in case of emergency. In this connection, Regulation 38 of *Central Electricity Authority* (*Measures relating to Safety and Electric Supply*) *Regulations*, 2023 shall also be complied with (*see* Annex B).

The supplier in accordance with Regulation 18 of *Central Electricity Authority* (*Measures relating to Safety and Electric Supply*) *Regulations*, 2023 shall provide and maintain on the consumer's premises for the consumer's use, a suitable earth terminal in an accessible position or near the point of commencement of supply as per relevant standards (*see* Annex B).

No cut-out, link or switch other than a linked switch arranged to operate simultaneously on the earthed or earthed neutral conductor and live conductor shall be inserted or remain inserted in any earthed or earthed neutral conductor of a two wire-system or in any earthed or earthed neutral conductor of a multi-wire system or in any conductor connected thereto. This requirement shall however not apply in case of:

a) a link for testing purposes; or

b) a switch for use in controlling a generator or transformer.

In this connection, Regulation 17 (ii) of *Central Electricity Authority* (*Measures Relating to Safety and Electric Supply*) *Regulations*, 2023 shall also be complied with (*see* Annex B).

The neutral shall also be distinctly marked.

5.4.1.2 The main switch shall be easily accessible and situated as near as practicable to the termination of service line.

5.4.1.3 Where the conductors include an earthed conductor of a two-wire system or an earthed neutral conductor of a multi-wire system or a conductor which is to be connected thereto, an indication of a permanent nature shall be provided for identification in accordance with Regulation 17 (i) of *Central Electricity Authority* (*Measures Relating to Safety and Electric Supply*) *Regulations*, 2023 (*see* Annex B).

5.4.1.4 *Energy meters*

5.4.1.4.1 Energy meters conforming to accepted standards [D-2(29)] shall be installed in all buildings at such a place which is readily accessible to the owner/operator/occupant of the building and the Authority. Meters should not be located at an elevated area or a depressed area that does not have access by means of a stairway of normal rise. The height of meter display shall be between 750 mm and 1 800 mm. In case the meter is provided with a secondary display unit, this requirement applies to the secondary display unit only. A minimum clearance of 50 mm should be maintained around the meter itself for better inspection. This includes the space between two meters, between meter and the mounting box and between two mounting boxes as the case may be. The energy meters should either be provided with a protecting covering, enclosing it completely except the glass window through which the readings are noted or should be mounted inside a completely enclosed panel provided with hinged arrangement for locking. Additionally, for outdoor installations, the meters and associated accessories shall be protected by appropriate enclosure of level of protection IP 55 and ensuring compliance with above conditions.

In large multi-storeyed buildings, installation of a large number of energy meters at the ground floor (or first basement) switch-room for the convenience of the meter-reader poses high fire hazard. More than 24 energy meters on one switchboard is undesirable. In such cases, where number of energy meters to be installed for feeding exceeds 24, energy meters shall be installed at each floor and therefore, the rising main (bus trunking) with tapping point at individual floor shall be provided for meters.

The energy meters shall be protected by suitable circuit breaker. The provisions of 5.3.6.7 shall apply in case of energy meters installed in boards.

5.4.1.4.2 Main sources of energy, as given below shall be metered, as required at entry into the premises/ control panel:

a) utility grid points (high voltage/low voltage);

b) captive generator sets; and

c) on-site renewable energy system (if installed/operational) including net metering for grid connected system.

5.4.1.4.3 Testing, evaluation, installation and maintenance of energy meters shall be in accordance with the good practice [D-2(30)].

5.4.1.4.4 *Centralized metering system*

Smart metering and energy monitoring in a centralized metering system are used to monitor, measure and control the demand of electrical loads in a building. These systems are designed specifically for the control and monitoring of those facilities in a building which have significant electrical consumption, such as heating, ventilation, air conditioning, lifts, pumps and lighting installations at multiple locations in a campus. The scope may span from a single building to a group of buildings, such as residential apartments under common ownership, large multi-storeyed buildings, malls, university campuses, office buildings, retail store networks, factories, or any building with multi-tenanted occupancy. These systems provide metering, submetering and monitoring functions to allow facility and building managers to gather data and insight that allows them to make more informed decisions about demand management and demand control across their sites.

For such buildings with centralized metering, several main meters and sub-meters with following requirements should be provided:

a) Main meters should be digital energy meters with high accuracy, high sampling rates and power quality parameters, that is, harmonics, etc, for meters installed at incomer level;

b) Separate sub-meters should be provided for all energy end uses and functional areas that individually account for reasonable energy consumption in the building. These may include, but are not limited to, sub-meters for HVAC system; common area lighting, raw power, UPS, other common utility; lifts and escalators, pumps, external and internal lighting, individual units/flats/shops/offices; etc;

c) The sub-meters should be able to communicate data for monitoring. At a minimum, the sub-metering infrastructure should facilitate the aggregation of total energy use. For individual residential or commercial meters, if required it shall be controlled by the local electrical authority to take data for grid metering and later data be shared for emergency metering; and

d) Adequate smart metering and energy monitoring infrastructure should be installed in order to help monitor operational energy use and costs and to enable continuous energy performance improvement.

5.4.1.4.5 The *Central Electricity Authority* (*Installation and Operation of Meters*) *Regulations*, 2006, as amended from time-to-time shall also be complied with.

5.4.2 *Main Switches and Switchboard*

5.4.2.1 All main switches shall be either of metal-clad enclosed pattern or of any insulated enclosed pattern which shall be fixed at close proximity to the point of entry of supply. Every switch shall have suitable ingress protection level rating (IP), so that its operation is satisfactory and safe in the environment of the installation. All works under 5.4 shall comply with the provisions of relevant Indian Standards and good practice [D-2(1)].

NOTE — Woodwork shall not be used for the construction or mounting of switches and switch boards installed in a building.

5.4.2.2 *Location*

The main switchboard shall comply with the following requirements relating to its location:

a) The location of the main board should be such that it is easily accessible to fireman and other personnel to quickly disconnect the supply in case of emergencies. If the room is locked for security reasons, means of emergency access, by schemes such as break glass cupboard, shall be incorporated;

b) Main switch board shall be installed in rooms or fire safe cupboards so as to safeguard against operation by unauthorized personnel. Otherwise, the main switch board shall have lock and key facility for small installations in residences or other occupancies having sanctioned loads less than 5 kW;

c) Switchboards shall be placed only in dry situations and in ventilated rooms and they shall not be placed in the vicinity of storage batteries or exposed to chemical fumes;

d) In damp situation or where inflammable or explosive dust, gas or vapour is likely to be present, the switchboard shall be totally enclosed and shall have adequate degree of ingress protection (IP). In some cases, flameproof enclosure may be necessitated by particular circumstances {*see* accepted standard [D-2(31)]};

e) Switchboards shall not be erected above gas stoves or sinks, or within 2.5 m of any washing unit in the washing rooms or laundries, or in bathrooms, lavatories or toilets, or kitchens;

f) In case of switchboards unavoidably fixed in places likely to be located outdoor, exposed to weather, drip, or to abnormal moist temperature, the outer casing shall be weatherproof and shall be provided with glands or bushings or adopted to receive screwed conduit, according to the manner in which the cables are run. The casing as well as cable entries shall have suitable IP ratings according to the installation;

g) Adequate illumination shall be provided for all working spaces around the switchboards; and

h) Easy access to the enclosure around switchgear is essential to enable easy and safe operation and maintenance. The provisions as given in **5.3.6.7** including requirements for sufficient clearances shall be complied with.

5.4.2.3 Metal-clad switchgear shall be mounted on any of the following types of boards:

a) *Fixed-type metal boards* — These shall consist of an angle or channel iron frame fixed on the wall or on floor and supported on the wall at the top, if necessary;

   NOTE — Such type of boards is suitable for both small and large switchboards. They are particularly suitable for large switchboards for mounting number of switchgears or high capacity metal-clad switchgear or both in an arrangement which do not require rear access.

b) *Protected-type switchboards* — A protected switchboard is one where all of the switchgear and conductors are protected by metal or halogen free plastic enclosures. They may consist of a metal/plastic cubicle panel, or an iron frame upon which metal-clad switchgears are mounted. They usually consist of a main switch, busbars and circuit breakers or fuses controlling outgoing circuits; and

c) *Outdoor-type switchboards* — An outdoor-type switchboard is one which is totally enclosed and UV ray protected and having high ingress protection against dust and moisture and vermin-proof and high impact resistant (IP 55 or higher and IK 10). Such switchboards are of cubicle type and also provide high impact resistance. Cubicle type boards shall be with hinged doors interlocked with switch-operating mechanisms. The doors of these switchboards shall have facility to ensure that it is always in closed conditions. All such switches shall bear labels indicating their functions.

   NOTE — Such switchboards shall be located away from areas likely to be crowded by the public.

Open type switchboards, wherever existing in old buildings, shall be phased out and replaced with protected-type switchboards with suitable circuit breakers. Switchboards should be composite including incoming and outgoing circuit breakers, meters, cable alleys, bus-bars, accessories, etc.

5.4.2.4 *Recessing of boards*

Where so specified, the switchboards shall be recessed in the wall. Ample room shall be provided at the back for connection and at the front between the switchgear mountings.

5.4.2.5 *Marking of apparatus* {*see also* accepted standards [D-2(32)]}

Where a board is connected to voltage higher than 250 V, all the apparatus mounted on it shall be marked with the following colours to indicate the different poles or phases to which the apparatus or its different terminals may have been connected:

a) *Alternating current* (*three-phase*) *system*:

   Phase 1 – red, Phase 2 – yellow and Phase 3 – blue; and
   1 Neutral – black

b) *Direct current* (*three-wire system*):

   2 outer wire, Positive – red and Negative – blue; and
   1 Mid wire (Neutral) – black

Where four-wire three-phase wiring is done, the neutral shall be in one colour and the other three phase conductors in another colour (preferably red) or shall be suitably tagged or sleeved to ensure fool proof identification.

NOTE — Generally red colour identification is adopted for the phase conductors and black for neutral with additional tags or sleeves or coloured tapes at terminations.

Earth continuity conductor shall be marked with green colour or green with yellow line.

Where a board has more than one switchgear, each such switchgear shall be marked to indicate the section of the installation it controls. The main switchgear shall be marked as such. Where there is more than one main switchboard in the building, each such switchboard shall be marked to indicate the section of the installation and/or building it controls.

All markings shall be clear and permanent.

5.4.2.6 *Drawings*

Before proceeding with the actual construction, a proper drawing showing the detailed dimensions and design including the disposition of the mountings of the boards, which shall be symmetrically and neatly arranged for arriving at the overall dimensions, shall be prepared along the building drawing. Such drawings will show the mandatory clearance spaces if any, and clear height below the soffit of the beam required to satisfy regulations and safety considerations, so that other designers or installers do not get into such areas or spaces for their equipment.

5.4.3 *Distribution Boards*

A distribution board comprises of one or more protective devices against overcurrent and ensuring the distribution of electrical energy to the various circuits. Distribution board shall provide plenty of wiring space, to allow working as well as to allow keeping the extra length of connecting cables, likely to be required for maintenance.

5.4.3.1 Main distribution board shall be provided with a circuit breaker on each pole of each circuit, on the phase or live conductor and a link on the neutral or earthed conductor of each circuit. The switches shall always be linked.

All incomers should be provided with surge protection devices depending upon the current carrying capacity and fault level (*see* **11**). Surge protecting devices should be provided with backup circuit breaker/fuses, wherever required.

5.4.4 *Branch Distribution Boards*

5.4.4.1 Branch MCB distribution boards shall be provided, along with earth leakage protective device (RCCB/RCD) in the incoming, with a miniature circuit breaker of adequate rating/setting chosen on the live conductor of each sub-circuit and the neutral conductor shall be connected to a common link and be capable of being disconnected individually for testing purposes. At least one spare circuit of the same capacity shall be provided on each branch distribution board. Further, the individual branching circuits (outgoing) shall be protected against over-current with miniature circuit breaker of adequate rating. In residential/industrial lighting installations, the various circuits shall be separated and each circuit shall be individually protected so that in the event of fault, only the particular circuit gets disconnected. In order to provide protection against electric shock due to leakage current for human being, a 30 mA RCCB/RCD shall be installed at distribution board incomer of buildings, such as residential, schools and hospitals. For all other buildings, a 100 mA RCCB/RCD will suffice for protection against leakage current.

In case of phase segregated distribution boards, earth leakage protective device shall be provided in the sub-incomer to provide phase-wise earth fault protection. The provision of sub-incomer in distribution board shall be as per consumer requirement.

5.4.4.2 Common circuit shall be provided for installations at higher level (those in the ceiling and at higher levels, above 1 m, on the walls) and for installations at lower level but with separate switch control (sockets for portable or stationery plug in equipment). For devices consuming high power and which are to be supplied through supply cord and plug, separate wiring shall be done. For plug-in equipment provisions shall be made for providing RCCB/RCD protection in the distribution board. They shall be selected as per the type of load. The details of RCD classes are available in Part 1 'General and common aspects, Section 10 Protection for safety — Protection against electric shock' of good practice [D-2(1)].

5.4.4.3 It is preferable to have additional circuit for kitchen and bathrooms. Such sub-circuit shall not have more than a total of ten points of light, fans and 6 A socket-outlets. The load of such circuit shall be restricted to 800 W and the wiring with minimum 1.5 mm^2 copper conductor cable is recommended. If a dedicated circuit is planned for light fixtures, the load of such circuit shall be restricted to 800 W or 20 points whichever is less and the wiring with 1.5 mm^2 copper conductor cable is recommended. If a dedicated circuit is planned for 6 A sockets the load of such circuit shall be restricted to 800 W or a maximum of 8 numbers whichever is less, controlling MCB should be sized accordingly. The wiring shall be with 1.5 mm^2 copper conductor cable. If a separate fan circuit is provided, the number of fans in the circuit shall not exceed ten. Power sub-circuit shall be designed according to the load but in no case shall there be more than two 16A outlets on each sub-circuit which can be wired with 4 mm^2 copper conductor cable for miscellaneous socket loads and shall be with 4 mm^2 copper conductor cable for equipment consuming more than 1 kW. Power sockets complying with the accepted standards [D-2(33)] with current rated according to their starting load, wiring, MCB, etc, shall be designed for special equipment space heaters, air conditioners, heat pumps, VRF, etc.

For feeding final single phase domestic type of loads or general office loads it is advisable to introduce additional cables if required to allow lowering of short circuit rating of the switchgear required at user end so that use of hand held equipment, etc fed through flexible cords is safe.

5.4.4.4 The circuits for lighting of common area shall be separate. For large halls 3-wire control with individual control and master control installed near the entrance shall be provided for effective conservation of energy. Occupancy sensors, movement sensors, lux level sensors, etc, may also be considered as switching options for lights, fans, TV, etc, for different closed spaces [*see* also relevant guidelines/best practices (Handbook on 'Sustainability in Buildings')].

5.4.4.5 Where daylight is abundantly available, particularly in large halls, lighting in the area near the windows likely to receive daylight shall have separate controls for lights, so that they can be switched off/automatically reduce intensity selectively when daylight is adequate, while keeping the lights in the areas remote from the windows on [*see* also relevant guidelines/best practices (Handbook on 'Sustainability in Buildings')].

5.4.4.6 Circuits for socket-outlets may be kept separate from circuits feeding fans and lights. Normally, fans and lights may be wired on a common circuit. In large spaces, circuits for fans and lights may also be segregated. Lights may have group control in large halls and industrial areas. While providing group control, consideration may be given for the nature of use of the area lit by a group. Consideration has to be given for the daylight utilization, while grouping, so that a group feeding area near windows receiving daylight can be selectively switched off during daylight period.

5.4.4.7 The load on any low voltage sub-circuit shall not exceed 3 000 W. In case of a new installation, all circuits and sub-circuits shall be designed with an initial load of about 2 500 W, so as to allow a provision of 20 percent increase in load due to any future modification. Power sub-circuits shall be designed according to the load, where the circuit is meant for a specific equipment. Good practice is to limit a circuit to a maximum of three sockets, where it is expected that there will be diversity due to use of very few sockets in large spaces (example sockets for use of vacuum cleaner). General practice is to limit it to two sockets in a circuit, in both residential and non-residential buildings and to provide a single socket on a circuit for a known heavy load appliance such as air conditioner, cooking range, etc.

5.4.4.8 In wiring installations at special places like construction sites, stadia, shipyards, open yards in industrial plants, etc, where a large number of high wattage lamps may be required, there shall be no restriction of load on any circuit but conductors used in such circuits shall be of adequate size for the load and proper circuit protection shall be provided. The distribution boards (DBs) used in these areas shall be of UV resistant, double insulated type with IP 66 or higher degree of protection. Power tools and other temporary equipment connected to these DBs shall be sufficiently protected against electrical faults. Insulated IP 66 sockets complying with the accepted standards [D-2(28)] used in these DBs shall have interlocking facility in addition to protection to ensure safe plugging and unplugging of these equipment.

5.4.5 *Location of Distribution Boards*

a) The distribution boards shall be located as near as possible to the centre of the load they are intended to control;

b) These shall be fixed on suitable stanchion or wall and shall be accessible for replacement/reset of protective devices and shall not be more than 1.8 m from floor level;

c) These shall be of either metal-clad type, or polycarbonate enclosure of minimum IP 42. But, if exposed to weather or damp situations, these shall be of the weatherproof type conforming to IP 55 and, if installed where exposed to explosive dust, vapour or gas, these shall be of flameproof type in accordance with accepted standards [D-2(34)]. In corrosive atmospheres, these shall be treated with anti-corrosive preservative or covered with suitable plastic compound;

d) Where two and/or more distribution boards feeding low voltage circuits are fed from a supply of low voltage, the metal case shall be marked 'Danger 415 Volts' and identified with proper phase marking and danger marks;

e) Each shall be provided with a circuit list giving diagram of each circuit which it controls and the current rating of the circuit and capacity of MCB;

f) In wiring branch distribution board, total load of connecting devices shall be divided as far as possible evenly between the number of ways in the board leaving spare circuits for future extension;

g) Distribution board shall not be located at structural expansion joints of the building;

h) Distribution board/other electrical outlets shall have a minimum calculated separation distance from lightning protection down-conductors to avoid flash over in case of lightning; and

j) Walls with flushed distribution boards shall have adequate support behind and surrounding so that there is no physical weight of the distribution board on the civil structure around. Electrical switch sockets, etc shall also be avoided to be mounted behind the distribution board to avoid touching the board from behind.

5.4.6 *Protection of Circuits*

a) Appropriate protection shall be provided at switchboards, distribution boards and at all levels of panels for all circuits and sub-circuits against short circuit, over-current and other parameters as required. The protective device shall be capable of interrupting maximum short circuit current and the prospective earth fault current that may occur, without danger. The ratings and settings of the protective devices such as MCB shall be coordinated so as to afford selectivity in operation and in accordance with accepted standards [D-2(35)];

b) Where circuit-breakers are used for protection of a main circuit and of the sub-circuits derived therefrom, discrimination in operation may be achieved by adjusting the protective devices of the sub-main circuit-breakers to operate at lower current settings and shorter time-lag than the main circuit-breaker;

c) Where HRC type fuses are used for back-up protection of circuit-breakers, or where HRC fuses are used for protection of main circuits and circuit-breakers for the protection of sub-circuits derived there from, in the event of short-circuits protection exceeding the capacity of the circuit-breakers, the HRC fuses shall operate earlier than the circuit-breakers; but for smaller overloads within the short-circuit capacity of the circuit-breakers, the circuit-breakers shall operate earlier than the HRC fuse blows;

d) The current rating of a circuit breaker shall not exceed the current rating of the smallest cable in the circuit protected by it; and

e) All distribution board or panel incomer may be protected by a surge protection device, if found necessary (*see* **11**). Separate CB with proper enclosure may be required in series with the surge protection device with main incomer. Back-up CB shall be of the capacity not lower than that recommended by the SPD manufacturer. Short circuit withstand capability of the SPDs should be coordinated with the CB and SPD should be selected to be matching the fault power expected/calculated at that point.

5.4.7 *Cascading, Discrimination and Limitation*

Cascading and discrimination in switchgear downstream and upstream shall be designed and maintained such that the continuity of power in case of any abnormal conditions such as overload, short circuit and earth faults, etc is maintained and only faulty circuit is isolated and power is made available to other loads.

Cascading technique allows the designer to select circuit breakers of lower breaking capacities. Utilizing the current limiting effect of the incoming breaker, outgoing breaker can sustain the higher faults than its capacity and even maintain the discrimination. The provisions of good practice [D-2(1)] and relevant Indian Standards shall be complied with while carrying out necessary works under **5.4**.

5.5 Protection Class of Equipment and Accessories

The class of ingress protection (IP) and protection against mechanical impact (IK) {*see also* accepted standard [D-2(36)]} shall be specific depending on the requirement at the place of installation.

5.6 Voltage and Frequency of Supply

It should be ensured that all equipment connected to the system including any appliances to be used on it are suitable for the voltage and frequency of supply of the system. The nominal values of low systems in India are 240 V single phase and 415 V a. c. three phase, respectively, and the frequency is 50 Hz.

NOTE — The design of the wiring system and the sizes of the cables should be decided taking into account following factors:

a) *Voltage drop* — This should be kept below 6 percent to ensure proper functioning of all electrical appliances and equipment including motors.

b) Thermal limit based current carrying capacity of the cable with appropriate derating factors applicable to the installation conditions.

c) Capacity to withstand the let through fault current based on the fault level and the controlling switchgear disconnection characteristics.

5.7 Rating of Cables and Equipment

The rating of the cables and the equipment shall be chosen based on the relevant Indian Standards, good practice [D-2(1)] and accepted standard [D-2(37)] read with availability of the material in the market.

5.8 Installation Circuits

5.8.1 The nominal cross-sectional area of copper phase conductors in a. c. circuits and of live conductors in d. c.

circuits shall be not less than the values specified below:

Sl No. (1)	*Type of Circuit* (2)	*Minimum Copper Wire Size* (3)	*Remarks* (4)
i)	Lighting	1.5 mm^2	Per circuit for 2 or more circuits
ii)	Socket-outlets, 6 A	2.5 mm^2	Earthing of the 3rd pin shall be ensured
iii)	Socket-outlets, 16 A	2.5 mm^2	1
iv)	Water heater < 3 kW	2.5 mm^2	1
v)	Heaters or electric equipment more than or equal to 3 kW	4.0 mm^2	1
vi)	Free standing electric range Separate oven and/or cook top	4.0 mm^2	1
vii)	Air conditioner up to 2 T	4.0 mm^2	1
viii)	Permanently connected appliances including dishwashers, heaters, etc	2.5 mm^2	1 above 10 A. Up to 10 A can be wired as part of a socket-outlet circuit
ix)	Appliance rated > 3 kW < 6 kW	6.0 mm^2	–
x)	Submains to garage or out-building	2.5 mm^2	1 for each
xi)	Mains cable		It should be based on demand load/peaking loads and future loading

NOTE — The minimum conductor size in point wiring shall not be less than 1.5 mm^2 copper conductor cable for fixed (permanent) wiring insulations.

5.8.2 For conductor sizes less than or equal to 25 mm^2, only copper conductor cables shall be used since aluminium conductor cables in sizes less than 25 mm^2 may cause termination problems leading to heating at the terminals and enhance the possibility of a fire.

In case of very important public buildings and multi-storey buildings, for connections to meter board and connections from tap-off box to floor panel and beyond, use of copper conductor cable up to 50 mm^2 be considered to avoid frequent failure and fire accidents.

5.8.3 Switch or isolator controlling a water heater or geyser should not be located within 1 m from the location of a shower or bath tub, to avoid a person in wet condition reaching the switch or isolator. It is preferable to provide the control switch outside the bath room near the entrance and provide an indication at the water heater. A socket or a connector block with suitable protection against water spray should be provided to connect the water heater. The above considerations apply to switches for outdoor lights and other appliances, with the object of avoidance of operation of a switch when a person is wet.

5.8.4 Sockets in kitchen, bathroom, toilet, garage, etc, should not be provided within a height of 1 m from the ground level. Similar care has to be taken for installations involving fountains, swimming pools, etc. Light fittings in such areas should be fed at low voltage, preferably through an isolating transformer with a proper earth leakage protection. Where possibility of a person in contact with a wet surface has to operate or touch an electrical switch or an appliance the circuit should be protected by a 30 mA RCCB/RCD, as applicable.

5.8.5 *Selecting and Installing Cables*

5.8.5.1 *Cable types*

For the purpose of this NBCS, cables above 1 mm^2 shall have stranded conductors. All cables when installed, shall be adequately protected against mechanical damage. This can be carried out by either having additional protection, such as being enclosed in PVC conduit or metal pipes, or placing the cables in a suitable location that requires no additional protection. The cables for wiring circuits in electrical installation shall have the appropriate wire size matching the requirement of the loads. The following table gives the recommendations for different types of loads:

For the mains cable	Cross-linked polyethylene (XLPE) cable
For internal wiring	Class II copper conductor flame retardant, low smoke halogen (FRLSH) cable
Fire alarm and other related services	Halogen free flame retardant (HFFR)/Fire survival copper conductor cable
For main earth or main equipotential wire	Poly vinyl chloride (PVC) insulated copper wire
Underground installation and installation in cable trench, feeders between buildings, etc	PVC insulated, PVC sheathed armoured cables or XLPE insulated, PVC sheathed cables armoured cables
Installation in plant rooms, switch rooms, etc, on cable tray or ladder or protected trench, where risk of mechanical damage to cable does not exist	PVC insulated, PVC sheathed or XLPE insulated, PVC sheathed unarmoured cables

5.8.5.2 *Circuit wire sizes*

Recommended minimum wire sizes for various circuits is given below:

Sl No. (1)	*Circuits* (2)	*Minimum Size of Copper Conductor Cable* (3)	*Wire Colour* (4)
i)	1-way lighting	2 + E cable of 1.5 mm^2	Red-black and green-yellow
ii)	2-way lighting control	3 wire cable of 1.5 mm^2	Red-white-blue
iii)	Storage water heaters up to 3 kW	2 + E cable of 2.5 mm^2 (stranded conductors)	Red-black and green-yellow
iv)	Storage water heaters between 3 kW and 6 kW	2 + E cable of 4 mm^2 (stranded conductors)	Red-black and green-yellow
v)	Socket-outlets and permanent connection units	2 + E cable of 2.5 mm^2 (stranded conductors)	Red-black and green-yellow

Table (*Concluded*)

Sl No. (1)	*Circuits* (2)	*Minimum Size of Copper Conductor Cable* (3)	*Wire Colour* (4)
vi)	Submains to garages or out buildings	2 + E cable 2.5 mm^2 (stranded conductors)	Red-black and green-yellow
vii)	Cooking hobs	2 + E cable 1.5 mm^2	Red-black and green-yellow
viii)	Separate ovens	2 + E cable 4 mm^2 (stranded conductors)	Red-black and green-yellow
ix)	Electric range	2 + E cable 6 mm^2 (stranded conductors)	Red-black and green-yellow
x)	Mains	2 wire cable Upto 25 mm^2 (stranded conductors)	Red-black
xi)	Main equipotential bonding wire	4 mm^2 (stranded conductors)	Green-yellow
xii)	Main earth wire	6 mm^2 (stranded conductors)	Green-yellow

NOTES

1 2 + E cable is also known as twin and earth wire cable (two wires and earth).

2 Earth wire can be as per the following:

- a) Green-Yellow throughout their length with, in addition, light blue markings at the terminations; or
- b) Light blue throughout their length with, in addition, green/yellow markings at the terminations.

3 The above sizes are recommendatory and shall be modified as per voltage drop, starting current, distance from DB, etc.

5.8.6 *Requirements for Physical Protection of Underground Cables*

Sl No. (1)	*Protective Element* (2)	*Specifications* (3)
i)	Bricks	a) 100 mm minimum width b) 25 mm thick c) sand cushioning 100 mm and sand cover 100 mm
ii)	Concrete slabs	At least 50 mm thick
iii)	Plastic slabs (polymeric cover strips) fibre reinforced plastic	At least 10 mm thick, depending on properties and has to be matched with the protective cushioning and cover
iv)	PVC conduit or PVC pipe or stoneware pipe or hume pipe	The pipe diameter should be such so that the cable is able to easily slip down the pipe
v)	Galvanized pipe	The pipe diameter should be such so that the cable is able to easily slip down the pipe

The trench shall be backfilled to cover the cable initially by 200 mm of sand fill; and then a plastic marker strip shall be put over the full length of cable in the trench. The marker signs shall be provided where any cable enters or leaves a building. This will identify that there is a cable located underground near the building. The trench shall then be completely filled. If the cables rise above ground to enter a building or other structure, a mechanical protection such as a GI pipe or PVC pipe for the cable from the trench depth to a height of 2.0 m above ground shall be provided.

5.9 Lighting and Levels of Illumination

5.9.1 *General*

Lighting installation shall take into consideration the numerous factors on which the quality and quantity of artificial lighting depends. Recent practice in illumination is to provide the required illumination with a large number of light sources (not of higher illumination level) instead of fewer number of light sources of higher illumination level, to produce higher uniformity in illumination level.

With the increase in energy costs and awareness of the need to conserve energy for the protection of the environment, there has been a drastic change in the use of light sources during the last 10 years. Fluorescent lamps [tubular lamp (TL) and compact fluorescent lamp (CFL)] are no longer available in the market. Use of general lighting service (GLS) lamps, known as light bulbs, has almost become extinct. The space vacated by these light sources has been taken over by LED lamps in different configurations in the form of LED based bulbs, tube lights, ceiling flush light sources and floodlights with different wattages.

With this the lighting design has become more complex. With the developments in the types of light sources and their control systems now available, lighting design goes with the concept of better light with less energy and least impact on environment.

Automatic lighting control schemes may be considered to have efficient utilization of lights. Automatic controls can take care of the switching off when the space served has no activity or is illuminated by daylight.

While carrying out lighting design and layout reference shall also be made to good practice [D-2(38)].

5.9.2 *Electrical Installations for Lighting*

The concepts or needs of energy conservation today require more lights to be provided so that different sets of lights are used to light up the area of activity to the required higher level of lighting needed for the activity and provide a general minimum background level of lighting. Any space requires two or three different combination of lighting sets associated with the activity and this may require the wiring to be provided to accommodate the lighting groups in different circuits with group controls, automatic controls and remote controls.

Availability of LED lights with a wide range from 1 W to 100 W allows designers to provide spot task lighting of a high illumination level combined with a general space lighting of low illumination. As light follows the inverse square law, provision of the light source close to the task reduces the energy need.

Lighting demand for buildings should be considered as per type of building. Where nothing is specified, for lighting demand of any type of building a maximum of 13 W/m^2 of all built-up areas including balconies. Covered parking areas may be considered at 3.23 W/m^2 including balconies is to be considered. Service areas, corridors, etc, may be considered with very basic diversity of 80 percent to 100 percent. Power requirements shall be considered at least 55 W/m^2 with an overall diversity not exceeding 50 percent. These shall be excluding defined loads such as lifts, plumbing system, firefighting systems, ventilation requirement, etc.

Light emitting diode (LED) lamps have non-linear characteristics and require specifically made controlgear for each type of lamp for their proper operation. In some cases the controlgear is integral with the lamp, in some with light fitting and in some it is external. The electrical installation and wiring has to take this into account and provide appropriate space for such controlgear. There will be heat emission, introduction of harmonics, etc, and they also consume some energy. The electrical and lighting system design has to keep this aspect in the wiring design and installation.

5.9.3 *Principles of Lighting*

When considering the function of artificial lighting, attention shall be given to the following principle characteristics before designing an installation:

a) Illumination and its uniformity.

b) Special distribution of light. This includes a reference to the composition of diffused and directional light, direction of incidence, the distribution of luminances and the degree of glare.

c) Colour of the light and colour rendition.

d) Natural light sources, if possible such as light tubes.

e) System wattage of the luminaire proposed.

5.9.4 The variety of purposes which have to be kept in mind while planning the lighting installation may be broadly grouped as:

a) industrial buildings and processes;

b) offices, schools and public buildings;

c) surgeries and hospitals; and

d) hostels, restaurants, shops and residential buildings.

5.9.4.1 It is important that appropriate levels of illumination for these and the types and positions of fittings determined to suit the task and the disposition of the working planes are ensured.

5.9.5 For detailed requirements for lighting and lighting design and installations, reference shall be made to the good practice [D-2(38)] and provisions in Part D 'Building Services, Section 1 Lighting and Natural Ventilation' of this NBCS.

5.10 In locations where the system voltage exceeds 415 V three phase, as in the case of industrial locations, for details of design and construction of wiring installation, reference may be made to good practice [D-2(18)].

5.11 Guideline for Electrical Layout in Residential Buildings

For guidelines for electrical installation in residential buildings, reference may be made to accepted standard [D-2(39)] and good practice [D-2(1)].

A typical distribution scheme in a residential building with separate circuits for lights and fans and for power appliances is given in Fig. 3.

5.12 For detailed information regarding the installation of different electrical equipment, reference may be made to good practice [D-2(40)].

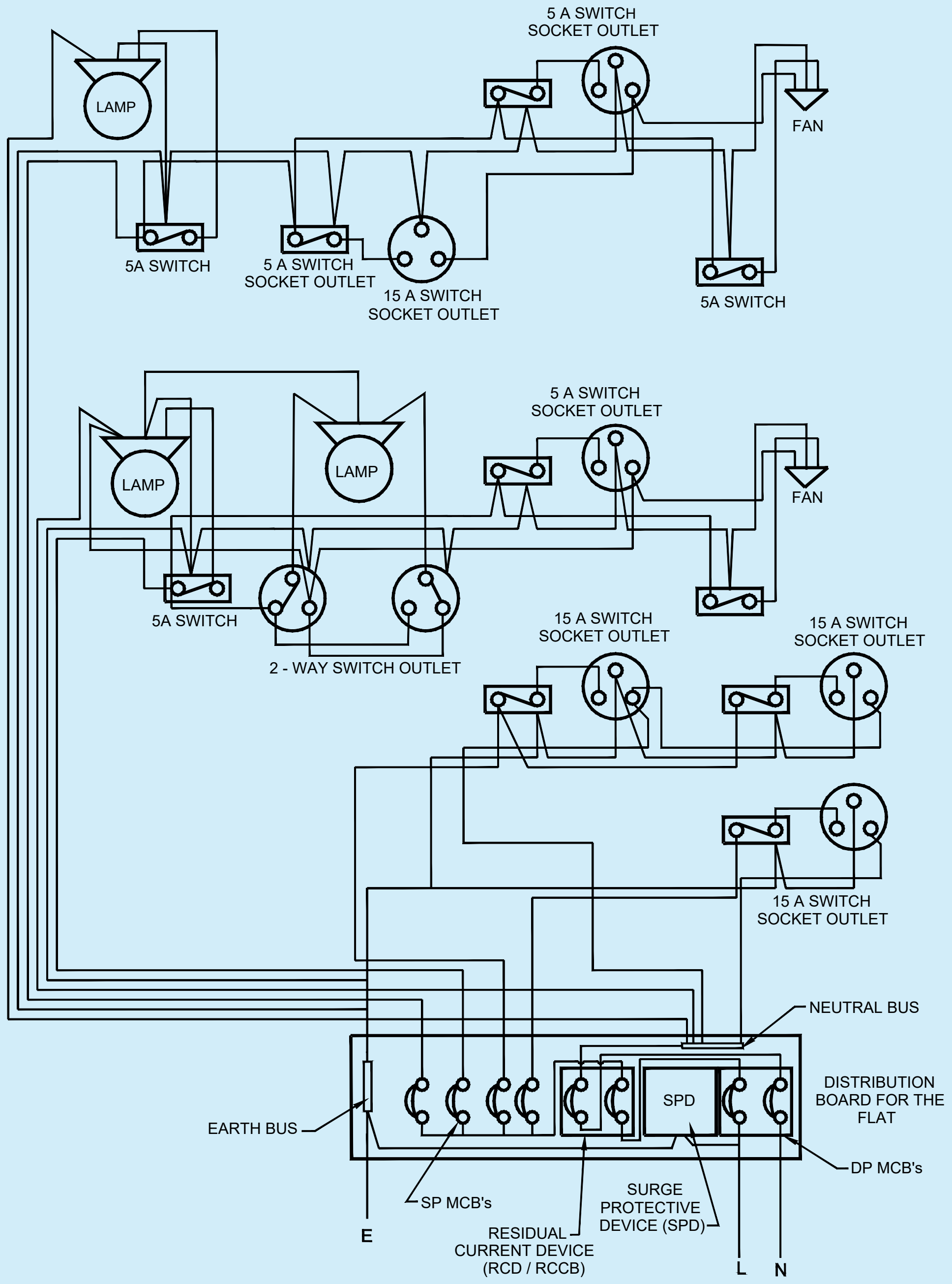

5 A SWITCH
SOCKET OUTLET
LAMP
FAN
5A SWITCH
5 A SWITCH
SOCKET OUTLET
15 A SWITCH
SOCKET OUTLET
5A SWITCH
5 A SWITCH
SOCKET OUTLET
LAMP
LAMP
FAN
5A SWITCH
2 - WAY SWITCH OUTLET
15 A SWITCH
SOCKET OUTLET
15 A SWITCH
SOCKET OUTLET
15 A SWITCH
SOCKET OUTLET
NEUTRAL BUS
DISTRIBUTION
BOARD FOR THE
FLAT
SPD
EARTH BUS
DP MCB's
SURGE
PROTECTIVE
DEVICE (SPD)
SP MCB's
RESIDUAL
CURRENT DEVICE
(RCD / RCCB)
E
L
N

FIG. 3 WIRING DIAGRAM FOR A TYPICAL DISTRIBUTION SCHEME IN A RESIDENTIAL BUILDING FLAT

6 WIRING

6.1 General

The generic guidelines for wiring in buildings depending on the type of occupancy, local conditions, material selection and other relevant points are covered hereunder. Also, the construction requirements, safety aspects to be considered during construction and maintenance aspects which should be considered during construction are addressed. All works under this shall also comply with the relevant Indian Standards and provisions in good practice [D-2(1)].

6.1.1 *Estimation of Load Requirements*

All conductors, switches and accessories shall be of such size as to be capable of carrying, without their respective ratings being exceeded, the maximum current which will normally flow through them.

In estimating the current to be carried by any conductor the following ratings shall be taken, unless the actual values are known or specified for these elements:

Sl No. (1)	*Element* (2)	*Rating*, W (3)
i)	Light point	60
ii)	Fan point	75
iii)	6 A 3/5 pins socket-outlet	100
iv)	16 A 3/6 pins socket-outlet	2 000
v)	High pressure mercury vapour (HPMV) lamps, high pressure sodium vapour (HPSV) lamps	According to their capacity, controlgear losses shall be also considered as applicable
vi)	Geyser (storage type)	2 000
vii)	Geyser (instant)	3 000
viii)	Computer point	150
ix)	Printer, laser	1 500
x)	Air conditioner:	
	a) Up to 1.5 TR	2 000
	b) 1.5 to 2 TR	3 000

6.1.2 *Commencement of Electrical Work*

Electrical installation in a new building shall normally begin with conduit laying at the commencement of preparations for first roof concreting work. The necessary conduits and ducts shall be positioned firmly by tying the conduit to the reinforcement before concreting in an RCC building. Location of fan points should be properly marked and fan clamp boxes should be provided along with conduit laying in roof. Care should be taken to avoid use of damaged conduit or ducts, the conduits ends shall be given suitable anti-corrosive treatment and holes blocked off by putties or caps to protect conduits from getting blocked. All conduit openings and junction box openings, etc shall be properly protected against entry of mortar, concrete, etc during construction. Laying of conduits in walls shall start with the taking up of wall construction work. In case of surface wiring, the work will start after completion of interior plaster including curing. The wiring, fixing of switch boxes and fixing of switches will start only after ensuring necessary weatherproof area with locking arrangement is available to take up electrical work.

6.2 Selection of Size of Conductors

The size of conductors for circuits shall be selected after fixing the location of main sub-station, main switchboard for the building, location of distribution board and the electrical points under the planning of electrical services. The overall voltage drop from the transformer end to consumer's final distribution board shall not exceed six percent. The voltage drop of six percent will be divided between different points indicated above in such a way that from the distribution board to the last point shall be three percent. From main board to distribution board, from distribution board to sub distribution board if any, circuit wiring from DB/SDB to switch board and from switch board to light/fan points/plug points shall be with Class II category copper conductors. The size of the conductor cable shall be decided based on the maximum load on each point. In main/submain/circuit/sub-circuit, the circuit-breaker shall be selected to match the current rating of the circuit to ensure the desired protection.

6.3 Branch Switches

Where the supply is derived from a three-wire or four-wire source, and distribution is done on the two-wire system, all branch switches shall be placed in the outer or live conductor of the circuit and no single phase switch or protective device shall be inserted in the middle wire, earth or earthed neutral conductor of the circuit. Single-pole switches (other than for multiple control) carrying not more than 16 A may be of flush/modular type. For controlling points for air conditioners and geysers, suitable MCB type switches shall be provided.

6.4 Layout and Installation Drawing

6.4.1 The electrical layout should be drawn indicating properly the locations of all outlets, such as lamps, fans, appliances (both fixed and movable), and motors and best route for wiring.

6.4.2 All runs of wiring and the exact positions of all points of switch-boxes and other outlets shall be first marked on the plans of the building and approved by the engineer-in-charge or the owner before actual commencement of the work.

6.4.3 Industrial layout drawings should indicate the relative civil and mechanical details.

6.4.4 *Layout of Wiring*

The layout of wiring should be designed keeping in view disposition of the lighting system to meet the illumination levels. All wirings shall be done on the distribution system with main and branch distribution boards at convenient physical and electrical load centres. All types of wiring, whether concealed or unconcealed, should be as near the ceiling as possible. In all types of wirings due consideration shall be given for neatness and good appearance.

6.4.5 Balancing of circuits in three-wire or poly-phase installation shall be arranged beforehand. Proper balancing can be done only under actual load conditions. Conductors shall be so enclosed in earthed metal or incombustible insulating material that it is not possible to have ready access to them. Means of access shall be marked to indicate the voltage present.

Where terminals or other fixed live parts between which a voltage exceeding 250 V exists are housed in separate enclosures or items of apparatus which, although separated are within reach of each other, a notice shall be placed in such a position that anyone gaining access to live parts is warned of the magnitude of the voltage that exists between them.

Where loads are single phase, balancing should be for the peak load condition based on equipment usage. Facility for change should be built into the distribution design.

NOTE — The above requirements apply equally to three-phase circuits in which the voltage between lines or to earth exceeds 250 V and to groups of two or more single-phase circuits, between which medium voltage may be present, derived therefrom. They apply also to 3 wire d.c. or 3 wire single-phase a.c. circuits in which the voltage between lines or to earth exceeds 250 V and to groups of 2 wire circuits, between which medium voltage may be present, derived there from.

6.4.6 Low voltage wiring and associated apparatus shall comply, in all respects, with the requirements of Regulation 35, 36, 37, 39, 40, 41 and 42 of *Central Electricity Authority* (*Measures Relating to Safety and Electric Supply*) *Regulations*, 2023, as amended from time to time (*see* Annex B).

6.5 Conductors and Accessories

6.5.1 *Conductors*

Conductors for all the internal wiring shall be of copper. Conductors for power and lighting circuits shall be of adequate size to carry the designed circuit load without exceeding the permissible thermal limits for the insulation. For final selection of wiring to larger loads, the current carrying capacity will preside. The conductor size shall also be based on the voltage drop in the line so as to provide a terminal voltage not below the prescribed voltage requirement.

The conductor for final sub-circuit for fan and light wiring shall have a nominal cross-sectional area not less than 1.50 mm^2 copper. The cross-sectional area of conductor for power wiring shall be not less than 2.5 mm^2 copper. The minimum cross-sectional area of conductor of flexible cord shall be 1.50 mm^2 copper. All copper conductors used in wiring shall be of class II category for permanent wiring system.

In existing buildings where aluminum wiring has been used for internal electrification, changeover from aluminum conductor cables to copper conductor cables is recommended as it has been found that aluminum conductors pose a number of hazards.

NOTE — It is advisable to replace wiring which is more than 30 years old as the insulation also would have deteriorated, and will be in a state to cause failure on the slightest of mechanical or electrical disturbance.

6.5.2 *Flexible Cables and Flexible Cords*

Flexible cables and cords shall be of copper and stranded, and protected by flexible conduits or tough rubber or PVC sheath to prevent mechanical damage.

6.5.3 *Cable Ends*

When a stranded conductor having a nominal sectional area less than 6 mm^2 is not provided with cable sockets (thimbles/lugs) for end termination, all strands at the exposed ends of the cable shall be soldered together or crimped using suitable sleeve or ferrules.

6.5.4 *Special Risk*

Special forms of construction, such as flameproof enclosures, shall be adopted where there is risk of fire or explosion.

6.5.5 *Connection to Ancillary Buildings*

Unless otherwise specified, electric connections to ancillary buildings, such as out-houses, garages, etc adjacent to the main building and when no roadway intervenes shall be taken in an earthed GI pipe or heavy duty PVC or HDPE pipe of suitable size. This pipe can be taken either underground or over ground, however, in latter case, its height from the ground shall not be less than 5.8 m. This applies to both runs of mains or sub-mains or final sub-circuit wiring between the buildings.

6.5.6 *Expansion Joints*

Distribution boards shall be so located that the conduits shall not normally be required to cross expansion joints in a building. Where such crossing is found to be unavoidable, special care shall be taken to ensure that the conduit runs and wiring are not in any way put to strain or damaged due to expansion of building structure. Anyone of the standard methods of connection at a structural expansion joint shall be followed:

a) Flexible conduit shall be inserted at place of expansion joint;

b) Oversized conduit overlapping the conduit; and

c) Expansion box.

Supports and flexible joints shall be of same requirement as the rising main/bus duct in so far as resistance to seismic forces is concerned. This is further important when rising mains and bus-ducts cross expansion joints.

6.5.7 *Extra Low Voltage* (*Types of Wires/Cables*)

Extra low voltage services utilize various categories of cables/wires, such as fibre optic cable, co-axial cable, etc. These shall be laid at least at a distance of 300 mm from any power wire or cable. The distance may be reduced only by using completely closed earthed metal trunking with metal separations for various kind of cable. Special care shall be taken to ensure that the conduit runs and wiring are laid properly for low voltage signal to flow through it.

The power cable and the signal or data cable may run together under floor and near the equipment. However, separation may be required from the insulation aspect, if the signal cable is running close to a conductor carrying power at low voltage. All types of signal cables are required to have insulation level for withstanding 2 kV impulse voltage even if they are meant for service at low voltage.

6.6 Passing Through Walls, Floors and Expansion Joints

6.6.1 Where wires/cables are required to pass through walls, care shall be taken to see that wires/cables pass freely through protective pipe or box and that the wires pass through in a straight line without any twist or cross in wires. In case of wires crossing expansion joints in a recessed conduit system there shall be two loop wire boxes on two sides of the expansion joint which shall be connected with concentric pipes of different diameter in such a way that one box will hold the bigger diameter conduit while the other box will hold the smaller diameter conduit pipe. This way, the two sides can move freely as per structure without having any effect either on the structure or on the wiring system.

One of the following methods shall be employed for laying wires/cables:

a) *Conduit wiring system* (*see* **6.9**) — The conductor shall be drawn in either in a rigid steel conduit or a rigid non-metallic conduit conforming to relevant Indian Standards {*see* accepted standards [D-2(41)] and [D-2(42)]}. All conduits used for fire alarm and other fire related emergency relief services as well as security and UPS system shall only be of metallic conduit system.

The conduits shall be colour coded as per the purpose of wire carried in the same. The recommended colour coding may be in form of bands of colour (100 mm thick, with centre to centre distance of 300 mm) or coloured throughout. The colour scheme may be as follows:

Sl No. (1)	*Conduit Type* (2)	*Colour Scheme* (3)
i)	Power conduit	Black
ii)	Security conduit	Blue
iii)	Fire alarm conduit	Red
iv)	Extra low voltage conduit	Brown
v)	UPS conduit	Green

Conduit wiring system shall comply with relevant Indian Standards. The number of insulated conductors that can be drawn into rigid conduit is given in Table 1 (*see* Table 1A for rigid steel conduits and Table 1B for rigid non-metallic conduits). As far as possible, cables of one circuit shall be housed in one conduit only.

b) *Cable trunking/cable ways/race ways* (*see* **6.10**) — Cable trunking/cable ways/race ways system should be used when number of wires/small cable sizes to be laid is more than the conduit capacity. Care should be taken to have space in the trunking system to minimize heating of wires and to provide identification of the different circuits. These can be laid in both floor and ceiling. Adequate junction boxes, access points shall be provided to pull in and out wire.

Cable trunking or ducting system shall comply with accepted standards [D-2(43)].

c) *Tray and ladder rack* — As tray provides continuous support, unless mounted on edge or in vertical runs (when adequate strapping or clipping is essential), the mechanical strength of supported cable is not as important as with ladder-racking or structural support methods. Consequently, tray is eminently suitable for the smaller unarmoured cabling while ladder racks call for armoured cables or larger unarmoured cables as they provide the necessary strength to avoid sagging between supports. Both tray and ladder racks are provided with accessories to facilitate changes of route, and they provide no difficulty in this respect on vertical runs.

Cable tray/ladder racks and support systems shall be installed in such a way that the deflection between the spans shall be less than 1 percent of the span.

Power cables running in cable ladders both horizontal and vertical shall be fixed with proper clamps which can withstand the mechanical force created on the cable in case of short circuit current. The complete installation consisting of cables, ladders, clamps, ladder supports and fixtures shall also withstand the mechanical force of short circuit current. Only one layer of power cable shall be laid in a ladder. The minimum space between two cables shall be equal to the diameter of the biggest cable.

Cable tray and ladder system shall comply with accepted standard [D-2(44)].

6.6.2 Insulated conductors while passing through floors shall be protected from mechanical injury by means of rigid steel/non-metal conduit or by mechanical protection up to a height not less than 1.5 m above the floor and flush with the ceiling below. These steel conduits shall be earthed and securely bushed.

Power outlets and wiring in the floor shall be generally avoided. If not avoidable, false floor trunking or metal floor trunking should be used. Power sockets of adequate IP/IK rating shall be used.

False floor shall be provided where density of equipment and interconnection between different pieces of equipment is high. Examples are, mainframe computer station, telecommunication switch rooms, etc. Floor trunking shall be used in large halls, convention centres, open plan offices, laboratory, etc.

In case of floor trunking, drain points/weep holes shall be provided within the trunking for installation for convention centres, exhibition areas or any other place where water may spill into the trunking, as there might be possibility of water seepage in the case of wiring passing through the floors. Proper care should be taken for providing suitable means of draining of water. Possibility of water entry exists from floor washing, condensation in some particular weather and indoor temperature conditions. At the design stage, these aspects shall be assessed and an appropriate means of avoiding or reducing ingress of water and draining method shall be built in. Floor trunking outlets shall be suitably IP rated for protection against dust and water. Floor trunking shall be of adequate IK rating. Floor or ceiling trunking shall have a maximum of 40 percent fill.

Floor outlet boxes are generally provided for the use of appliances, which require a signal or communication connection. The floor box and trunking system should cater to serve both power distribution and the signal distribution, with appropriate safety and non-interference.

6.6.3 Where a wall tube passes outside a building and be exposed to weather, the outer end shall be bell-mouthed and turned downwards and properly bushed at the open end.

6.7 Wiring of Distribution Boards

6.7.1 All connections between parts of apparatus or between apparatus and terminals on a board shall be neatly arranged in a definite sequence, following the arrangements of the apparatus mounted thereon, avoiding unnecessary crossings.

6.7.2 Cables shall be connected to a terminal only by soldered or welded or crimped lugs using suitable sleeve, lugs or ferrules unless the terminal is of such a form that it is possible to securely clamp them without the cutting away of cables strands. Cables in each circuit shall be bunched together.

6.7.3 All bare conductors shall be rigidly fixed in such a manner that a clearance of at least 25 mm is maintained between conductors or opposite polarity or phase and between the conductors and any material other than insulation material.

6.7.4 If required, a pilot lamp shall be fixed and connected through an independent single pole switch and fuse to the busbars of the board. Leads connecting bus-bars to any instrument or indicating lamp or an outgoing connection switch or breaker face the same fault current that is applicable to the busbar and as such should be provided with a fuse capable of handling the prospective fault current.

6.7.5 In a hinged type board, the incoming and outgoing cables shall be fixed at one or more points according to the number of cables on the back of the board leaving suitable space in between cables and shall also, if possible, be fixed at the corresponding points on the switchboard panel. The cables between these points shall be of such length as to allow the switchboard panel to swing through an angle of not less than 90° and cables arranged and clamped in such a manner that the cables do not face bending, but only face a twist, when the hinged door is opened. The circuit breakers in such cases shall be accessible without opening the door of distribution board. Circuit breakers or any other equipment (having cable size more than 1.5 mm^2 multi-strand wire) shall also not be mounted on the door.

NOTE — Use of hinged type boards is discouraged, as these boards lead to deterioration of the cables in the hinged portion, leading to failures or even fire.

6.7.6 Wires terminating and originating from the protective devices shall be properly lugged and taped.

6.8 PVC-Sheathed Wiring System

6.8.1 *General*

Wiring with PVC-sheathed cables may be used for temporary installations for medium voltage installation and may be installed directly under exposed conditions of sun and rain or damp places.

6.8.2 *PVC Clamps/PVC Channel*

The clamps shall be used for temporary installations of 1 to 3 sheathed wires only. The clamps shall be fixed on wall at intervals of 100 mm in the case of horizontal runs and 150 mm in the case of vertical runs.

PVC channel shall be used for temporary installations in case of more than 3 wires or unsheathed wires. The channel shall be clamped on wall at intervals not exceeding 300 mm. PVC clamps/PVC channel shall conform to accepted standards.

6.8.3 *Protection of PVC-Sheathed Wiring from Mechanical Damage*

a) In cases where there are chances of any damage to the wirings, such wirings shall be covered with sheet metal protective covering, the base of which is made flush with the plaster or brickwork, as the case may be, or the wiring shall be drawn through a conduit complying with all requirements of conduit wiring system (*see* **6.9**); and

b) Such protective coverings shall in all cases be fitted on all down-drops within 1.5 m from the floor.

6.8.4 *Bends in Wiring*

The wiring shall not in any circumstances be bent so as to form a right angle but shall be rounded off at the corners to a radius not less than six times the overall diameter of the cable.

6.8.5 *Passing Through Floors*

All cables taken through floors shall be enclosed in an insulated heavy gauge steel conduit extending 1.5 m above the floor and flush with the ceiling below, or by means of any other approved type of metallic covering. The ends of all conduits or pipes shall be neatly bushed with porcelain, wood or other approved material.

6.8.6 *Passing Through Walls*

The method to be adopted shall be according to good practice. There shall be one or more conduits of adequate size to carry the conductors [*see* **6.9.1**(a)]. The conduits shall be neatly arranged so that the cables enter them straight without bending.

6.8.7 *Stripping of Outer Covering*

While cutting and stripping of the outer covering of the cables, care shall be taken that the sharp edge of the cutting instrument does not touch the rubber or PVC-sheathed insulation of conductors. The protective outer covering of the cables shall be stripped off near connecting terminals, and this protective covering shall be maintained up to the close proximity of connecting terminals as far as practicable. Care shall be taken to avoid hammering on link clips with any metal instruments after the cables are laid. Where junction boxes are provided, they shall be made moisture-proof with an approved plastic compound.

6.8.8 *Painting*

If so required, the tough rubber-sheathed wiring shall, after erection, be painted with one coat of oil-less paint or distemper of suitable colour over a coat of oil-less primer, and the PVC-sheathed wiring shall be painted with a synthetic enamel paint of quick drying type.

6.9 Conduit Wiring System

Conduit wiring system shall comply with accepted standards [D-2(45)]. Requirements relating to conduit wiring system with rigid steel and non-metallic conduits shall be as per **6.9.1** to **6.9.3**.

6.9.1 *Surface Conduit Wiring System with Rigid Steel Conduits*

a) *Type and size of conduit* — All conduit pipes shall conform to accepted standards [D-2(46)], finished with galvanized or stove enamelled surface. All conduit accessories shall be of threaded type and under no circumstance pin grip type or clamp type accessories shall be used. No steel conduit less than 16 mm in diameter shall be used. The number of insulated conductors that can be drawn into rigid steel conduit is given in Table 1A.

b) *Bunching of cables* — Unless otherwise specified, insulated conductors of a.c. supply and d.c. supply shall be bunched in separate conduits. For lighting and small power outlet circuits phase segregation in separate conduits is recommended.

c) *Conduit joints* — Conduit pipes shall be joined by means of screwed couplers and screwed accessories only {*see* accepted standard [D-2(47)]}. In long distance straight runs of conduit, inspection type couplers at reasonable intervals shall be provided or running threads with couplers and jam-nuts (in the latter case the bare threaded portion shall be treated with anti-corrosive preservative) shall be provided. Threaded portion on conduit pipes in all cases shall be between 11 mm and 27 mm long sufficient to accommodate pipes to full threaded portion of couplers or accessories. Cut ends of conduit pipes shall have no sharp edges or any burrs left to avoid damage to the insulation of conductors while pulling them through such pipes.

d) *Protection against dampness* — In order to minimize condensation or sweating inside the tube, all outlets of conduit system shall be properly drained and ventilated, but in such a manner as to prevent the entry of insects as far as possible.

e) *Protection of conduit against rust* — The outer surface of the conduit pipes, including all bends, unions, tees in the conduit system shall be adequately protected against rust particularly when such system is exposed to weather. In all cases, no bare threaded portion of conduit pipe shall be allowed unless such bare threaded portion is treated with anti-corrosive preservative or covered with suitable plastic compound.

f) *Fixing of conduit* — Conduit pipes shall be fixed by heavy gauge saddles, secured to suitable wood plugs or other plugs with screws in an approved manner at an interval of not more than 1 m, but on either side of couplers or bends or similar fittings, saddles shall be fixed at a distance of 300 mm from the centre of such fittings. Conduit fittings shall be avoided as far as possible on conduit system exposed to weather; where necessary, solid type fittings shall be used.

g) *Bends in conduit* — All necessary bends in the system including diversion shall be done by bending pipes; or by inserting suitable solid or inspection type normal bends, elbows or similar fittings; or fixing cast iron, thermoplastic or thermosetting plastic material inspection boxes; whichever is more suitable. Radius of such bends in conduit pipes shall be not less than 75 mm. No length of conduit shall have more than the equivalent of four quarter bends from outlet to outlet, the bends at the outlets not being counted.

h) *Outlets* — All outlets for fittings, switches, etc, shall be boxes of suitable metal or any other approved outlet boxes for either surface mounting or flush mounting system.

j) *Conductors* — All conductors used in conduit wiring shall preferably be stranded. No single-core cable of nominal cross-sectional area greater than 130 mm^2 shall be enclosed along in a conduit and used for alternating current.

k) *Erection and earthing of conduit* — The conduit of each circuit or section shall be completed before conductors are drawn in. The entire system of conduit after erection shall be tested for continuity using a fish wire and permanently connected to earth conforming to the requirements. Gas or water pipes shall not be used as earth medium. If conduit pipes are liable to mechanical damage they shall be adequately protected.

m) Inspection type conduit fittings, such as inspection boxes, draw boxes, bends, elbows and tees shall be so installed that they can remain accessible for such purposes withdrawal of existing cables or of new cables.

Table 1A Maximum Permissible Number of Single-Core Copper Cables up to and Including 1 100 V that can be Drawn into Rigid Steel Conduits

[*Clauses* 6.6.1(a) *and* 6.9.1(a)]

Sl No.	**Size of Cable** Nominal Cross-Sectional Area mm^2	**Size of Conduit** mm											
		20		25		32		40		50		63	
		Number of Cables, *Max*											
		S	B	S	B	S	B	S	B	S	B	S	B
(1)	(2)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
i)	1.5	7	5	12	10	20	14	–	–	–		–	–
ii)	2.5	6	5	10	8	18	12	–	–	–	–	–	–
iii)	4	4	3	7	5	12	10	–	–	–	–	–	–
iv)	6	3	2	6	5	10	8	–	–	–	–	–	–
v)	10	2	–	4	3	6	5	8	6	–	–	–	–
vi)	16	–	–	2	–	4	3	7	6	–	–	–	–
vii)	25	–	–	–	–	3	2	5	4	8	6	9	7
viii)	35	–	–	–	–	2	–	4	3	7	5	8	6

NOTES

1 The table shows the maximum capacity of conduits for the simultaneously drawing of cables. The columns headed S apply to runs of conduit which have distance not exceeding 4.25 m between draw-in boxes and which do not deflect from the straight by an angle of more than 15. The columns headed B apply to runs of conduit which deflect from the straight by an angle of more than 15.

2 In case an inspection type draw-in box has been provided and if the cable is first drawn through one straight conduit, then through the draw-in box and then through the second straight conduit, such systems may be considered as that of a straight conduit even if the conduit deflects through the straight by more than 15.

3 Conductor sizes for cables and wires above and including 2.5 mm^2 core size shall be multi-stranded.

6.9.2 *Recessed Conduit Wiring System with Rigid Steel Conduit*

Recessed conduit wiring system shall be laid in concrete in the roof slab and in walls, and shall comply with all the requirements for surface conduit wiring system specified in **6.9.1(a)** to **6.9.1(k)** and also conform with the requirements specified under:

a) *Making of chase* — The chase in the wall shall be neatly made and be of ample dimensions to permit the conduit to be fixed in the manner desired. In the case of buildings under construction, chases shall be provided in the wall, ceiling, etc at the time of their construction and shall be filled up neatly after erection of conduit and brought to the original finish of the wall. In case of exposed brick/rubble masonry work, special care shall be taken to fix the conduit and accessories in position along with the building work.

b) *Fixing of conduit in chase* — The conduit pipe shall be fixed by means of staples or by means of saddles not more than 600 mm apart. Fixing of standard bends or elbows shall be avoided, as far as practicable and all curves maintained by bending the conduit pipe itself with a long radius which will permit easy drawing-in of conductors. All threaded joints of rigid steel conduit shall be treated with preservative compound to secure protection against rust.

c) *Inspection boxes* — Suitable inspection boxes shall be provided to permit periodical inspection and to facilitate removal of wires, if necessary. These shall be mounted flush with the wall. Suitable ventilating holes shall be provided in the inspection box covers. The minimum sizes of inspection boxes shall be 75 mm × 75 mm.

d) *Types of accessories to be used* — All outlet, such as switches and wall sockets, may be either of flush mounting type or of surface mounting type, as given below:

    1) *Flush mounting type* — All flush mounting outlets shall be of cast-iron or mild steel boxes with a cover of insulating material or shall be a box made of a suitable insulating material. The switches and other outlets shall be mounted on such boxes. The metal box shall be efficiently earthed with conduit by a suitable means of earth attachment.

    2) *Surface mounting type* — If surface mounting type outlet box is specified, it shall be of any suitable insulating material and outlets mounted in an approved manner.

The switches/socket-outlets shall have adequate IP rating for various utilizations.

6.9.3 *Conduit Wiring System with Rigid Non-Metallic Conduits*

Rigid non-metallic conduits are used for concealed conduit wiring. This type of wiring system is more preferred for coastal areas.

6.9.3.1 *Type and size*

All non-metallic conduits used shall conform to accepted standards [D-2(45)] and shall be used with the corresponding accessories {*see* accepted standards [D-2(48)]}. The conduits shall be circular or rectangular cross sections.

6.9.3.2 *Bunching of cables*

Conductors of a.c. supply and d.c. supply shall be bunched in separate conduits. For lighting and small power outlet circuits phase segregation in separate circuits is recommended. The number of insulated cables that may be drawn into the conduits are given in Table 1B. In Table 1B, the space factor does not exceed 40 percent of the available space.

Table 1B Maximum Permissible Number of 250 V Grade Single-Core Copper Cables that may be Drawn into Rigid Non-Metallic Conduits

[*Clauses* 6.6.1(a) *and* 6.9.3.2]

Sl No.	**Sizes of Cable**	**Size of Conduit,** mm				
	Nominal Cross-Sectional Area mm^2	20	25	32	40	50
		Number of Cables, *Max*				
(1)	(2)	(5)	(6)	(7)	(8)	(9)
i)	1.5	6	10	14	–	–
ii)	2.5	5	10	14	–	–
iii)	4	3	6	10	14	–
iv)	6	2	5	9	11	–
v)	10	–	4	7	9	–
vi)	16	–	2	4	5	12
vii)	25	–	–	2	2	6
viii)	35	–	–	–	2	5

6.9.3.3 *Conduit joints*

Conduits shall be joined by means of couplers. Where there are long runs of straight conduit, inspection type couplers shall be provided at intervals. For conduit fittings and accessories reference may be made to the accepted standard [D-2(48)].

6.9.3.4 *Fixing of conduit in chase*

The conduit pipe shall be fixed by means of stapples or by means of non-metallic saddles placed at not more than 600 mm apart or by any other approved means of fixing. Fixing of standard bends or elbows shall be avoided, as far as practicable and all curves shall be maintained by bending the conduit pipe itself with a long radius which will permit easy drawing in of conductors. At either side of bends, saddles/stapples shall be fixed at a distance of 150 mm from the centre of bends.

6.9.3.5 *Inspection boxes*

Suitable inspection boxes to the nearest minimum requirements shall be provided to permit periodical inspection and to facilitate replacement of wires, if necessary. The inspection/junction boxes shall be mounted flush with the wall or ceiling concrete. Where necessary deeper boxes of suitable dimensions shall be used. Suitable ventilating holes shall be provided in the inspection box covers, where required.

6.9.3.6 The outlet boxes such as switch boxes, regulator boxes and their phenolic laminated sheet covers shall be as per requirements of **6.9.1**(h). They shall be mounted flush with the wall.

6.9.3.7 *Types of accessories to be used*

All accessories such as switches, wall sockets, etc, may be either flush mounting type or of surface mounting type.

6.9.3.8 *Bends in conduits*

Wherever necessary, bends or diversions may be achieved by bending the conduits or by employing normal bends, inspection bends, inspection boxes, elbows or similar fittings. Heat may be used to soften the conduit for bending and forming joints in case of plain conduits.

6.9.3.9 *Outlets*

In order to minimize condensation or sweating inside the conduit, all outlets of conduit system shall be properly drained and ventilated, but in such a manner as to prevent the entry of insects.

6.10 Cable Trunking/Cable Ways

Cable trunking and ducting system of insulating material are used for laying of cables and wire both in floor and ceiling. The maximum number of cables with sizes that can be drawn in a cable trunking or ducting shall be limited to a maximum of 40 percent of space available.

7 FITTINGS AND ACCESSORIES

7.1 General

This covers the requirements of fittings and accessories which are normally used in fixed wiring installations of buildings. This includes type of light fixtures which are typically selected based on the requirement of light at a particular location and fans based on the requirement of air movement for the purpose of comfort of occupants, especially during hot summer months, and also of exhaust fans to maintain the enclosed area with fresh outside air so that a hygienic and comfortable atmosphere is created inside the enclosed area. For buildings other than small dwellings the requirement of lighting is normally selected based on the illumination level for different areas and that of the fans based on the type of occupancy and different comfort levels. The fittings and accessories shall comply with relevant Indian Standards and ISI marked (where mandated).

7.2 Ceiling Roses and Similar Attachments

A ceiling rose or any other similar attachments shall only be used as a final terminating point in single phase and voltage not exceeding 250 V.

Normally, only one flexible cord shall be attached to a ceiling rose. Specially designed ceiling roses shall be used for multiple pendants.

A ceiling rose shall not embody fuse terminal as an integral part of it.

7.3 Socket-Outlets and Plugs

There are two types of socket-outlets, one for the use of light loads not exceeding 100 W which are designated as 6 A and is normally provided with 3 pin socket-outlets in which both 3 pin plug tops and 2 pin appliances like mobile chargers can be used. This type of socket-outlet shall normally be kept on the switch board as well as individually at convenient heights not exceeding 1.2 m from the floor level based on requirement.

The second type of socket-outlets is normally of 16 A capacity and are provided with 6 pin socket-outlets in which 3 pin plug tops of 16 A capacity as well as smaller type 3 pin plug tops of about 10 A capacity can be used. These types of socket-outlets are recommended for use in respect of domestic appliances not exceeding 2 kW. These are normally placed independently at suitable heights and also above kitchen slab at appropriate level based on the requirement (*see* Fig. 4).

Each socket-outlet shall be controlled by a switch which shall preferably be located immediately adjacent thereto or combined therewith. The switch controlling the socket-outlet shall be on the live side of the line.

In respect of individual air conditioners, it is recommended to use MCB controlled socket-outlet so that proper overload protection can be maintained based on the capacity of air conditioner used which may not exceed 3 TR.

In case of public buildings, to facilitate operation of switches/socket-outlets by persons with disabilities and the elderly, these shall be installed at an accessible height for reaching and operating, between 800 mm and 1 100 mm above floor level and shall be located at a minimum of 600 mm with a preference of minimum 700 mm from any internal corner. They shall be so fixed so as to be away from danger of mechanical injury.

Suitable earth wire shall be drawn along with the power wiring for the respective socket-outlets so that the third pin is effectively earthed to ensure the equipment connected to the respective socket-outlet is properly earthed at the time of use.

NOTES

1 In situations where a socket-outlet is accessible to children, it is necessary to install an interlocked plug and socket or alternatively a socket-outlet which automatically gets screened by the withdrawal of plug. In industrial premises socket-outlet of rating 20 A and above shall preferably be provided with interlocked type switch.

2 As an exception, electrical wall socket-outlets, telephone points and TV sockets can be located at a minimum height of 400 mm above floor level.

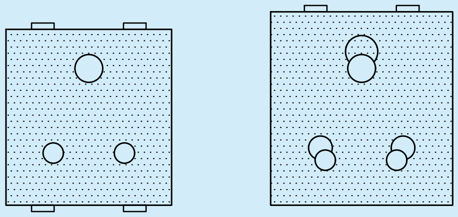


FIG. 4 6 A 3 PIN, 6/16 A COMBINED SOCKET-OUTLET

7.4 Light Fittings

7.4.1 *Lamp Holders*

There are different types of lamp holders namely pendant type, angle bracket type and batten mounted type lamp holders, each of which is further categorized as pin type and different sizes of screw type. These lamp holders are used in combination with different type of lamp shades to form ceiling suspended light fittings, wall mounted bracket type light fittings and chandelier type light fittings. These fittings can hold any of the GLS lamps of different wattage or CFL lamps and even the LED bulbs.

A switch shall be provided for control of every lighting fitting or a group of lighting fittings in the live wire. The neutral wire shall normally be looped in a light circuit. The earth wire of each point shall be used to earth the lamp holder or any such metallic point in the light fitting which does not carry electric current. Where control at more than one point is necessary, either two way or intermediate switches may be provided as required.

Shade made of flammable material shall not form a part of lighting fittings unless such shade is well protected against all risks of fire.

General and safety requirements for electrical lighting fittings shall be in accordance with provisions contained in good practice [D-2(1)] and relevant Indian Standards.

7.4.2 *Lamps*

All bare lamps including light fittings unless otherwise required and suitably protected, shall be hung at a height of not less than 2.4 m above the finished floor level. All electric lamps and accessories shall conform to relevant Indian Standards.

7.4.3 *Outdoor Lighting*

External street light fittings, bollards light fittings, bulk-head fittings, etc shall be weatherproof to prevent the ingress of moisture and dust effectively.

7.5 Fans, Regulators and Clamps

7.5.1 *Ceiling Fans*

Ceiling fans, including their suspension, shall conform to the relevant Indian Standards and good practice [D-2(1)]. There are two main types of ceiling fans available, the conventional type regular a.c. fans and the brushless direct current (BLDC) type fans which consume less power but may be expensive. Selection of the fans shall be on the basis of following technical parameters:

a) fan sweep, in mm (900/1 050/1 200/1 400/1 500);

b) air delivery, in m^3/min;

c) maximum power input, in w; and

d) service value, in m^3/min/W.

The bottom most point of the ceiling fan shall not be less than 2 400 mm above the finished floor level {*see* good practice [D-2(1)]}.

All ceiling fans shall meet the following requirements:

a) Control of a ceiling fan shall be through its own regulator as well as a switch in series.

b) All ceiling fans shall be wired with normal wiring to ceiling roses or to special connector boxes to which fan rod wires shall be connected and suspended from hooks or shackles with insulators between hooks and suspension rods. There shall be no joint in the suspension rod. The suspension rod shall be of adequate strength to withstand the dead and impact forces imposed on it. Suspension rods should preferably be procured along with the fan.

c) Fan hooks (clamp) shall be of suitable design according to the nature of construction of ceiling on which these clamps are to be fitted. In all cases fan clamps shall be fabricated from new metal of suitable sizes and they shall be as close fitting as possible. Fan clamps for reinforced concrete roofs shall be buried with the casting of roof and care shall be taken to tie the fan clamp with the reinforcement of the roof slab. Fan clamps for wooden beams shall be of suitable flat iron fixed on two sides of the beam, and according to the size and section of the beam one or two mild steel bolts passing through the beam shall hold both flat irons together. Fan clamps for steel joist shall be fabricated from flat iron to fit rigidly to the bottom flange of the beam. *See also* good practice [D-2(1)]. Care shall be taken during fabrication that the metal does not crack while hammer to shape. Other fan clamps shall be made to suit the position, but in all cases, care shall be taken to see that they are rigid and safe.

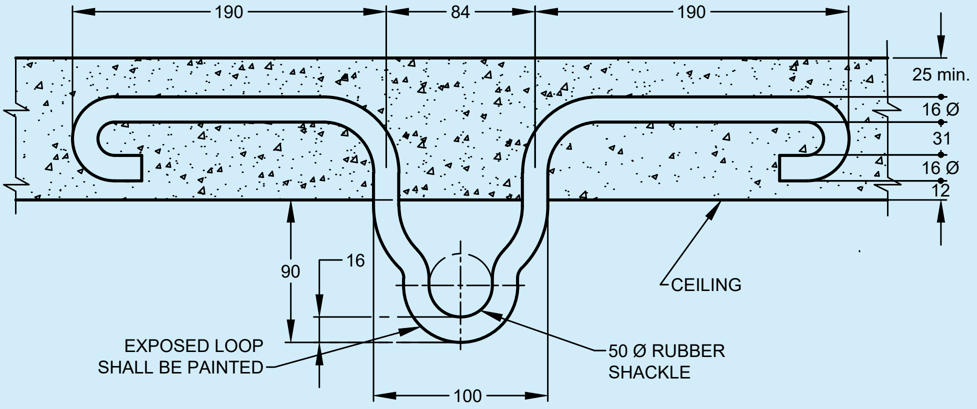
d) Canopies on top and bottom of suspension rods shall effectively conceal suspensions and connections to fan motors, respectively.

e) The lead-in-wire shall be of nominal cross-sectional area, not less than 1.5 mm^2 copper and shall be protected from abrasion.

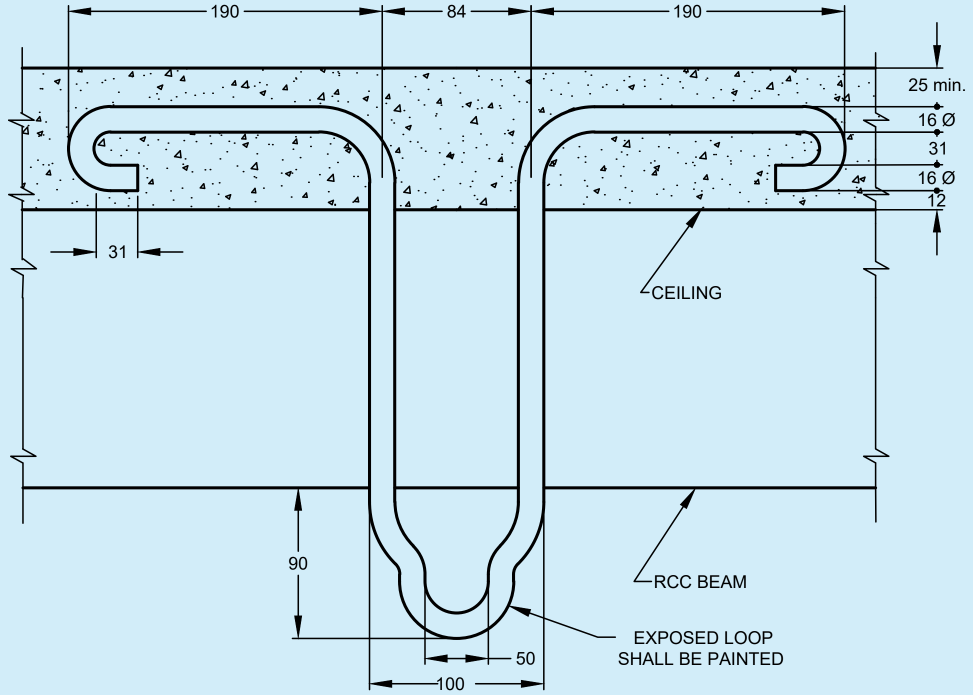
f) Unless otherwise specified, the clearance between the bottom most point of the ceiling fan and the floor shall be not less than 2.4 m. The minimum clearance between the ceiling and the plane of the blades shall be not less than 300 mm.

A typical arrangement of a fan clamp is given in Fig. 5.

NOTE — All fan clamps shall be so fabricated that fans revolve steadily.


190
84
190
25 min.
16 Ø
31
16 Ø
12
90
16
CEILING
EXPOSED LOOP
SHALL BE PAINTED
50 Ø RUBBER
SHACKLE
100

5A Slab


190
84
190
25 min.
16 Ø
31
16 Ø
12
31
CEILING
90
RCC BEAM
EXPOSED LOOP
SHALL BE PAINTED
50
100

5B Slab with Beam

ALL DIMENSIONS IN MILLIMETRES.

NOTES

1 RCC SLAB STEEL REINFORCEMENT NOT SHOWN.

2 FAN CLAMP SHALL BE PLACED IN POSITION SUCH THAT ITS PROJECTING ARMS ARE IN THE LINE OF LENGTH OF BEAM.

Fig. 5 Typical Design of Fan Clamps

7.5.2 *Exhaust Fans*

Exhaust fans are necessary for spaces, such as community toilets, kitchens and canteens and godowns to provide the required number of air changes (*see* Part D 'Building Services, Section 3 Air Conditioning, Heating and

Mechanical Ventilation' of this NBCS). Since the exhaust fans are located generally on the outer walls of a room, appropriate openings in such walls shall be provided for, in the planning stage.

NOTE — Exhaust fan requirement is based on the recommended air changes (*see* Part D 'Building Services, Section 3 Air Conditioning, Heating and Mechanical Ventilation' of this NBCS). Reference should also be made to Part F 'Fire and Life Safety' of this NBCS for exhaust fan requirements for smoke extraction.

Selection of exhaust fan can be made on the basis of:

a) blade sweep size in mm;
b) air changes in CFM or m^3/min; and
c) power input in W.

For fixing of an exhaust fan, a circular hole shall be provided in the wall to suit the size of the frame which shall be fixed by means of rag-bolts embedded in the wall. The hole shall be neatly plastered with cement and brought to the original finish of the wall. The exhaust fan shall be connected to exhaust fan point which shall be wired as near to the hole as possible by means of a flexible cord, care being taken that the blades rotate in the proper direction.

7.5.3 *Air Circulation* (*Ceiling Fans*)

7.5.3.1 Proper air circulation of rooms and halls of residential buildings/office can be achieved by suitable selection of ceiling fans based on their size and air displacement. In big halls, this can be done either by larger number of smaller fans or smaller number of larger fans. The economics of the system as a whole should be a guiding factor along with the bays of the building. For design guidelines in this regard, reference shall be made to Part D 'Building Services, Section 1 Lighting and Natural Ventilation' of this NBCS and good practice [D-2(1)].

7.5.3.2 Where ceiling fans are provided, the bay sizes of a building, which control fan point locations, play an important part. Fans of 1 200 mm/1 400 mm sweep normally cover an area of 9 m^2 to 10 m^2, for every part of a bay to be served by the ceiling fans, it is necessary that the bays shall be so designed that full number of fans can be suitably located for the bay, otherwise it will result in ill-ventilated pockets. In general, fans in long halls may be spaced at 3 m in both the directions. If building modules do not lend themselves for proper positioning of the required number of ceiling fans, other fans such as, air circulators or bracket fans will have to be employed for the areas uncovered by the ceiling fans. For this, suitable electrical outlets shall be provided although result may be disproportionate to cost on account of fans.

7.5.3.3 High volume low speed (HVLS) fans are generally ceiling fans having more number of blades which move slowly and distribute large amounts of air at low rotational speed. These are installed in very large areas like airports, hangers, warehouses and in commercial spaces like malls, etc, which have very big area with large movement of people. These are primarily recommended for bigger areas from the consideration of energy conservation.

7.5.3.4 Nowadays BLDC type fans having low wattage and higher air displacement are available with remote control operation. Choice of the same may be decided based on their operational efficiency in relation to cost.

7.6 Interchangeability

Similar parts of all switches, lamp holders, distribution fuse-boards, ceiling roses, brackets, pendants, fans and all other fittings shall be so chosen that they are of the same type and interchangeable in each installation.

7.7 Equipment

7.7.1 Electrical equipment which form integral part of wiring intended for switching or control or protection of wiring installations shall conform to the relevant Indian Standards, wherever they exist.

7.7.2 Positioning of fans and light fittings shall be chosen to make these effective without causing shadows and stroboscopic effect on the working planes.

8 EARTHING

8.1 General

8.1.1 Earthing is an important part of any electrical installation. It is essential to provide safety of human beings from electrical shock. It is also necessary to prevent fire from electrical fault and to operate the protective devices to disconnect power during an electrical fault and to ensure safe operation of the equipment. Earthing is therefore meant to divert the fault current to the protective earth conductor without causing any major damage to the installations. Thus earthing/earth conductor (also known as a ground conductor or earthing conductor) is a safety feature in electrical systems which provides a low-impedance path to the earth and helps to prevent hazardous voltages from appearing on equipment ensuring that faults are cleared quickly. In principle, it acts as a safeguard, protecting both people and equipment from electrical hazards. With the proliferation in electrical/electronic gadgets and greater dependency on voice and data communication systems, proper and effective earthing or grounding is very important. Earthing is also necessary for safe dissipation of the effects of lightning strikes from the buildings and its contents, including from sensitive equipment. All works under earthing shall comply with the provisions of good practice [D-2(1)] and [D-2(11)] apart from other Indian Standards, where applicable.

8.1.2 Different types of earth electrodes and different types of earthing systems are available. For low voltage and high voltage systems which apply to almost all electrical systems of buildings, the common earthing system followed is with the neutral solidly earthed at the source. This system requires that there is always a protective earth continuity conductor running all through the system and all metal parts of electrical appliances connected to an electrical system are connected to the earth continuity conductor. The exception to this system is the double insulated appliances which are connected to the line and neutral and operate on low voltage (single phase) and are also of low power consumption. All appliances (other than double insulated devices) use the earthing through the earth continuity conductor. Single phase appliances use a 3 wire connection with line (live wire), neutral (return path wire) and the earth-wire. Three phase appliances use a connection with 4 wires for a load which does not require a neutral connection or use a 5 wire connection if the appliance requires a neutral connection. Care should be taken to ensure that the earthing system, the protective earth conductor and the earthing pin of the socket-outlets are not disconnected.

8.1.3 Different earthing systems have features which are suitable for different applications. Earthing system adopted should be so selected so as to match with the type of load, protection device, application, degree of reliability, etc. For classification of electrical systems based on the relationship of the source and of exposed-conductive parts of the installation, to earth, *see* **2.1.185**.

8.1.4 *System Earthing*

Earthing of system is designed primarily to preserve the security of the system by ensuring that the potential on each conductor is restricted to a value consistent with the level of applied insulation. It is equally important that earthing should ensure efficient and fast operation of protective gear in the case of earth faults.

a) *TN system* — A system having one or more points of the source of energy directly earthed, the exposed conductive-parts of the installation being connected to that point by protective conductors. This is divided into TN-C system, TN-S system and TN-C-S system which are described below:

   1) *TN-C system* — A system in which neutral and protective conductors are combined in a single conductor throughout the system. This is normally provided at their source by the electrical supply company in single phase two wire or three phase four wire system.

   2) *TN-S system* — A system having separate neutral and protective conductor throughout the system. This is provided by the consumer at the point of receipt of electric supply.

   3) *TN-C-S system* — A system in which neutral and protective conductors are combined in a single conductor in part of the system. It involves a shared neutral and earth conductor from the source up to the consumer's intake, where it is then separated into individual neutral (N) and protective earth (PE) conductors.

b) *TT system* — A system having one point of the source of energy directly earthed, the exposed-conductive-parts of the installation being connected to the earth electrodes electrically independent of the earth electrodes of the source.

c) *IT system* — A system in which all live parts are isolated from earth or point connected to earth through high impedance. The exposed-conductive-parts of the electrical installation are earthed independently or collectively to the earthing of the system. This system is mostly used in hospitals, sensitive areas and places where stable power supply is essential for critical loads.

8.2 Selection and Design of Earthing System

8.2.1 Earthing shall generally be carried out in accordance with the requirements of Regulation 18, 43 and 50 of *Central Electricity Authority* (*Measures Relating to Safety and Electric Supply*) *Regulations*, 2023 (*see* Annex B), relevant Indian Standards and the relevant regulations of the Electricity Supply Authority concerned. All materials, fittings, etc used in earthing shall conform to relevant Indian Standard specification.

8.2.2 Conductors and earth electrodes in an earthing system shall be so designed and constructed that in normal use their performance is reliable and without danger to persons and surrounding equipment. Earthing system shall be designed so as to have touch potential, step potential and transfer potential within the specified limits as indicated in good practice [D-2(18)] and [D-2(11)] as amended up to date. The choice of a material depends on its ability to match the particular application requirement. The requirements for earthing arrangements are intended to provide a connection to earth which:

a) is reliable and suitable for the protective requirements of the installation;

b) can carry earth fault currents and protective conductor currents to earth without danger from thermal, thermo-mechanical and electromechanical stresses and from electric shock arising from these currents;

c) if relevant, is also suitable for functional requirements; and

d) is suitable for the foreseeable external influences as provided in good practices [D-2(1)], [D-2(18)], [D-2(11)] and IEC 60364-5-51 : 2005 'Electrical installations of buildings — Part 5-51: Selection and erection of electrical equipment — Common rules', for example, mechanical stresses and corrosion.

8.2.3 The main earthing system of an electrical installation shall consist of:

a) an earth electrode (electrode can be vertical rod/pipe/buried plate or an earth mat with several vertical installations or a ring earthing strip/conductor);

b) a main earthing wire;

c) main earthing terminal (MET), an earth bar (located on the main switchboard for small installation and installed in the wall/room in case of large industrial electronic installations) for the connection of the main earthing wire, protective earthing wires and/or bonding wires within the installation; and

d) a removable link, which effectively disconnects the neutral bar from the earth bar.

NOTE — The requirements of (c) and (d) above shall be carried out by a licensed electrician as part of the switchboard installation.

8.2.4 The main earthing wire connection shall:

a) be mechanically and electrically sound;

b) be protected against damage, corrosion, and vibration;

c) not place any strain on various parts of the connection;

d) not damage the wire or fittings; and

e) be secured at the earth electrode.

8.2.4.1 The main earthing wire termination shall be readily accessible at the earth electrode except for **8.2.22**. As far as possible, all earth connections, except exothermically welded, shall be visible for inspection.

8.2.5 Consideration shall be given to the earthing arrangements where currents with high frequencies are expected to flow {*see* good practice [D-2(18)] and IEC 60364-4-44 : 2007 'Low-voltage electrical installations — Part 4-44: Protection for safety — Protection against voltage disturbances and electromagnetic disturbances'}.

8.2.6 Protection against electric shock {*see* good practice [D-2(18)] and IEC 60364-4-41: 2005 'Low-voltage electrical installations — Part 4-41: Protection for safety — Protection against electric shock'}, shall not be adversely affected by any foreseeable change of the earth electrode resistance (for example, due to corrosion, drying or freezing).

8.2.7 Where the supply to an installation is at high or extra high voltage, requirements concerning the earthing arrangements of the high or extra high voltage supply and of the low-voltage installation shall also comply with provisions of good practice [D-2(18)] and IEC 60364-4-44 : 2007 'Low-voltage electrical installations — Part 4-44: Protection for safety — Protection against voltage disturbances and electromagnetic disturbances'.

8.2.8 A permanent fitting (like a screwed-down label, or one that can be threaded onto the cable) shall be used at the connection point that is clearly marked with the words: 'EARTHING LEAD — DO NOT DISCONNECT' or 'EARTHING CONDUCTOR — DO NOT DISCONNECT'.

8.2.9 All low voltage, three phase equipment shall be earthed by two separate and distinct connections with earth. In case of single phase equipment, single distinct earth connection is sufficient. The contact area of earth conductor/plate shall be determined in accordance with good practice [D-2(11)].

8.2.9.1 The 415/240 V, 4 wire, 3 phase systems are normally operated with the neutral solidly earthed at source. At low voltage, the Central Electricity Authority regulations require that the neutral be earthed by two separate and distinct connections with earth. Neutral of transformers of 33 kV/415 V, 11 kV/415 V and neutral of low voltage DG sets and similar equipment shall be of the same size as the phase conductor or higher as per relevant Indian Standard.

NOTE — Neutral conductor of half the size of the phase conductor was permitted in earlier installations. But with the proliferation of equipment using non-linear devices and consequent increase in harmonics, the neutral will carry a current more than the notional out-of-balance current and therefore neutral conductor shall be of the same size as the phase conductor.

8.2.10 In the case of high and extra high voltages, the neutral points shall be earthed by not less than two separate and distinct connections to earth, each having its own electrode at the generating station or substation and may be earthed at any other point, provided no interference is caused by such earthing. The neutral may be earthed through suitable impedance. Neutral earthing conductor shall be sized as to have a current carrying capacity not less than the phase current.

8.2.11 For industrial/commercial installations having a transformer within the facility, soil resistivity of the place of installation shall be measured and recorded {*see* good practice [D-2(11)]}. For the adopted type of earth electrode configuration, earth fault impedance of the configuration shall be calculated and recorded {*see* good practice [D-2(11)]}.

8.2.12 It is recommended that a drawing showing the main earth connection and earth electrodes be prepared for each installation.

8.2.13 Earth system shall be so devised that the testing of individual earth electrode is possible. It is recommended that the value of any earth system resistance shall be such as to conform to the degree of shock protection desired. For measuring purposes, the joint shall be capable of being opened with the aid of a tool. In normal use it shall remain closed. Inclusion of online earth monitoring system with real time earthing grid resistance and integrity measurement at site level can be considered for buildings which house lot of sensitive systems and also number of electronic devices to ensure human safety and equipment protection.

8.2.14 Conductors, other than live conductors and any other parts intended to carry a fault current, shall be capable of carrying that current without attaining an excessive temperature.

8.2.15 No addition to the current carrying system, either temporary or permanent, shall be made which will increase the maximum earth fault current or its duration until it has been ascertained that the existing arrangement of earth electrodes, earth busbar, etc are capable of carrying the new value of earth fault current which may be obtained by this addition.

8.2.16 No cut-out, link or switch other than a linked switch arranged to operate simultaneously on the earthed conductor or earthed neutral conductor and the live conductors, shall be inserted on any supply system. This, however, does not include the case of a switch used in controlling a generator or a transformer or a link for test purposes.

8.2.17 The number of connections along the conductors shall be minimized to reduce potential failure points. The high energy lightning currents can induce significant thermal expansion, if bonding is inadequate and overlap is poor. Also, mechanical connections should be minimized. All conductors used in earthing and lightning protection system should be joined using methods that ensure long-term electrical, mechanical and environmental reliability. Critical connections, especially those below ground or exposed to moisture shall be made using exothermic welding which provides a permanent molecular bond with superior thermal and corrosion resistance. Exothermic welded joints shall conform to the relevant standards.

8.2.18 Earthing associated with current-carrying conductor is normally essential for the function of the system and is generally known as system earthing or functional earthing, while earthing of non-current carrying metal work and conductor is essential for the safety of human life, animals and of property and it is generally known as equipment earthing or equipotential bonding. The requirements for protective purposes shall always take precedence.

8.2.19 *Equipotential Bonding*

Equipotential bonding is through connecting exposed and extraneous conductive parts in a building to the main earthing terminal of the installation by protective bonding conductors. Where such conductive parts originate outside the building, they shall be bonded near their entry point within the building.

It shall be ensured that all exposed metal parts and extraneous conductive parts within a specific area or system are at the same potential. The same is achieved by creating a low resistance path between these conductive parts. Equipotential bonding allows fault currents to flow to earthed conductor without creating dangerous voltage difference that could harm individuals.

Equipotential bonding is used in various settings including buildings, industrial facilities, swimming pools and areas with lightning protection system. In the event of a fault equipotential bonding helps limit touch voltages and ensures that fault currents are safely directed to earth preventing electric shock (*see* Fig. 6).

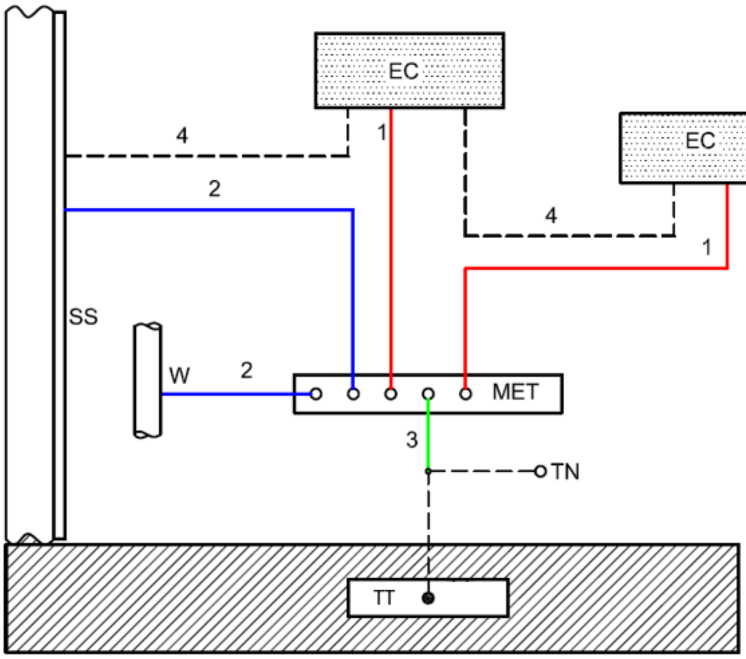
8.2.20 All earthing systems in a building shall be interconnected at the earth level (ground).

8.2.21 For selection of electrodes for use in corrosive environments, reference shall be made to good practice [D-2(11)].

8.2.22 Test joints are not required in the case of natural down-conductors combined with foundation earth electrodes (*see* Fig. 7).

8.2.23 For computer and other sensitive electronic equipment system in industrial and commercial application, special bonding techniques with isolation transformer can be employed (*see* Fig. 8).

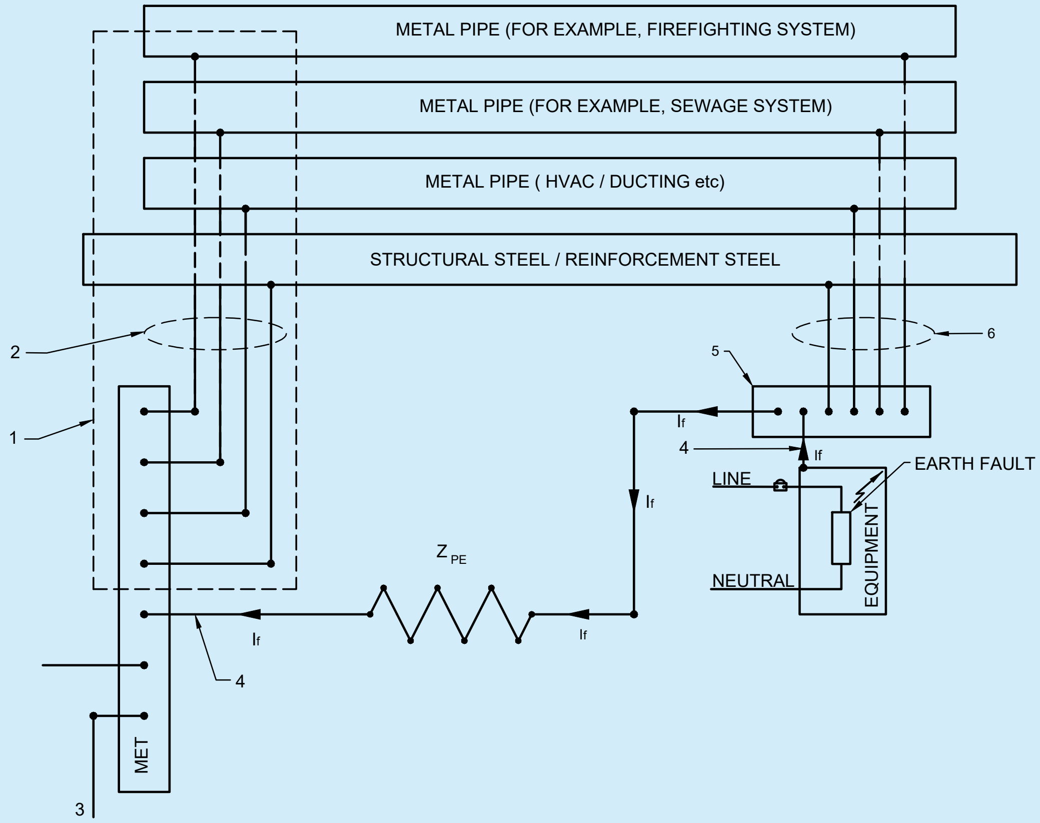
8.2.24 Isolated earthing is unsafe during a transient condition. In unavoidable conditions if isolated earthing is used to reduce potential difference between isolated earthing, earth couplers or isolating spark gaps shall be installed. This will reduce potential difference during a transient condition such as lightning.



Key

EC	Exposed conductive part (panel board body)
MET	Main earthing terminal
SS	Structural steel (extraneous conductive part)
W	Metallic water pipe (extraneous conductive part)
TT	Earth electrode in a TT or IT system
TN	Other means of earthing in a TN system, for example, connection to earthed point of the power system
1	Circuit protective conductor
2	Main protective bonding conductor
3	Earthing conductor
4	Supplementary protective bonding conductors (additional bonding, if required)
1,2,3,4	Protective conductors

6A Illustration of Earthing and Protective Conductors


METAL PIPE (FOR EXAMPLE, FIREFIGHTING SYSTEM)
METAL PIPE (FOR EXAMPLE, SEWAGE SYSTEM)
METAL PIPE (HVAC / DUCTING etc)
STRUCTURAL STEEL / REINFORCEMENT STEEL
2
6
5
1
If
4
If
EARTH FAULT
LINE
If
EQUIPMENT
Z PE
NEUTRAL
If
If
4
MET
3

KEY

1 MAIN EQUIPOTENTIAL BONDING (CONNECTION BETWEEN MET AND EXTRANEOUS CONDUCTIVE PARTS).

2 MAIN EQUIPOTENTIAL BONDING CONDUCTOR (INDIVIDUAL CONNECTION, NO LOOPING). IN CASE OF LARGE NUMBER OF EXTRANEOUS CONDUCTIVE PARTS, AN EARTHING TERMINAL CAN BE LOCATED NEAR THE EXTRANEOUS CONDUCTIVE PARTS FOR INDIVIDUAL CONNECTION TO THESE PARTS AND A COMMON CONNECTION FROM THIS EARTHING TERMINAL TO MET. SUITABLE INDICATIONS SHALL BE MADE TO EVERY CONNECTION OF EQUIPOTENTIAL BONDING CONDUCTOR TO AVOID ACCIDENTAL DISCONNECTIONS.

3 EARTHING CONDUCTOR. (CONNECTS MET AND EARTHED POINT OF THE SOURCE IN TN SYSTEM OR MET AND EARTH ELECTRODE IN CASE OF TT/IT SYSTEM). ONE CONNECTION FROM MET IS ALSO NECESSARY TO LPS (IF INSTALLED).

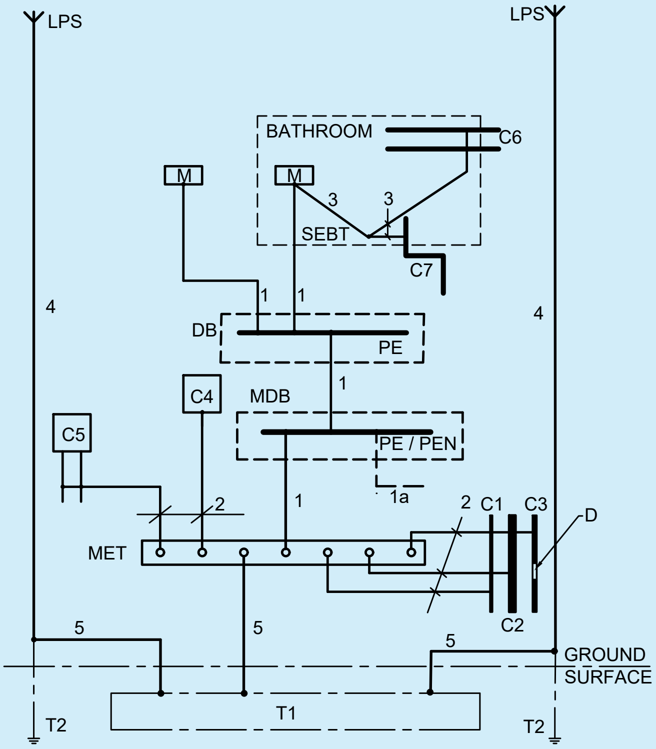
4 PROTECTIVE EARTHING BY PROTECTIVE EARTHING CONDUCTOR (PE).

5 SUPPLEMENTARY EQUIPOTENTIAL BONDING TERMINAL (SEBT) (TO RE DUCE TOUCH VOLTAGE < 50 V).

6 SUPPLEMENTARY EQUIPOTENTIAL BONDING CONDUCTOR.

6B Main and Additional Protective Equipotential Bonding

Fig. 6 Protective Equipotential Bonding

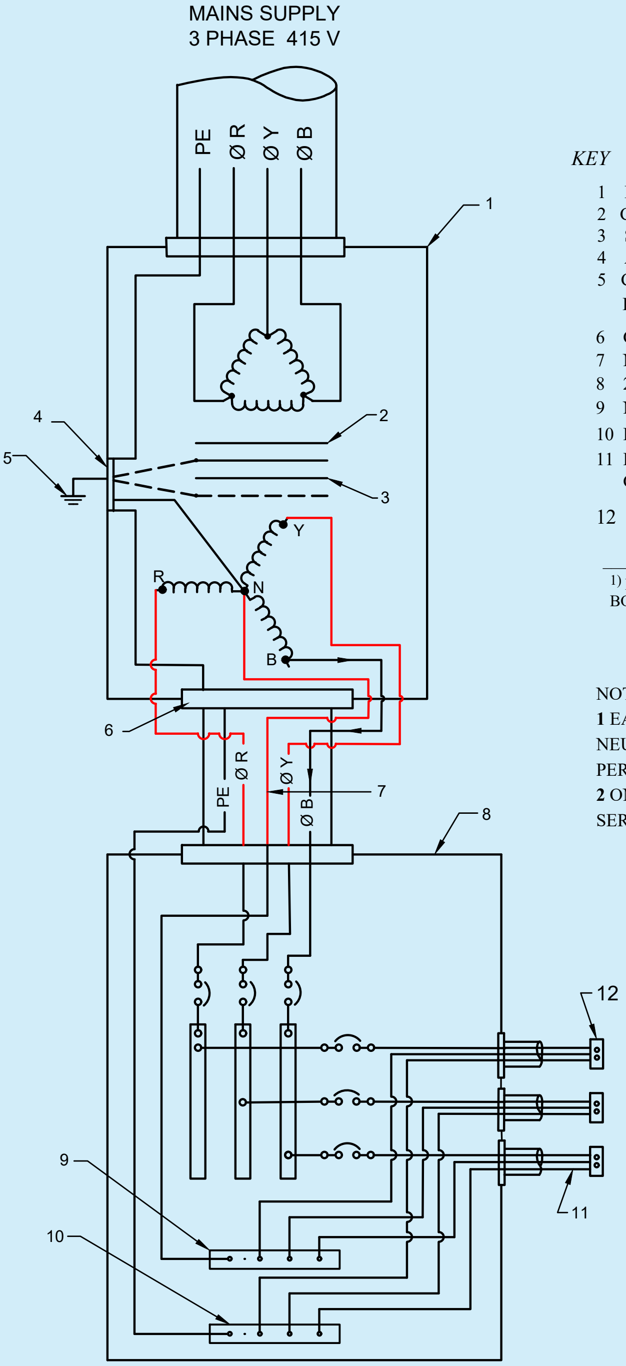


KEY	
C	Extraneous-conductive-part
C1	Water pipe, metal from outside
C2	Waste water pipe, metal from outside
C3	Gas pipe with insulating insert, metal from outside
C4	Air conditioning
C5	Heating system
C6	Water pipe, metal for example in a bathroom
C7	Waste water pipe, metal for example in a bathroom
D	Insulating insert
MDB	Main distribution board
DB	Distribution board
MET	Main earthing terminal
SEBT	Supplementary equipotential bonding terminal
T1	Concrete-embedded foundation earth electrode or soil-embedded foundation earth electrode
T2	Earth electrode for LPS, if necessary
LPS	Lightning protection system (if any)
PE	PE terminal(s) in the distribution board
PE/PEN	PE/PEN terminal(s) in the main distribution board
M	Exposed-conductive-part
1	Protective earthing conductor (PE)
1A	Protective conductor, or PEN conductor, if any, from supplying network
2	Protective bonding conductor for connection to the main earthing terminal
3	Protective bonding conductor for supplementary bonding
4	Down conductor of a lightning protection system (LPS), if any
5	Earthing conductor

NOTES

1 FUNCTIONAL EARTHING CONDUCTORS ARE NOT SHOWN IN FIGURE.
2 WHERE A LIGHTNING PROTECTION SYSTEM IS INSTALLED, THE ADDITIONAL REQUIREMENTS ARE GIVEN IN 11.

FIG. 7 EXAMPLE OF AN EARTHING ARRANGEMENT FOR FOUNDATION EARTH ELECTRODE, PROTECTIVE CONDUCTORS AND PROTECTIVE BONDING CONDUCTORS



KEY

1 ISOLATION TRANSFORMER
2 CORE
3 SHIELD
4 ALL EARTHING CONNECTIONS MADE AT A POINT
5 CONNECTIONS TO BUILDING STEELS/EARTH PITS/RING EARTHING
6 CONDUIT EARTHING
7 NEUTRAL
8 240/415 VOLT POWER PANEL
9 NEUTRAL BUS[1)]
10 EARTH BUS [1)]
11 EARTH CONNECTION FOR SOCKET/WORK STATION/ COMPUTERS
12 3 PIN SOCKETS WITH ISOLATED EARTH PIN

[1)] BOTH BUSBARS ISOLATED FROM PANEL ENCLOSURE. NO BONDING CONNECTION BETWEEN NEUTRAL AND EARTH.

NOTES

1 EARTH BRANCH CIRCUIT SHALL HAVE A SEPARATE NEUTRAL AND EARTH WIRE. NO DAISY CHAINING PERMITTED.

2 ONLY COMPUTER OR CONTROL SYSTEM SHOULD BE SERVED FROM THIS PANEL.

FIG. 8 RECOMMENDED POWER DISTRIBUTION FOR A COMPUTER AND CONTROL SYSTEM WITH A DELTA/STAR ISOLATION TRANSFORMER

8.3 Earth Electrodes

The efficacy of any earth electrode depends on its configuration and upon local soil conditions. Number of earth electrodes suitable for the soil conditions and the value of resistance to earth as well as earth fault impedance shall be considered. It is essential that earthing conductors of the earth system shall follow the provisions as per good practice [D-2(1)] read with good practice [D-2(11)] in view of provisions in CEA Regulation No. 43 (*see* Annex B) regarding earth fault loop impedance. Examples of earth electrodes which may be used are:

a) concrete-embedded foundation earth electrode;

b) soil-embedded foundation earth electrode;

c) metallic electrode embedded directly in soil vertically or horizontally (for example rods, wires, tapes, pipes or plates);

d) metal sheath and other metal coverings of cables according to local conditions or requirements;

e) other suitable underground metalwork (for example pipes) according to local conditions or requirements; and

f) welded metal reinforcement of concrete (except pre-stressed concrete) embedded in the earth.

The type, materials and dimensions of earth electrodes shall be selected to withstand corrosion and to have adequate mechanical strength for the intended lifetime. For materials commonly used for earth electrodes, the minimum sizes, from the point of view of corrosion and mechanical strength, when embedded in the soil or in concrete, shall be as specified in Table 2. In the case of lightning protection system, the provisions of **11.6.3** shall also be complied with.

NOTES

1 For corrosion, the parameters to be considered are: the soil *p*H at the site, soil resistivity, soil moisture, stray and leakage a.c. and d.c. current, chemical contamination, and proximity of dissimilar materials.

2 The minimum thickness of protective coating is greater for vertical earth electrodes than for horizontal earth electrodes because of their greater exposure to mechanical stresses while being embedded.

3 Interconnection of dissimilar metals should be avoided in earthing systems and earth conductors to prevent corrosion and loose connections.

Earth electrode either in the form of solid rod, pipe, plate or earth grid should be provided at all premises for providing an earth system. Details of typical pipe, rod and plate earth electrodes are given in Fig. 9 and Fig. 10. Other electrode configurations can be as in Fig. 11 {*see* good practice [D-2(11)]}.

Although electrode material does not affect initial earth resistance, care should be taken to select a material which is resistant to corrosion in the type of soil in which it is used. In case where soil condition leads to excessive corrosion of the electrode and the connections, it is recommended to use either copper/stainless steel or copper coated steel electrode and copper/stainless steel connections. Exothermic welding may also be adopted to have enhanced life and strength to the connection. It is recommended to use similar material for earth electrodes and earth conductors or otherwise precautions should be taken to avoid corrosion. As an alternate, 50 mm GI earth strip and 100 mm CI pipe can be provided as per good practice [D-2(11)].

Table 2 Minimum Size of Commonly Used Earth Electrodes, Embedded in Soil or Concrete, Used to Prevent Corrosion and Provide Mechanical Strength1)

[*Clauses* 8.3, 9.2.2.1(s) *and Fig.* 9]

Sl No.	**Material and Surface**	**Shape**	**Diameter**	**Cross-Sectional Area**	**Thickness**	**Weight of Coating**	**Thickness of Coating/ Sheathing**
			mm	mm^2	mm	g/m^2	µm
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	Steel embedded in concrete (bare, hot galvanized or stainless)	Round wire	10	–	–	–	–
		Solid tape or strip	–	75	3	–	–
ii)	Steel hot-dip galvanized2)	Strip3) or shaped strip/plate – solid plate – lattice plate	–	90	3	500	63
		Round rod installed vertically	16	–	–	350	45
		Round wire installed horizontally	10	–	–	350	45
		Pipe	25	–	2	350	45
		Stranded (embedded in concrete)	–	70	–	–	–
		Cross profile installed vertically	–	(290)	3	–	–
iii)	Steel copper sheathed	Round rod installed vertically	(15)	–	–	–	2 000
iv)	Steel with electro-deposited copper coating	Round rod installed vertically	14	–	–	–	2506)
		Round wire installed horizontally	(8)	–	–	–	70
		Strip installed horizontally	–	90	3	–	70
v)	Stainless steel 4)	Strip3) or shaped strip/plate	–	90	3	–	–
		Round rod installed vertically	16	–	–	–	–
		Round wire installed horizontally	10	–	–	–	–

Table 2 (*Concluded*)

Table 2 Minimum Size of Commonly Used Earth Electrodes, Embedded in Soil or Concrete, Used to Prevent Corrosion and Provide Mechanical Strength[1]

[*Clauses* 8.3, 9.2.2.1(s) *and Fig.* 9]

Sl No.	Material and Surface	Shape	Diameter	Cross-Sectional Area	Thickness	Weight of Coating	Thickness of Coating/ Sheathing
			mm	mm^2	mm	g/m^2	µm
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
		Pipe	25	–	2	–	–
vi)	Copper	Strip		50	2	–	–
		Round wire installed horizontally	–	(25)[5] 50	–	–	–
		Round rod installed vertically	(12) 15	–	–	–	–
		Stranded wire	1.7 for individual strands of wire	(25)[5] 50	–	–	–
		Pipe[6]	20	–	2	–	–
		Solid plate	–	–	(1.5) 2	–	–
		Lattice plate	–	–	2	–	–

---

[1] As per Table B-1 under Part 1 'General and Common Aspects, Section 18: Earthing' of good practice [D-2(1)].

[2] The coating shall be smooth, continuous and free from flux stains.

[3] As rolled strip or slit strip with round edges.

[4] Chromium ≥ 16 percent, nickel ≥ 5 percent, molybdenum ≥ 2 percent, carbon ≤ 0.08 percent.

[5] Where experience shows that the risk of corrosion and mechanical damage is extremely low, 16 mm^2 can be used.

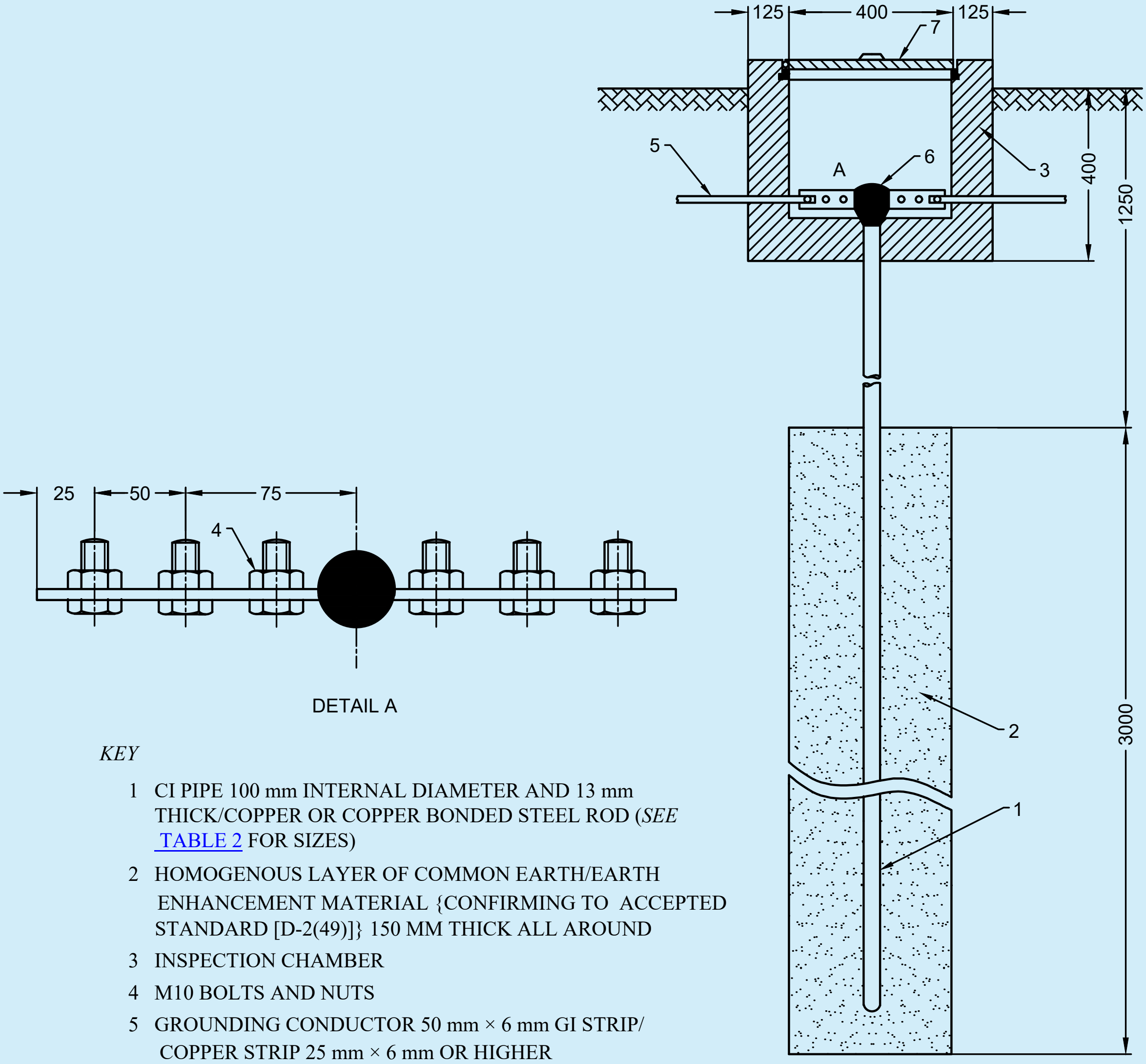
[6] This thickness is provided to withstand mechanical damage of copper coating during the installation process. It may be reduced to not less than 100 µm where special precautions to avoid mechanical damage of copper during the installation process (for example, drilling holes or special protective tips) are taken according to the manufacturer's instruction.

NOTES

1 Values in bracket are applicable for protection against electric shock only, while values not in brackets are applicable for lightning protection and for protection against electric shock.

2 Metals inserted inside pipe will not influence in the final earth resistance value.

3 Unprotected ferrous materials are not recommended due to high corrosion (*see* IEC 60364-4-43 : 2008 'Low-voltage electrical installations — Part 4-43: Protection for safety — Protection against overcurrent').



KEY

1 CI PIPE 100 mm INTERNAL DIAMETER AND 13 mm THICK/COPPER OR COPPER BONDED STEEL ROD (*SEE* TABLE 2 FOR SIZES)

2 HOMOGENOUS LAYER OF COMMON EARTH/EARTH ENHANCEMENT MATERIAL {CONFIRMING TO ACCEPTED STANDARD [D-2(49)]} 150 MM THICK ALL AROUND

3 INSPECTION CHAMBER

4 M10 BOLTS AND NUTS

5 GROUNDING CONDUCTOR 50 mm × 6 mm GI STRIP/ COPPER STRIP 25 mm × 6 mm OR HIGHER

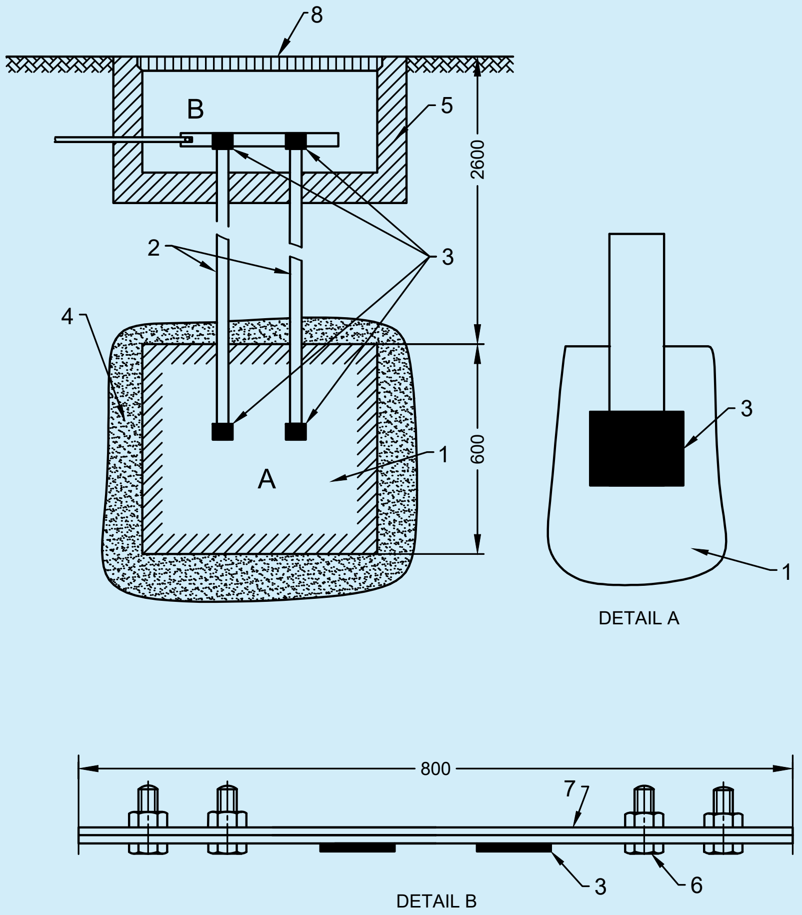
6 EXOTHERMIC WELDING

7 CI LID/COVER

ALL DIMENSIONS IN MILLIMETRES.

NOTE — INSPECTION HOUSING CAN ALSO BE OF FRP MATERIALS WITH CI COVER TESTED ACCORDING TO ACCEPTED STANDARD [D-2(50)].

FIG. 9 TYPICAL ARRANGEMENT OF EARTHING WITH COPPER/COPPER BONDED ELECTRODE WITH EXOTHERMIC WELDING (MAINTENANCE FREE ARRANGEMENT)



KEY

1 600 mm × 600 mm × 3 mm COPPER PLATE
2 30 mm × 6 mm COPPER STRIP
3 EXOTHERMIC WELDING
4 EARTH ENHANCEMENT MATERIAL {CONFORMING TO ACCEPTED STANDARD [D-2(49)]}
5 INSPECTION CHAMBER
6 M12 × 40 STAINLESS STEEL BOLTS AND NUTS
7 50 mm × 6 mm COPPER STRIP
8 CI LID/COVER

ALL DIMENSIONS IN MILLIMETRES.

NOTE — INSPECTION HOUSING CAN ALSO BE OF FRP MATERIALS WITH CI COVER TESTED ACCORDING TO ACCEPTED STANDARD [D-2(50)].

FIG. 10 TYPICAL ARRANGEMENT OF COPPER ELECTRODE PLATE EARTHING WITH EXOTHERMIC WELDING (MAINTENANCE FREE ARRANGEMENT)

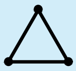
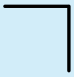
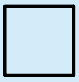
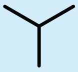
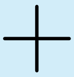
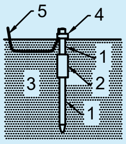
1		THREE RODS AT THE VERTICES OF AN EQUILATERAL TRIANGLE
2		TWO STRIPS SET AT RIGHT ANGLES TO EACH OTHER MEETING AT ONE CORNER
3		VERTICAL ELECTRODES INTERCONNECTED AS A SQUARE
4		THREE STRIPS SET AT 120°, MEETING AT THE STAR POINT ALL OF EQUAL LENGTH
5		FOUR STRIPS SET IN A CRUCIFORM
6		VERTICAL ROD 1 EXTENSIBLE EARTH ROD 2 ROD COUPLING 3 SOIL 4 CONDUCTOR TO ROD CLAMP 5 EARTHING CONDUCTOR

FIG. 11 MISCELLANEOUS ELECTRODE CONFIGURATIONS

8.4 Earth Enhancing Compound

Multiple rods, even in large numbers, may sometime fail to produce an adequately low resistance to earth. This condition arises in installations involving soils of high resistivity. The alternative is to reduce the resistivity of the soil immediately surrounding the earth electrode. To reduce the soil resistivity, artificial soil treatment shall be adopted.

8.4.1 Earthing enhancing compound is a conductive compound producing low resistance of an earth-termination system. These compounds used for artificial treatment of soil shall satisfy the requirements as per accepted standard [D-2(49)].

8.4.2 The material of the earthing enhancing compound shall be chemically inert to subsoil. It shall not pollute the environment. It shall provide a stable environment in terms of physical and chemical properties and exhibit low resistivity. The earthing enhancing compound shall not be corrosive to the earth electrodes being used. The usage of earth enhancing compound shall adhere to the conditions detailed in accepted standard [D-2(49)].

8.4.3 The materials used for artificial treatment should also fulfil toxicity characteristic leaching procedure (TCLP) requirements.

8.4.4 Use of salt [sodium chloride (NaCl)] for artificial treatment of soil should be avoided as it accelerates corrosion of ferrous materials.

8.4.5 The requirement and use of earth enhancing compound shall comply with the provisions as per accepted standard [D-2(49)].

8.5 Earth Electrode Inspection Housings and Earth Electrode Seals

8.5.1 *Earth Electrode Inspection Housing*

Earth electrode inspection housing is the metallic or non-metallic enclosure that houses the down-conductor/earth-termination connection for inspection and testing purposes and consists of a housing and a removable lid. The design of the earth electrode inspection housing shall be such that it carries out its function of enclosing the down-conductor/earth rod termination in an acceptable and safe manner, and has sufficient internal dimensions to permit the assembly/disassembly of the earth rod clamp. The material of the earth electrode inspection housing shall be compatible with its surrounding environment and shall comply with the tests given in accepted standard [D-2(50)]. The work shall also comply with the provisions of good practice [D-2(11)].

8.5.2 *Earth Electrode Seal*

Water pressure seal used in conjunction with an earth rod electrode shall be such that there will be no effect on the water proofing treatment for the foundation of the building. The design of the earth electrode seal shall be such that it carries out its function of preventing ground water bypassing the earth rod and entering the basement of a building, in an acceptable and safe manner and shall be compatible with its surrounding environment and comply with the tests given in accepted standard [D-2(50)].

8.6 Bonding and Inter Connection

All connections made in an earthing system above or below ground should meet electrical conductivity, corrosion resistance, current carrying capacity and mechanical strength of the conductor. These connections should be strong enough to maintain a temperature rise below that of the conductor and to withstand the effect of heating and the mechanical forces caused by fault currents. Consideration shall be given to electrolytic corrosion when using different materials in an earthing arrangement. The complete connections shall be able to resist corrosion for the intended life of the installation.

8.6.1 For external conductors (for example, earthing conductor) connected to a concrete-embedded foundation earth electrode, the connection made from hot-dip galvanized steel shall not be embedded in the soil.

8.6.2 Where an earth electrode consists of parts that should be connected together, the connection shall be by exothermic welding, pressure connectors, clamps or other suitable mechanical connectors.

8.6.3 All connection components shall meet the requirements according to accepted standard [D-2(51)] and also provisions of good practice [D-2(11)] and [D-2(1)] where applicable.

8.7 Equipment and Portions of Installations which shall be Earthed

8.7.1 *Equipment to be Earthed*

Except for equipment provided with double insulation, all the non-current carrying metal parts of electrical installations are to be earthed properly. All metal conduits, trunking, cable sheaths, switchgear, distribution fuse boards, lighting fittings and all other parts made of metal shall be bonded together and connected by means of two separate and distinct conductors to an efficient earth electrode.

8.7.2 *Structural Metal Work*

Earthing of metallic parts of the structure shall be done according to good practice [D-2(11)].

8.8 Neutral Earthing

To comply with relevant Central Electricity Authority regulations, no fuses or circuit breakers other than a linked circuit breaker shall be inserted in an earthed neutral conductor. A linked switch or linked circuit breaker shall be arranged to break the neutral either with or after breaking all the related phase conductors. This shall make (or close) the neutral before making (or closing) the phases.

If this neutral point of the supply system is connected permanently to earth, then the above rule applies throughout the installation including 2 wire final circuits. This means that no fuses may be inserted in the neutral or common return wire. And the neutral should consist of a bolted solid link or part of a linked switch, which completely disconnects the whole system from the supply. This linked switch shall be so arranged that the neutral makes before and break after the phases. For further details, reference should be made to good practice [D-2(11)].

8.9 System of Earthing

Equipment and portions of installations shall be deemed to be earthed only if the earthing is done as per TN-S system with equipotential bonding as required. In all cases, the relevant provisions of the Central Electricity Authority regulations shall be complied along with provisions under good practice [D-2(11)].

8.10 The earthing of electrical installations for non-industrial and industrial buildings shall be done in accordance with good practice [D-2(11)] and good practice [D-2(1)].

9 INSPECTION, TESTING, VERIFICATION AND COMMISSIONING OF INSTALLATION

9.1 General Requirements

9.1.1 Before the completed installation, or an addition to the existing installation, is put into service, inspection and testing shall be carried out in accordance with the *Central Electricity Authority* (*Measures Relating to Safety and Electric Supply*) *Regulations*, 2023, with special reference to Regulation numbers 5, 8, 14, 17, 18, 20, 21, 29 to 39, 42, 43, 46 to 48 and 50 (*see* Annex B), and also as per provisions in Part 1 'General and common aspects, Section 17 Erection and pre-commissioning — Testing of installations' of good practice [D-2(1)]. In the event of defects being found, these shall be rectified, as soon as practicable and the installation retested.

9.1.2 Initial and periodic inspection and testing shall be carried out in order to maintain the installation in a sound condition after putting into service. The periodicity shall be as per provisions in Annex E under Part 1 'General and common aspects, Section 17 Erection and pre-commissioning — Testing of installations' of good practice [D-2(1)].

9.1.3 Where an addition is to be made to the fixed wiring of an existing installation, the latter shall be examined for compliance with the recommendations of this NBCS.

9.1.4 The individual equipment and materials which form part of the installation shall generally conform to the relevant Indian Standard, wherever applicable. If there is no relevant Indian Standard for any item, these shall be approved by the appropriate authority.

9.1.5 *Completion Drawings*

On completion of the electric work, a wiring diagram shall be prepared and submitted to the Engineer-in-Charge or the owner. All wiring diagrams shall indicate clearly the main switch board, the runs of various mains and submains cables and the position of all points and their controls. All circuits shall be clearly indicated and numbered in the wiring diagram and all points shall be given the same number as the circuit in which they are electrically connected. Also the location and number of earth points and the run of each loads should be clearly shown in the completion drawings.

9.1.6 *Inspection and Testing*

The substations and other electrical installations shall be checked and tested as detailed in **4.2** and **4.3** under Part 1 'General and common aspects, Section 17 Erection and pre-commissioning — Testing of installations' of good practice [D-2(1)] and necessary test reports shall be prepared in the prescribed proforma therein. In addition, additional checks and tests as mentioned under the **9.2** and **9.3** shall also be carried out if not included in good practice [D-2(1)]. In case any defects are noticed, the same shall be rectified, retested and their test format shall be completed.

9.2 Inspection of the Installation

9.2.1 *General*

On completion of wiring a general inspection shall be carried out by competent personnel in order to verify that the provisions of this NBCS and that of *Central Electricity Authority* (*Measures Relating to Safety and Electric Supply*) *Regulations*, 2023 have been complied with. This, among other things, shall include checking whether all equipment, fittings, accessories, wires/cables used in the installation are of adequate rating and quality to meet the requirement of the load. General workmanship of the electrical wiring with regard to the layout and finish shall be examined for neatness that would facilitate easy identification of circuits of the system, adequacy of clearances, soundness, contact pressure and contact area. A complete check shall also be made of all the protective devices, with respect to their ratings, range of settings and co-ordination between the various protective devices. It is preferable to have a third party inspection to maintain quality assurance.

9.2.2 *Items to be Inspected*

All equipment in a substation including HV panel, transformer, LV panel, emergency DG sets, battery bank, cables, cable terminations, etc need inspection. Healthiness of the main distribution boards, metering panels, distribution cables, rising mains, bus ducts, etc need to be verified along with earthing system. In case of provisions of rooftop solar PV system and other services, the equipment connected therein shall also be included in the items to be inspected.

9.2.2.1 *Substation installations*

In substation installation, it shall be checked whether:

a) the installation has been carried out in accordance with the approved drawings;

b) phase to phase and phase to earth clearances are provided as required;

c) all equipment are efficiently earthed and properly connected to the required number of earth electrodes;

d) HV and LV switchgears are all vermin and damp-proof and all unused openings or holes are blocked properly;

e) the required ground clearance to live-terminals is provided;

f) suitable fencing is provided (with gate, lockable arrangements) and suitably earthed as required;

g) there is no vegetation in outdoor substation;

h) the required number of caution boards, firefighting equipment, operating rods, insulation mats of appropriate rating, etc, are kept in the substation;

j) in case of indoor substation sufficient ventilation and draining arrangements are made;

k) all cable trenches are provided with non-inflammable covers;

m) free accessibility is provided for all equipment for normal operation;

n) all name plates are fixed and the equipment are fully painted;

p) all construction materials and temporary connections are removed;

q) oil-level, busbar tightness, transformer tap position, etc are in order;

r) earth pipe troughs and cover slabs are provided for earth electrodes/earth pits and the neutral earth pits and earth pits of lightning protection system are marked for easy identification;

s) earth electrodes are of GI pipes or CI pipes or copper plates or Cu bonded rods as per Table 2 and, for earth connections, brass bolts and nuts with lead washers are provided in the pipes/plates;

t) earth pipe troughs and oil sumps/pits are free from rubbish and dirt and stone jelly, and the earth connections are visible and easily accessible;

u) earthing system designed are periodically checked for permissible limits of step and touch potential;

w) the earth busbars have tight connections and corrosion-free joint surfaces;

y) operating handle of protective device are provided at an accessible height from ground, that is, 300 mm to 1 800 mm;

z) adequate headroom is available in the transformer room for easy topping-up of oil, maintenance, etc;

aa) safety devices, horizontal and vertical barriers, busbar covers/shrouds, automatic safety shutters/doors interlock and handle interlock are safe and in reliable operation in all panels and cubicles;

bb) clearances in the front, rear and sides of the main HV, LV and sub-switch boards are adequate;

cc) the switches operate freely, the 3 blades make contact at the same time, the arcing horns contact in advance, and the handles are provided with locking arrangements;

dd) insulators are free from cracks, and are clean;

ee) in oil cooled transformers, leakage of oil, if any should be checked;

ff) connections to bushing in transformers are tight and have good contact;

gg) bushings are free from cracks and are clean;

hh) accessories of transformers like breathers, vent pipe, buchholz relay, etc, are in order;

jj) connections to gas relay in transformers are in order;

kk) oil and winding temperature are set for specific requirements in transformers;

mm) in case of cable cellars, adequate arrangements made to pump out water that has entered due to seepage or other reasons;

nn) all incoming and outgoing circuits of HV and LV panels are clearly and indelibly labelled for identification;

pp) no cable is damaged;

qq) there is adequate clearance around the equipment installed; and

rr) cable terminations are proper.

9.2.2.2 *High/low voltage installation*

In high and low voltage installations, it shall be checked whether:

a) all blocking materials that are used for safe transportation in switchgears, contactors, relays, etc are removed;

b) all connections to the earthing system are feasible for periodical inspection;

c) sharp cable bends are avoided and cables are taken in a smooth manner in the trenches or alongside the walls and ceilings using suitable support clamps at regular intervals;

d) suitable circuit breaker or lockable push button is provided near the motors/apparatus for controlling supply to the motor/apparatus in an easily accessible location;

e) two separate and distinct earth connections are provided for the motor/apparatus;

f) control switch-fuse is provided at an accessible height from ground for controlling supply to overhead travelling crane, hoists, overhead busbar trunking;

g) the metal rails on which the crane travels are electrically continuous and earthed and bonding of rails and earthing at both ends are done;

h) four core cables are used for overhead travelling crane and portable equipment, the fourth core being used for earthing, and separate supply for lighting circuit is taken;

j) if flexible metallic hose is used for wiring to motors and other equipment, the wiring is enclosed to the full lengths, and the hose secured properly by approved means;

k) the cables are not taken through areas where they are likely to be damaged or chemically affected;

m) the screens and armours of the cables are earthed properly;

n) the belts of the belt driven equipment are properly guarded;

p) adequate precautions are taken to ensure that no live parts are so exposed as to cause danger;

q) ammeters and voltmeters are tested;

r) the relays are inspected visually by removing covers for deposits of dusts or other foreign matter;

s) wherever bus ducts/rising mains/overhead bus trucking are used, special care being taken for earthing the system, and all tap off points are provided with adequately rated protective device like MCB, MCCB, fuses, RCCB/RCD, SPD (*see* **11**), etc;

t) all equipment are weather, dust and vermin proof; and

u) any and all equipment having air insulation as media maintain proper distances between phases, phase to neutral, phase to earth and earth to neutral.

9.2.2.3 *Overhead lines*

For overhead lines, it shall be checked whether:

a) all conductors and apparatus including live parts thereof are inaccessible;

b) the types and size of supports are suitable for the overhead lines/conductors used and are in accordance with approved drawing and standards;

c) clearances from ground level to the lowest conductor of overhead lines, sag conditions, etc, are in accordance with the relevant Indian Standards and the CEA Regulations;

d) where overhead lines cross the roads or cross each other or are in proximity with one another, suitable guarding is provided at road crossings and to also protect against possibility of the lines coming in contact with one another;

e) every guard wire is properly earthed;

f) the type, size and suitability of the guarding arrangement provided is adequate;

g) stays are provided suitably on the overhead lines, as required and are efficiently earthed or provided with suitable stay insulators of appropriate voltages;

h) anti-climbing devices and danger board/caution board notices are provided on all HV supports;

j) clearances along the route are checked and all obstructions, such as, trees/branches and shrubs are cleared on the route to the required distance on either side;

k) clearance between the live conductor and the earthed metal parts are adequate;

m) for the service connections tapped-off from the overhead lines, cut-outs of adequate capacity are provided;

n) all insulators are properly and securely mounted, also they are not damaged;

p) all poles are properly grouted/insulated so as to avoid bending of pole towards tension; and

q) steel poles, if used is properly earthed.

9.2.2.4 *Lighting and convenience power circuits*

For the lighting and convenience power circuits, it shall be checked whether:

a) wooden boxes are avoided;

b) panels are provided for mounting the lighting boards and switch controls, etc;

c) neutral links are provided in double pole switch-fuses which are used for lighting control and no protective device (such as MCB, MCCB, fuses, RCCB/RCD, etc) is provided in the neutral;

d) the plug points (6 A) in the lighting circuit are all of 3/5-pin type, the third pin being properly earthed;

e) the plug points (16 A) in the lighting circuit are all of 3/6-pin type, the third pin being properly earthed;

f) tamper-proof interlocked switch socket and plug are used for locations easily accessible;

g) wiring for lighting is taken in surface or recessed conduit and conduit properly earthed, or alternatively, armoured cable wiring is used in factories;

h) a separate earth wire is run in the lighting installation to provide earthing for plug points, fixtures and equipment;

j) proper connectors and junction boxes are used wherever joints are to be made in conductors or cross-over of conductors takes place;

k) clear and permanent identification marks are painted in all distribution boards, switchboards, sub-main boards and switches as necessary;

m) the polarity has been checked and all protective devices (such as MCB, MCCB, fuses, RCCB/RCD, etc) and single pole switches are connected on the phase conductor only and wiring is correctly connected to socket-outlets;

n) spare knockouts are provided in distribution boards and switch fuses are blocked;

p) the ends of conduits enclosing the wiring leads are provided with ebonite or other suitable bushes;

q) the fittings and fixtures used for outdoor use are all of weather-proof construction and of suitable IP and IK rating and similarly, fixtures, fittings and switchgears used in the hazardous area, are of flame-proof application;

r) proper terminal connectors are used for termination of wires (conductors and earth leads) and all strands are inserted in the terminals;

s) flat ended screws are used for fixing conductor to the accessories;

t) as desirable, flat washers backed up by spring washers are used for making end connections; and

u) all metallic parts of installation, such as conduits, distribution boards, metal boxes, etc, have been properly earthed.

9.3 Testing of Installation

9.3.1 *General*

After inspection, the tests as indicated in **9.3.2** shall be carried out, before an installation or an addition to the existing installation is put into service. Any testing of the electrical installation in an already existing installation shall commence after obtaining permit to work from the Engineer-in-Charge and after ensuring the safety provisions.

Testing of the installations will cover the testing of equipment, connections, cables, switchgear, protective devices, circuit breakers and the associated relays, measuring instruments and earthing. Periodicity of testing should not exceed six months. More frequent testing may be prescribed for complex installations and installations feeding sensitive loads. Due date of next test cycle should be displayed on the equipment.

The tests as detailed in **4.3** under Part 1 'General and common aspects, Section 17 Erection and pre-commissioning — Testing of installations' of good practice [D-2(1)] shall be carried out before energizing the installation and shall be recorded in the proforma attached under Annex E.

9.3.2 *Testing*

9.3.2.1 *Switchboards*

HV and LV switchboards shall be tested in the manner indicated below:

a) All high voltage switchboards shall be tested for insulation (phase to phase, phase to earth and body to earth);

b) In case of oil type switchboards, dielectric strength of oil shall also be tested;

c) All earth connections shall be checked for continuity;

d) The operation of the protective devices shall be tested by means of secondary or primary injection tests;

e) The operation of the breakers shall be tested from all control stations;

f) Indication/signalling lamps shall be checked for proper working;

g) The operation of the breakers shall be tested for all interlocks;

h) The closing and opening timings of the breakers shall be tested wherever required for auto-transfer schemes;

j) Contact resistance of main and isolator contacts shall be measured; and

k) The specific gravity and the voltage of the control battery shall be measured.

9.3.2.2 *Transformers*

Transformers shall be tested in the manner indicated below:

a) All commissioning tests shall be in accordance with good practice [D-2(16)]; and

b) Insulation resistance on HV and LV windings shall be measured at the end of 1 min, as also at the end of 10 min of measuring the polarization index. The absolute value of insulation resistance should not be the sole criterion for determining the state of dryness of the insulation. Polarization index values should form the basis for determining the state of dryness of insulation. For any class of insulation, the polarization index should be greater than 1.5. In case of oil type transformers, the dielectric strength shall be tested.

9.3.2.3 *Cables*

Cable installations shall be checked as given below:

a) It shall be ensured that the cables conform to the relevant Indian Standards. Tests shall also be done in accordance with good practice [D-2(23)]. The insulation resistance before and after the tests shall be checked;

b) The insulation resistance between each conductor and against earth shall be measured. The insulation resistance varies with the type of insulation used and with the length of cable;

c) Physical examination of cables shall be carried out;

d) Cable terminations shall be checked; and

e) Continuity test shall be performed before charging the cable with current.

9.3.2.4 *Motors and other equipment*

The following tests shall be made on motor and other equipment.

The insulation resistance of each phase winding against the frame and between the windings shall be measured. Megger of 500 V or 1 000 V rating shall be used. Star points should be disconnected. Minimum acceptable value of the insulation resistance varies with the rated power and the rated voltage of the motor.

The following relation may serve as a reasonable guide:

$$R_i = \frac{20 \times E_n}{1\,000 + 2P}$$

where

R_i = insulation resistance in MΩ at 25 °C;

E_n = rated phase to phase voltage; and

P = rated power, in kW.

If the resistance is measured at a temperature different from 25 °C, the value shall be corrected to 25 °C.

The insulation resistance as measured at ambient temperature does not always give a reliable value, since moisture may have been absorbed during shipment and storage. When the temperature of such a motor is raised, the insulation resistance will initially drop considerably, even below the acceptable minimum. If any suspicion exists on this score, motor winding shall be dried out.

9.3.2.5 *Wiring installation*

The following tests shall be done:

a) The insulation resistance shall be measured by applying between earth and the whole system of conductor or any section thereof with all fuses in place and all switches closed, and except in earthed concentric wiring, all lamps in position or both poles of installation otherwise electrically connected together, a d.c. voltage of not less than twice the working voltage, provided that it does not exceed 500 V for low voltage circuits. Where the supply is derived from three-wire (a.c. or d.c.) or a poly-phase system, the neutral pole of which is connected to earth either direct or through added resistance, the working voltage shall be deemed to be that which is maintained between the outer or phase conductor and the neutral;

b) The insulation resistance in mega-ohm (MΩ) of an installation measured as in (a) shall be not less than 50 divided by the number of points on the circuit, provided that the whole installation need not be required to have an insulation resistance greater than 1 MΩ;

c) Control rheostats, heating and power appliances and electric signs, may, if desired, be disconnected from the circuit during the test, but in that event the insulation resistance between the case of framework, and all live parts of each rheostat, appliance and sign shall be not less than that specified in the relevant Indian Standard or where there is no such specification, shall be not less than 0.5 MΩ; and

d) The insulation resistance shall also be measured between all conductors connected to one pole or phase conductor of the supply and all the conductors connected to the middle wire or to the neutral on to the other pole of phase conductors of the supply. Such a test shall be made after removing all metallic connections between the two poles of the installation and in these circumstances the insulation resistance between conductors of the installation shall be not less than that specified in (b).

9.3.2.6 *Earthing*

The following tests shall be done for the earth electrodes (earthing):

a) The earth resistance of each electrode shall be measured;

b) Earth resistance of earthing grid shall be measured;

c) All electrodes shall be connected to the grid and the earth resistance of the entire earthing system shall be measured; and

d) After receipt of electrical supply, the fault loop impedance shall be measured to ensure that the value obtained is minimal and to comply with the provisions under the CEA Regulations No. 43 (*see* Annex B) and good practice [D-2(11)].

These tests shall preferably be done during the summer months.

9.3.2.7 *Lightning protection system* (*LPS*)

Lightning protection system (LPS) verification shall be done as per accepted standards [D-2(52)] including the details of calculation of risk assessment and the selection of lightning protection level. The objective of inspection of LPS shall include whether all components of LPS are in good condition and capable of performing their designed functions and there is no corrosion. Inspections shall include checking of embedded electrodes, earth resistance values for the earth termination system, conditions of connections, equipotential bonding and fixings. The complete LPS shall be tested by opening one of the test joints to ensure that the total LPS system does not have more than 10 Ω to the earth. In case, if the total resistance of LPS exceeds 10 Ω then additional down conductors should be planned from air terminations and mesh conductor system, based on rolling sphere/mesh/protection angle method, to the earth so that the overall resistance is brought down to below 10 Ω by uniformly placing the additional down conductors. The testing shall also comply with all provisions included in **4.4** of Part 1 ‘General and common aspects, Section 17 Erection and pre-commissioning — Testing of installations’, of good practice [D-2(1)] and IEC 62305-3 : 2024 ‘Protection against lightning — Part 3: Physical damage to structures and life hazard’.

9.4 Checklist for Installation

The testing and submission of reports of all electrical installations shall be done as detailed in the model form in Annex D of Part 1 ‘General and common aspects, Section 17 Erection and pre-commissioning — Testing of installations, of good practice [D-2(1)]. In addition, the checklist covering set of checks for installation, handing over and commissioning of typical equipment of a substation as given in Annex E is for general reference and use. For other allied installation, the proper checklist should be developed keeping in view the type of loads, quality of service, environmental conditions and operating requirements of redundancy and reliability.

9.5 Completion Certificate

On completion of an electrical installation (or an extension to an installation) a certificate shall be furnished by the contractor, counter-signed by the certified supervisor under whose direct supervision the installation was carried out. This certificate shall be in a prescribed form as required by the local electric supply authority. One such recommended form is given in Annex F. This is a general form giving the minimum basic requirements and the items in the form have to be augmented keeping in view the features of the particular equipment, system or installation and environmental conditions of its operation.

10 ALLIED/MISCELLANEOUS SERVICES

10.0 General

The allied and miscellaneous services covered under this are special type of services which may or may not be part of the main electrical installations of the building but are services which are used in the building and may sometimes use electrical supply to run the services. This also covers the photovoltaic and other rooftop generation system which will get integrated with the electrical supply system for the building. This clause also covers inverters, UPS and small portable generation system to meet certain emergency requirements. The chapter also covers broadly the provisions for EV charging, Data centres and multeystorey buildings beyond 24 storeys. This clause provides the requirements related to these services.

10.1 Telecommunication and Information and Communication Technology Services

10.1.1 *Telephone/Intercom Services*

10.1.1.1 House wiring of telephone subscribers in small buildings may be on the surface of walls or desirably, in a concealed manner through conduits. In large multi-storeyed buildings intended for commercial, business and office use as well as for residential purposes, wiring for telephone connections should be done in a concealed manner through conduits. The requirements of telecommunication facilities like telephone connections, private branch exchange and intercommunication facilities, should be planned well in advance so that suitable provisions are made in the building plan in such a way that the demand for telecommunication services in any part of the building at any floor are met at any time during the life of the building.

10.1.1.2 Layout arrangements, methods for internal block wiring and other requirements regarding provisions of space, etc may be decided depending on the number of phone outlets and other details in consultation with engineer/architect and user. *See also* Part D ‘Building Services, Section 6 Information and Communication Enabled Installations’ of this NBCS.

10.1.2 *Fibre to The Home* (*FTTH*) *Services*

Fibre to the home (FTTH) services provide high speed internet, television and phone directly to a home or business using fibre optic cables. These services provide significantly higher bandwidth, faster speeds and more reliable connections compared to traditional broadband with advanced features such as high-definition video streaming, online gaming, etc. Instead of copper wires, FTTH uses thin strands of glass or plastic fibre(s) which transmit data as light signals.

Installing FTTH network is straightforward fibre installation with some additional components like splitters, an optical network terminal (ONT) and associated hardware at the customer premises. For more details, reference may be made to Part D 'Building Services, Section 6 Information and Communication Enabled Installations' of this NBCS.

10.1.3 *Information and Communication Technology Services including Computer Networking*

See Part D 'Building Services, Section 6 Information and Communication Enabled Installations' of this NBCS.

10.2 Public Address System

See Part F 'Fire and Life Safety' of this NBCS.

10.3 Emergency and Standby Power Supply Systems

10.3.1 *General*

Use of electricity has grown tremendously and for various activities the dependency on electricity has increased to such an extent as to cause serious problems even with loss of electrical power for a very short time. As a result, a wide variety of alternate sources of electricity are being used in our built environment.

The different alternative sources of power are the uninterrupted power supply (UPS) system, inverter, diesel (CNG/LPG) generator sets, petrol/kerosene oil generator sets and bio-gas generator sets.

In addition to the above, there is a proliferation of power sources, such as solar photo-voltaic cells, wind generators, bio-mass and waste-based power plants, etc, primarily oriented towards reduction of the environmentally harmful CO_2 emissions.

These systems give electricity during the periods of the failure of the conventional grid based public energy system and keep our critical systems in continued operation. However, introduction of more than one source of electrical power results in safety related issues. For safety from electrical shock to human beings or livestock, the hazard is not just dependent on the main high-powered source such as the grid, but the hazard is the same from a low powered source also. Shock from a small 20 W inverter can be as dangerous as a shock from the grid with megawatts of power at the back. As such precautions from the angle of safety apply equally to all sources of power. Electric shock hazards are dependent on the system voltage and as such even a low capacity generator or an inverter (of capacity 100 VA) poses the same level of shock hazard as a multi-kilovolt ampere capacity generator and all protection provisions (such as earthing, earth leakage and overload breakers) shall be provided as done for a large capacity system.

Power devices contain fuel, batteries which are points of concentrated sources of energy constrained in a small place. Any unintended improper release of this bottled up energy can unleash devastating consequences, such as fire and as such care is required in location which houses any of these sources of electrical power and its associated components.

10.3.2 *Uninterrupted Power Supply* (*UPS*) *System*

UPS is an electrical device providing an interface between the mains power supply and sensitive loads (computer systems, instrumentation, etc). The UPS supplies sinusoidal a.c. power free of disturbances and within strict amplitude and frequency tolerances. It is generally made up of a rectifier/charger and an inverter together with a battery for backup power in the event of a mains failure with virtually no time lag.

In general UPS system shall be provided for sensitive electronic equipment like computers, printers, fire alarm panel, public address system equipment, access control panel, EPABX, etc, with the following provisions. In addition, provisions as given in good practice [D-2(1)] shall also be followed.

a) Isolation transformers may be provided for UPS systems to provide higher grade of power supply quality to the loads fed by the UPS.

b) UPS shall have dedicated neutral earth pits of IT system. This earth pit shall be interconnected with other earth pits below soil for equipotential bonding and comply with the provisions of good practice [D-2(11)].

c) Adequate rating of protective devices such as MCB, MCCB, fuses, RCD, etc shall be provided at both incoming and outgoing sides.

d) UPS room shall be provided with adequate ventilation and/or air conditioning as per requirement, to avoid thermal runaway.

e) For all 3 phase UPS, 4 pole circuit breaker (CB) shall be used and for all 1 phase UPS, double pole CB shall be used.

f) The system shall confirm to set of accepted standards [D-2(53)].

10.3.3 *Inverter*

In general inverter system shall be provided for house lighting, shop lighting, etc.

NOTE — While a UPS system is provided to maintain power supply without any break even in the event of a failure of the incoming power supply, an inverter system is provided where a short break is acceptable.

Inverter systems also have a battery bank to supply power during the failure of the main power supply and the battery charged through a rectifier. The following provisions shall apply to inverter systems:

a) Adequate rating of protective devices such as MCB, MCCB, fuses, RCD, etc, shall be provided at both incoming and outgoing sides;

b) Earthing shall be done in accordance with good practice [D-2(11)];

c) Adequate ventilation space shall be provided around the battery section of the inverter; and

d) Care shall be taken in circuit design to keep the connected load in such a manner that the demand at the time of mains failure is within the capability of the inverter.

NOTE — If the inverter fails to take over the load at the time of the mains failure, the purpose of providing the inverter and battery backup is defeated.

10.3.4 The following provisions shall apply to both inverter and UPS systems:

a) Circuits which are fed by the UPS or inverter systems should have suitable marking to ensure that a worker does not assume that the power is off, once the mains have been switched off from the DB for maintenance;

b) Electric shock hazards are dependent on the system voltage and as such even a low capacity generator or an inverter (of capacity 100 VA) poses the same level of shock hazard as a multi-kilovolt ampere capacity generator and all protection provisions (such as safety earthing, earth leakage and overload breakers) shall therefore be provided as done in case of a large capacity system;

c) UPS and inverter systems should be provided with protection to shut the output during abnormal conditions, such as overload or short circuit. Such systems may also have the choice of auto-restoration after a preset time delay and an ultimate lock-out after a number of restoration attempts. Warning should be displayed wherever the possibility of automatic restoration is possible;

d) Batteries that go with UPS and inverter systems are required to be placed in well-ventilated spaces as oxygen and hydrogen gasses are produced in the batteries, which unless ventilated, can cause explosive conditions; and

e) The flooring for the battery room should be with acid (or alkali as the case may be) resistant tiles or coating.

10.4 Building Management System (BMS)

10.4.1 *General*

Building management system (BMS) is a computer-based system for monitoring and managing the building's mechanical, electrical and electro-mechanical systems including electrical substation equipment, HVAC, lighting, energy management, lifts, escalators, fire safety, security systems car parking management, etc. By its usage, building operations are optimized, energy efficiency is enhanced besides ensuring performance of all systems, safety and improving occupant's comfort.

10.4.2 *Working*

BMS provides a central platform for effective monitoring and efficient management of various building services. It allows remote monitoring and control from a single desk/location.

Separate standalone monitoring and control system provided for each service like electrical sub-station equipment; solar power and renewable energy system; standby generation system; HVAC system for control of operation and monitoring of all equipment including comfort conditions like temperature, humidity and air quality; fire protection system combining fire detection and firefighting arrangements, public address system (evacuation system); security system consisting of access control, CCTV, security fencing, water management system; etc can all be further integrated with BMS for remote monitoring, control and management .

By using sensors, it collects data on various parameters of all systems including comfort conditions of individual rooms/areas such as temperature, humidity, air quality, energy consumption based on occupancy level and adjusts system settings automatically for optimization of performance and eliminating wastage of energy thereof. Additionally, it can also spot inconsistencies and can send alerts to maintenance engineers to address the problems promptly.

The software of BMS also includes various features of reporting and analytics for improving building performance and identification of improvement areas. By integrating it with other building systems a more comprehensive and efficient solution of building management can be attained.

10.4.3 *Compliance with Regulations and Standards*

Where mandated, the relevant energy efficiency and safety standards prescribed by the Bureau of Energy Efficiency (BEE), Part F ‘Fire and Life Safety’ of this NBCS and other relevant parts and sections of this NBCS should be complied with. It should also be capable of seamless integration and exchange of data with other systems and devices functioning within the building. Designed for optimal performance, this system should be protected against unauthorized access and cyber threats.

10.5 Security System

Security system may comprise an integrated closed circuit television system, access control system, perimeter protection systems, movement sensors, etc. These have a central control panel, which has a defined history storage capacity. This main control panel may be located where it can be manned suitably with provision for integration to the fire detection and alarm system when considered necessary.

These may be considered for high security areas or large crowded areas or complexes. High security areas may consider uncorded, high-resolution, black and white cameras in place of coloured cameras. These cameras may be accompanied or automatically controlled with movement sensors. Cameras may be linked to access controls so that proper recording of the movement at the points of access to high security areas is maintained.

Access control may be provided for entry to high security areas. The systems may have proximity card readers, magnetic readers, etc.

> NOTE — *See* relevant guidelines/best practices (Handbook on ‘Asset and Facility Management in Buildings’) for provisions relating to security system.

10.6 Car Parking Area

10.6.1 *Car Parking Management System*

Wherever car park management system is provided in multi-level parking or other parking lots with features of boom barriers, pay and display machines (manned or unmanned type) and parking guidance system (for displaying number of car spaces vacant on various floors, direction of entry and exit, etc), the electrical provisions for the same shall be adequately backed with UPS for protection of vehicle and for efficient car parking management.

10.6.2 *Emergency Lighting in Basement Car Parking*

Lighting at suitable points should be provided on the passageway of the cars so that the public in the area can safely move away from the passage in the event of power failure.

10.7 Electrical Vehicle Charging

10.7.1 *General*

Increased use of electric vehicles (EVs) here resulted in the need for providing adequate EV charging infra structure in the built environment. It is recommended to provide for EV charging infrastructure for 20 percent of the parking area of buildings. Provisions of charging infra structure should be adequately increased such that slow charging of vehicles in parked condition for long duration can be undertaken in parking area of residential, office, institutional and in about 40 percent of commercial parking areas. Further, considering the rising status of EV adoption, the initial proposal of 20 percent parking space allocation for EVs may be increased up to 30 percent, say by 2030.

10.7.2 *Charging Arrangement*

Standards for charging of electric vehicles presently restrict the charging arrangements to open area and upto first basement with provisions of necessary sprinkler arrangement for firefighting services and necessary water curtain/compartment for fire protection. The charging infrastructure in podium/above ground parking do not provide significant risk considering the availability of cross ventilation in most such parking arrangements. However, with increased demand for charging infrastructure, the use of other basement may have to be considered. The charging arrangement in parking should be segregated individually for two wheelers and for four wheelers.

Charging arrangement for cars (four wheelers), can be provided both in ground level and first basement having adequate ventilation. However, two wheelers need to be segregated from four wheelers in parking and charging arrangement; and should be restricted to only ground floor level with adequate ventilation and firefighting arrangement using water mist fire system. The use of water mist fire system having up to 85 percent reduced water required for fighting the fire makes it a better option for both cooling effect and controlling electric fire in electric vehicles. The parking facility for the two wheelers shall be so arranged that not more than two vehicles should be parked side by side for charging and a space of not less than 1 m should be kept between the vehicle groups. The charging infrastructure should be provided in groups of four outlet points with three pin socket-outlets of 10 A capacity with 30 mA RCD control for each socket-outlet with metering arrangement. The spacing of the charging outlet shall be at a distance of 4 m/5 m on the basis of the parking arrangement provided.

In residential complexes, charging of vehicles would be preferred while parked for the day. Accordingly, it will not be advisable to keep parking of electrical vehicles contiguous to/vicinity of the petrol/diesel/CNG gas based vehicles. Hence separate segregated parking lot is required to be created for EVs (four wheelers) preferably in ground level/first basement with compartmentalized and water sprinkler fire barrier arrangement (for the basement). Suitable fire alarm/fire detection and fire ventilation system shall also be provided. Building professionals can consider developing suitable independent tower arrangement (podium) for car parking of electrical vehicles among the residential/commercial tower blocks and the building plan approval authorities can consider for suitable exemptions from the permitted area for construction.

It is necessary to provide for at least 20 percent of the vehicles in a residential complex with electric charging using a slow charging arrangement, as per Government guidelines. Hence each charging point shall be provided with two numbers 15 kW single phase two wire and two numbers 15 kW three phase four wire outlets controlled by suitable MCCB and RCD of 30 mA capacity with suitable metering arrangement. Each outlet shall be controlled by appropriate RCD/RCBO with rated residual operating current not exceeding 30 mA and necessary metering arrangement. In case of covered parking (first basement/podium), each location shall be provided with two sets of charging points. Each charging point shall be provided with access to portable firefighting arrangement within 15 m. The charging arrangement will be initially permitted to first basement only with compartment/sprinkler based water curtain and normal ventilation requirement of 15 to 18 air changes per hour with gas monitoring system. No charging infrastructure or EV parking shall be provided in the last basement. EV charging is a critical application from the point of fire safety, it is essential that all cables used for feeding the

EV charging stations of both two wheelers and four wheelers shall be of copper conductors for sizes upto 50 mm^2 4 core cables to prevent overheating with adequate earthing connections. All terminals shall be crimped to prevent loose connections.

It is also necessary to provide in the open area of the residential complex slow and fast charging points for 5 percent of the number of flats subject to minimum of two points with independent meter reading so that in case the number of electric vehicles increase in the complex, the users can take advantage of the fast charging arrangement. The arrangement shall be with two numbers 15 kW single phase two wire, 15 kW three phase four wire and 30 kW four wire outlets each controlled by MCCB of appropriate capacity, RCD of 30 mA capacity and metering arrangement.

10.7.3 As far as possible, EV charging arrangement shall be provided with independent transformer to ensure that harmonics created during EV charging do not interfere with power supply to other system and also to maintain other electrical parameters. A separate transformer is recommended for EV charging points where the total connected load exceeds 100 kW. It shall be ensured that EV charging is not fed from diesel generator sets or gas generators or similar fuel based power generating systems.

In case of hospitals, commercial complexes and big residential complexes, necessary public charging infrastructure shall be provided with 15 kW/30 kW/60 kW charging points duly controlled by appropriate capacity RCD/RCBO having rated residual current of 30 mA, necessary metering arrangement for each point with fast charger provisions. Spaces for EVs to be provided with charging facility for at least 20 percent of total vehicles. However, in the first basement, charging points shall be of capacity less 15 kW only.

All charging points, cabling, etc shall comply with accepted standards [D-2(54)] and good practice [D-2(1)] and the *CEA* (*Measures Relating to Electric Supply and Safety*) *Regulations*, 2023, with special reference to Regulation No. 123, 124, 125, 126, 127 and 128 (*see* Annex B).

10.7.4 *Battery Swapping System*

Battery swapping systems provide quick, safe and reliable swapping of the swappable battery system (SBS) of electric vehicles preferably two wheelers. The batteries will be loaded in a battery swap station (BSS). The SBS are stored in a battery rack in the BSS. The battery swapping is carried out by means of appropriate manipulators. EV battery swap system consists of:

a) battery swap station (BSS);

b) supporting systems;

c) swappable battery system (SBS); and

d) power supply system.

See accepted standard [D-2(55)].

Battery swap system shall be permitted only on ground floor (or on above ground floors) or outside the building line including battery storage zone and battery charging zone.

10.7.5 *Charging Infrastructure for Electric Buses*

Each electric bus depot shall be equipped with a minimum of two direct current (d.c.) fast chargers, each rated at not less than 240 kW, conforming to power level 3 or level 4. Chargers shall comply with the following Indian Standards:

a) d.c. charging protocol for heavy-duty vehicles — as per accepted standards [D-2(56)].

b) High-power d.c. charging systems — as per accepted standards [D-2(57)].

c) EV-EVSE communication protocol (power line communication) — as per accepted standards [D-2(58)].

d) Connector and plug interface for M3 category vehicles — as per accepted standards [D-2(59)].

All installations shall conform to applicable safety norms as per the CEA Regulations and relevant Indian Standards.

10.7.6 *Safety Requirements for Residential Charging of Electric Vehicles*

10.7.6.1 *Scope*

This clause specifies safety requirements for the installation and use of electric vehicle (EV) charging systems in residential premises.

10.7.6.2 *General safety provisions*

a) Only devices listed by a qualified testing laboratory shall be used.

b) Manufacturer's instructions shall be read and complied with.

c) Chargers and cords shall be inspected for damage prior to use; damaged components shall not be used.

d) Use of extension cords with EV chargers shall not be permitted.

e) Charging equipment shall be installed in locations that are:

    1) away from high-traffic areas; and

    2) free from proximity to combustible materials.

f) Charging accessories shall be stored out of reach of children and animals when not in use.

g) Charging station outlets shall be covered to prevent ingress of water.

h) Prior to initiating home charging, a qualified electrician shall:

    1) assess the capacity of the existing electrical system; and

    2) install a dedicated circuit for the charging device.

10.7.6.3 *Precautionary measures*

Warning signs shall be prominently displayed to ensure the safety of maintenance personnel. The signage shall include the following statements:

a) The vehicle is equipped with high-voltage batteries;

b) Battery maintenance shall be undertaken only by the manufacturer or authorized personnel; and

c) Orange-coloured high-voltage cables shall not be touched.

10.8 Solar Photovoltaic Power Generating System in Buildings

10.8.1 *General*

Solar energy, which is available in two forms, heat and light, is a renewable and inexhaustible natural resource and can supplement/augment the depleting fossil fuel resources. Greenhouse gases and pollutant emissions which result from fossil fuel generation can also be offset by solar photovoltaic power generation. Most parts of the country receive good solar radiation of 4 kWh/m^2 to 7 kWh/m^2 per day and almost 300 sunny days in a year making solar PV system one of the most preferred renewable energy sources in the country.

10.8.2 Solar PV power generating system consists of components and subsystems that are used to convert incident solar radiation directly into electrical energy. The energy converter (namely, solar photovoltaic cells which convert solar energy directly into d.c. electric power) does not have moving parts and has a comparatively long lifetime. Also, it can be used in decentralized/distributed mode.

10.8.3 *Rooftop Solar System*

The energy received from the sun is converted into electricity through photovoltaic cells and is called solar photovoltaic electricity. This is done by solar photo-voltaic system consisting of solar PV panels containing group of solar cells which generate d.c. power and using inverter and other equipment of appropriate capacity, the d.c. power is converted into a.c. power. The complete system comprising of inverter, cables both d.c. as well as a.c., protection system, interconnections, etc, which together is known as balance of system. Thus, solar PV system consists of solar PV panel and balance of system. The basic unit of solar panel, that is, solar cells are semiconductors made of silicon. The PV cells are made using different technologies namely monocrystalline silicon, polycrystalline silicon, thin film, etc. The choice among them is based on efficiency, cost and application among other factors. (*See* Fig. 12).

The installation of rooftop solar PV system shall be in accordance with the Regulation No. 119 and 121 of *Central Electricity Authority* (*Measures Relating to Safety and Electric Supply*) *Regulations*, 2023 (*see* Annex B).

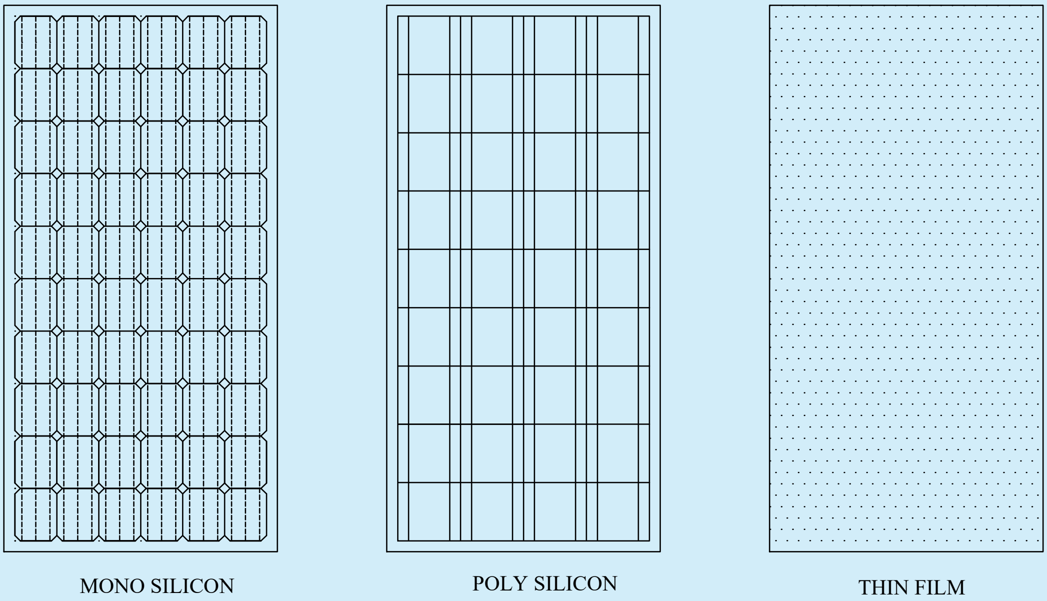


FIG. 12 MONO, POLY AND AMORPHOUS SILICON SOLAR CELL MODULE.

The solar PV systems used in buildings are of two types. Those installed on the rooftop are known as rooftop solar (RTS) system while solar PV system integrated with building facade is known as building integrated photovoltaic (BIPV) system.

10.8.3.1 *Solar PV components*

A brief description of all the major components are listed below:

Sl No. (1)	*Component* (2)	*Purpose* (3)	*Technical Requirements and Compliance Standard* (4)
i)	PV modules	To generate electricity utilizing the sunlight	Higher efficiency and lower cost meeting performance and safety standard as per accepted standards [D-2(60)] Modules to be connected in series and parallel to meet the inverter input requirement *See* accepted standard [D-2(61)].
ii)	Module mounting structure	To provide stability and rigidity to modules, to orient them towards the south direction at the appropriate latitude angle	Made of galvanized iron {*see* accepted standard [D-2(62)]} It should be capable of withstanding highest wind speed {*see* accepted standard [D-2(63)]}; and should have more than 25 years life.
iii)	d.c. and a.c. distribution boxes	To combine PV strings, to protect interconnections from corrosion, to house protective devices-fuses, surge protection devices, earth termination, breakers and isolators	GRP/FRP/powder coated aluminum enclosure. Should be weather and vermin proof, having required number of string entries and one cable exit having the required power rating and protection (IP 65) and as per relevant Indian Standard and good practice [D-2(1)]
iv)	Inverter	To convert d.c. power to a.c.	The inverter shall comply with all requirements as mandated in relevant Indian Standards, good practice [D-2(1)] and should produce grid quality power and be able to synchronize with it and having all mandated protection features of IP 54; accepted standards [D-2(64)]; and **5** of [D-2(65)] Interconnection and power quality shall be as per CEA/state regulation
v)	Cables (d.c. and a.c.)	To connect solar panels to inverter and enable safe flow of current	Copper cables with the required voltage rating and current carrying capacity shall be used for interconnection. The voltage drop should not exceed 2 percent. All d.c. cables shall be solar d.c. cable as per accepted standard [D-2(66)] and a.c. cables as per accepted standard [D-2(4)] and shall be copper conductor cable for sizes upto 50 mm^2.

Table (*Concluded*)

Sl No. (1)	*Component* (2)	*Purpose* (3)	*Technical Requirements and Compliance Standard* (4)
vi)	Earthing	To provide safe and alternate path for fault current and surge currents	Should be provided independently both on the d.c. and a.c. side of the circuit using copper/copper bonded steel down conductors {*see* good practice [D-2(11)]} and *CEA Safety Regulation*, 2023
vii)	Lightning protection system	To prevent damage caused by lightning surges	LPS should be provided as per accepted standard [D-2(52)]
viii)	Net meter	To measure net of energy exported to and imported from the grid	Installed by the DISCOM after calibration and sealing

10.8.3.2 *Solar PV systems classification*

There are mainly two types of PV systems namely grid tied system and the off-grid system.

In the grid tied system the building electrical loads are supported by both the solar power and the utility power. When solar power is insufficient to meet the load demand or is not available as during nights, power is drawn from the grid and when the generation is more, the excess is fed to the grid. A net meter is installed to measure the net of the energy drawn from and injected into the grid. The tariff for feeding excess power is typically fixed every year by the respective state regulatory commissions. A typical grid tie system is shown in Fig. 13.

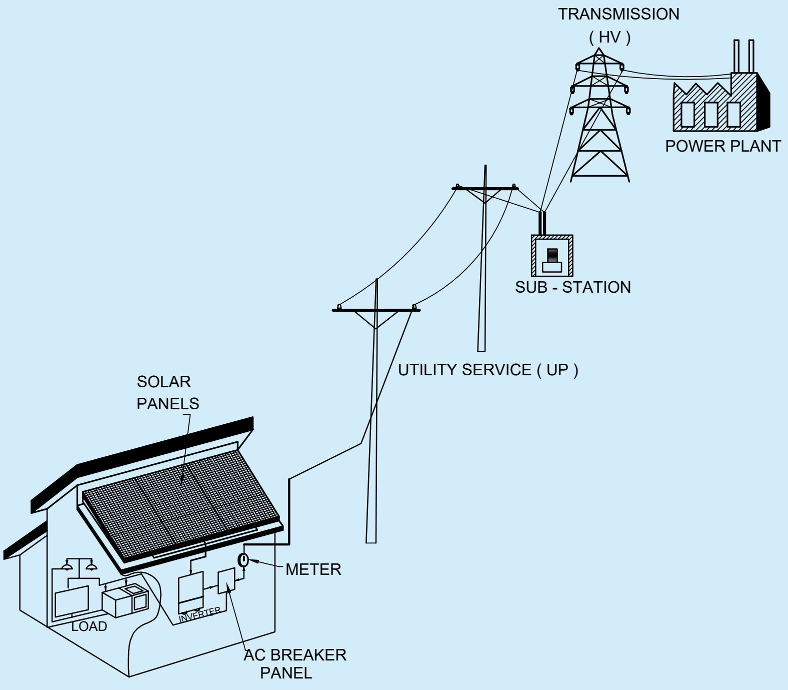


FIG. 13 GRID TIED SYSTEM

Off grid system is not connected to the grid and the loads are fully powered by solar. Since sunlight varies depending on the time of the day and the cloud levels and also since it is not available in the night, batteries are an inherent part of an off-grid system. These systems are used in places without electrical grid or by building owners desirous of being independent of grid connection (*see* Fig. 14).

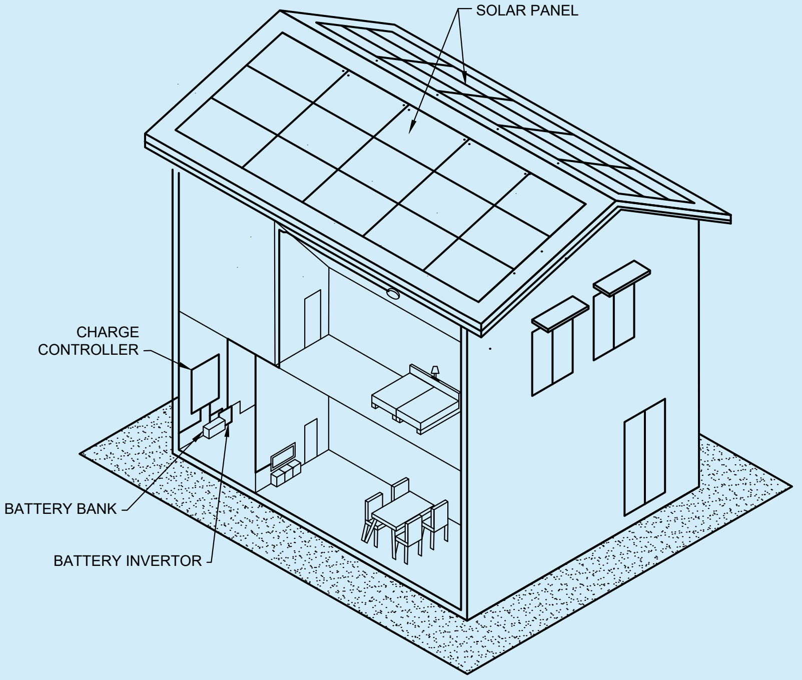


FIG. 14 AN OFF-GRID SYSTEM

10.8.3.3 *Protection system*

Since RTS is a power generating station on the topmost part of the building which is not in the view of occupants, it shall be protected against surge voltage, short circuit, lightning strike, earth fault, electrical fire, touch potential, shadow effect, etc by incorporating suitable protections into the system to avoid any mishap due to electrical fire. Special care should be taken to provide separate earth systems for d.c. power and a.c. power including interconnections and the earths will be interconnected at the earth level. The provisions for earthing and lightning protection shall be provided as per relevant Indian Standards and good practice [D-2(1)] including provision of necessary surge protection devices, where considered necessary.

10.8.3.4 *Solar PV system design*, *installation and maintenance*

Basic designing of the RTS depends upon the annual data relating to weather and solar insolation, shadow free area, generation potential, space required for other services, etc. For installation, all safety measures besides deployment of qualified personnel are required. Proper access to roof and distance between the row of solar panels is required for maintenance. System has to be maintained for guaranteed generation by regular cleaning of solar panels and inspection of the system for any abnormality from time to time.

10.8.3.5 *Regulations and standards relating to rooftop solar systems*

The system components shall comply with the relevant Indian Standards as amended up to date and work shall comply with the provisions of *Central Electricity Authority* (*Measures Related to Safety and Electric Supply*) *Regulations*, 2023 and good practice [D-2(1)]. Additionally, where mandated the use of solar d.c. cable as per accepted standard [D-2(67)] to prevent electrical fire on account of insulation failure due to exposure to UV radiations and weathering effect shall also be complied.

10.8.4 *Building Integrated Photovoltaic System* (*BIPV*)

BIPV system is an approach where conventional building components such as roofs and facades are replaced with multi-functional parts of a building envelope that integrate PV to generate electricity while still fulfilling their structural role.

BIPV refers to solar electric (photovoltaic) components that are integrated into the building envelope replacing the conventional building materials. Instead of being added on like traditional solar panels, BIPV models are designed to be part of building structure such as roofs, facades or skylights. This integration allows BIPV to serve both as a power generator and building material improving aesthetics and reducing reliance on conventional energy. Thus, there shall be regular meeting and consultation among the architects, engineers and builders to ensure seamless integration of BIPV into building design.

Building-integrated photovoltaics (BIPV) is an innovative technology that integrates seamlessly into a building envelope such as roofs, facades, windows and skylights. BIPV materials function both as conventional building elements as well as electricity producers (*see* Fig. 15).

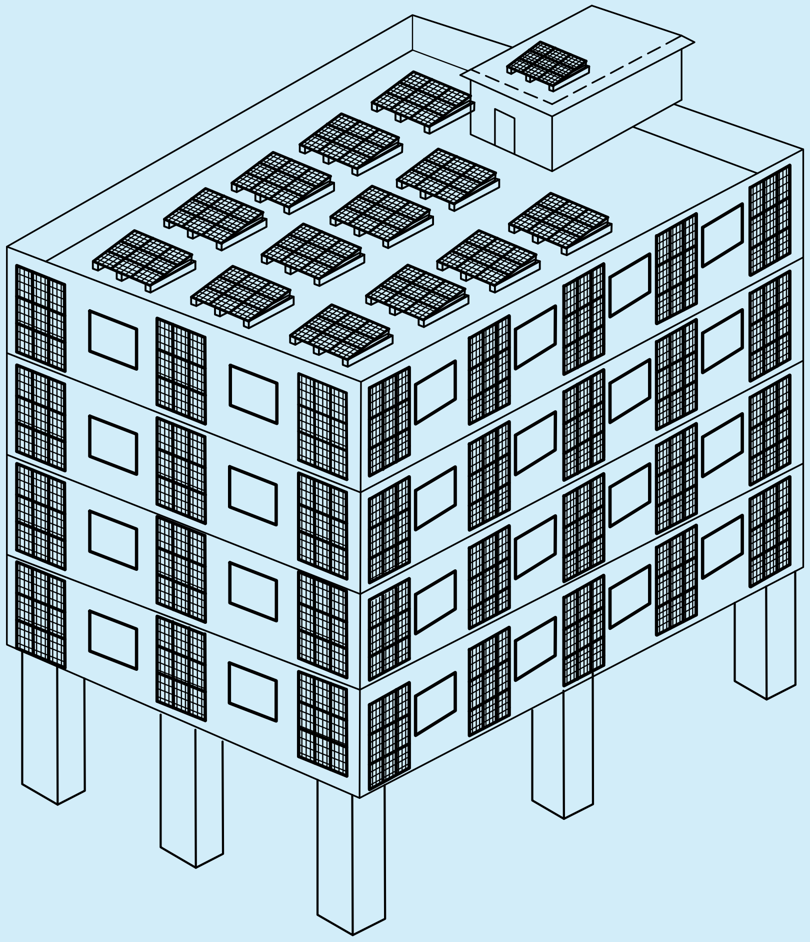


FIG. 15 BASIC STRUCTURE OF BIPV SYSTEM

10.8.4.1 *Design and planning of BIPV system*

a) *Building design integration* — Integration of BIPV technology into the building design is done, considering the factors like building orientation, shading, and structural integrity.

b) *Solar panel selection* — Solar panels are so selected to enable them to meet the structural and civil engineering requirements and are suitable for BIPV applications such as for facades, roof tiles, balustrades, window glazing/ atrium skylights.

c) *Energy generation* — The potential for energy generation is worked out based on system design optimization to achieve the maximum energy output for the components used.

10.8.4.2 *Installation and testing*

10.8.4.2.1 *Installation*

The installation of BIPV systems shall follow the manufacturer guidelines of the respective components and shall also comply with the relevant provisions of the structural requirements to ensure proper connectivity among the components. BIPV system design and installation should be optimized through BIM.

10.8.4.2.2 *Testing*

See accepted standards [D-2(67)].

a) *Performance testing* — After installation, the BIPV system shall be checked to ensure that the system generates power as envisaged in the planning stage and the energy produced shall be monitored for assessing the overall energy output and efficiency. Suitable solar power meter with data logger and performance monitoring software shall be used to monitor the performance of the BIPV system installed.

b) *Safety inspection* — Necessary earth test measurements, insulation resistance test, continuity test, measurement of voltage and current shall be measured using appropriate earth tester, insulation resistance tester and multi-meter to confirm that all connections have been made correctly and the electrical components function as planned in the planning stage.

c) *Electrical testing* — Confirm that electrical components function correctly and safely by performing insulation resistance test and continuity test and by measuring voltage and current, using a multimeter, insulation resistance tester and earth tester.

d) *Structural testing* — Necessary structural testing shall be carried out to ensure the BIPV system can withstand environmental stresses that may occur during the lifetime of the building and also withstand necessary sun, rain, wind, etc.

e) *Integration testing* — All systems of the building so installed may be integrated using integration software load testers and communication testing tools so that the complete building acts as a single envelope.

f) *Weatherproofing and sealing* — Necessary leakage deduction and sealant inspection shall be carried out as per weather proofing guidelines so that BIPV system is weatherproof and does not cause any leakage or damage to the building or to the structure as a whole.

10.8.4.3 *Safety and maintenance*

a) *Electrical safety* — Electrical safety shall be ensured by following relevant good practices and accepted standards.

b) *Fire safety* — Fire safety shall be ensured by using fire-resistant materials and following the good practices.

c) *Maintenance* — The BIPV system shall be inspected at least once in a month to ensure optimal performance and timely maintenance including replacement of damaged components if any without any delay.

10.9 Solar Water Heating System

10.9.1 *General*

This system is provided on the buildings to harness the energy of sun for heating water for kitchen and bathroom. Small systems from 100 litres to 300 litres are suitable for residential use while beyond this capacity are used for canteens, guest houses, hotels and hospitals. Located on top of building, the water is heated to 60 °C to 80 °C. However, in cloudy weather, back up electrical heater is sometimes required. Since it is provided on top of the building, it is necessary to provide equipotential bonding with the down conductor of LPS system as per relevant regulation and standards.

10.9.2 *Working*

When the sun's rays fall on the collector panel, which is a component of solar water heating system, a black absorbing surface (absorber) inside the collector absorbs solar radiation and transfers the heat energy to water flowing through it. Heated water is collected in a tank which is insulated to prevent heat loss. Circulation of water from the tank through the collectors and back to the tank continues automatically due to thermo-siphon system (*see* Fig. 16).

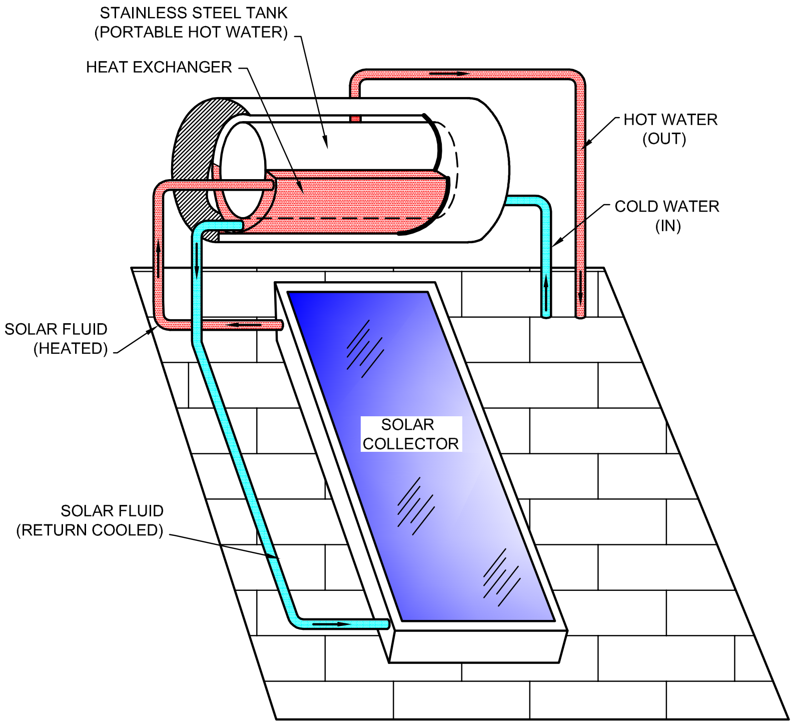
Solar water heating system are broadly categorized as active systems having pumps and controls, and passive systems relying on natural convection. Further, based on the collector system, solar water heaters can be of two types, namely flat plate collector type and evacuated tube collector type. In the first type, solar radiation is absorbed by flat plate collectors which consist of an insulated outer metallic box covered on the top with glass sheet. A black absorbing surface (absorber) inside the flat plate collectors absorbs solar radiation and transfers the energy to water flowing through it.

In the second type, the collector is made of double layer borosilicate glass tubes evacuated for providing insulation. The outer wall of the inner tube is coated with selective absorbing material. This helps absorption of solar radiation and transfers the heat to the water which flows through the inner tube.

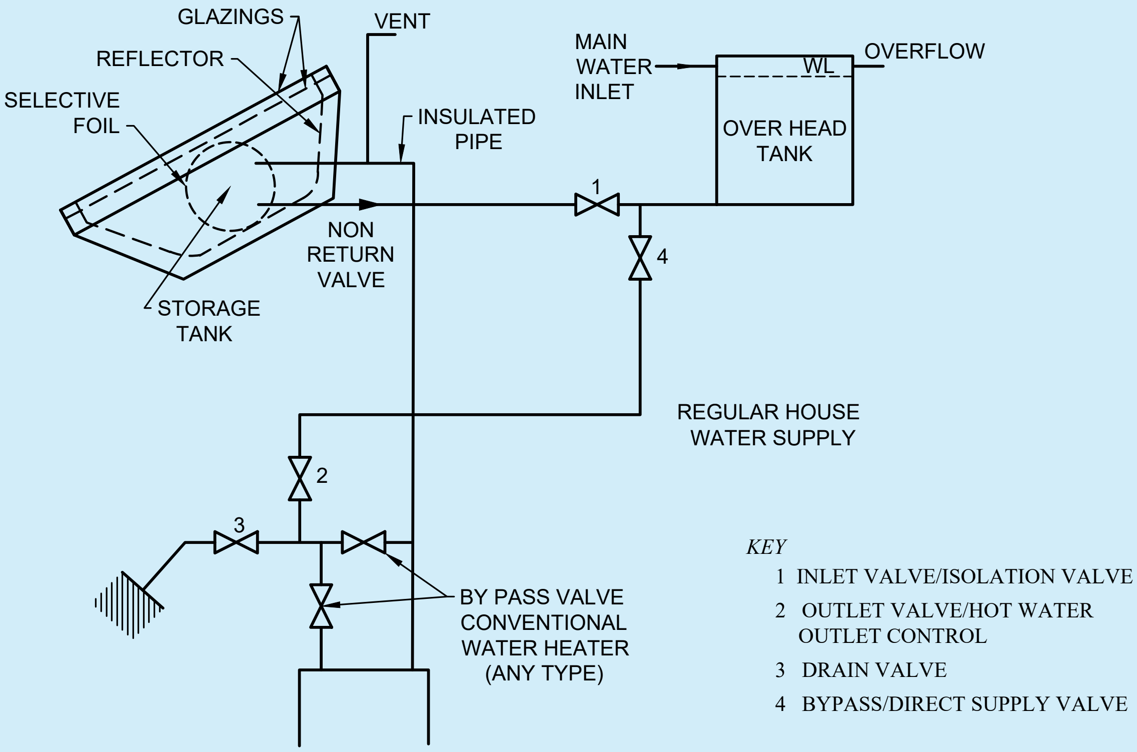
10.9.3 *Compliance with Regulations and Standards*

As mandated by the government solar collectors shall adhere to the accepted standard [D-2(68)]. Further, municipal corporation/local bodies may require solar water heating systems to be installed in new buildings in their territories including in renovated buildings.

Accepted standard [D-2(69)] caters to the requirements and components of flat plate collector type solar water heating system while accepted standard [D-2(70)] caters to glass evacuated tubes solar water heating system. Accepted standard [D-2(71)] caters to storage water tank for all glass evacuated tubes solar water heating systems.


STAINLESS STEEL TANK
(PORTABLE HOT WATER)
HEAT EXCHANGER
HOT WATER
(OUT)
COLD WATER
(IN)
SOLAR FLUID
(HEATED)
SOLAR
COLLECTOR
SOLAR FLUID
(RETURN COOLED)

16A SOLAR COLLECTOR BASED WATER HEATER


GLAZINGS
VENT
REFLECTOR
SELECTIVE
FOIL
INSULATED
PIPE
MAIN
WATER
INLET
OVERFLOW
WL
OVER HEAD
TANK
1
4
NON
RETURN
VALVE
STORAGE
TANK
REGULAR HOUSE
WATER SUPPLY
2
3
BY PASS VALVE
CONVENTIONAL
WATER HEATER
(ANY TYPE)

KEY

1 INLET VALVE/ISOLATION VALVE
2 OUTLET VALVE/HOT WATER OUTLET CONTROL
3 DRAIN VALVE
4 BYPASS/DIRECT SUPPLY VALVE

16B SCHEMATIC OF CONNECTION BETWEEN SOLAR BASED WATER HEATER OVERHEAD TANK BOTH CONNECTED TO THE CONVENTIONAL WATER HEATER

FIG. 16 WORKING OF SOLAR WATER HEATING SYSTEM

10.10 Aviation Obstacle Lights

High-rise buildings and structures such as chimneys and towers are potential hazards to aircraft. The provision of aviation obstacle lights (AOL) on tall buildings/structures is intended to reduce hazards to aircraft by indicating their presence. AOLs, low, medium or high intensity obstacle lights, or a combination of such lights, shall be provided on buildings of different heights as per the requirements of Annex 14 to the 'Convention on International Civil Aviation, Volume I Aerodrome Design and Operations', International Civil Aviation Organization (ICAO). A general arrangement of AOLs in case of group of buildings is given in Fig. 17.

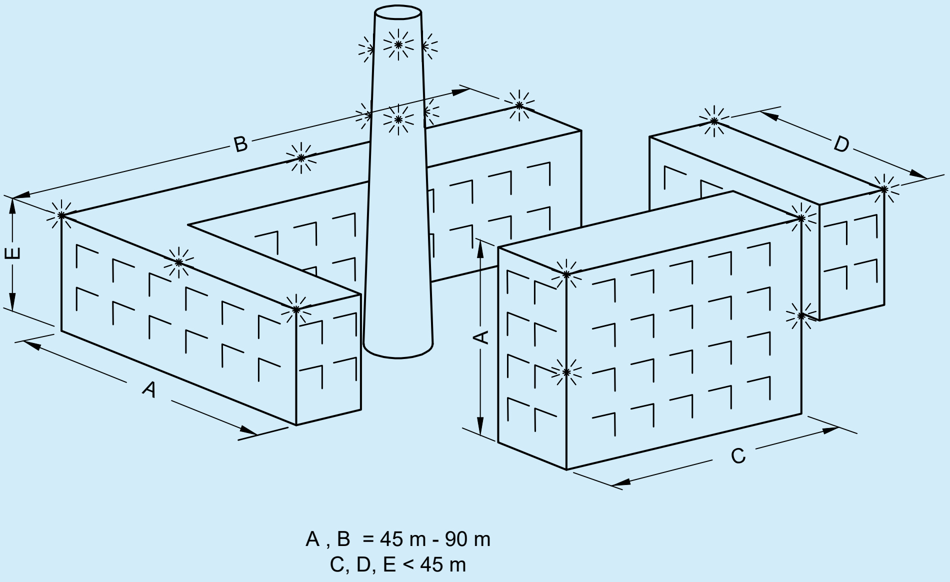


FIG. 17 TYPICAL ARRANGEMENT OF AVIATION OBSTACLE LIGHTS IN CASE OF GROUP OF BUILDINGS

10.11 Power/Electric Fence

10.11.1 *General*

Power/electric fence is provided in highly secured buildings to deter the intruders from climbing or sending a very low flying object, after proper risk assessment. It is provided on the boundary wall of the building and plays an important part in perimeter security by integrating with video surveillance software. This can also be used to protect the farms from the wild animals.

10.11.2 *Working*

This is a non-lethal fence consisting of wires carrying pulses of electric current and consists of an energizer producing regular current pulses. The supply lines conduct the pulses to the fence and takes back to the device from the earth stake. Wires should be good conductors and tied to the L-shaped posts securely over an insulator which separates the fence wire from the post and ensures that pulse current is not diverted to the ground. Height of the fence above the wall should be 1.5 m and spacing between wires shall be 100 mm. The distance between posts shall not be greater than 3 m and fence should be able to withstand the winds of 120 kmph when installed on boundary wall. A living object touching both wire and earth during pulse will get a shock and thus deter from entering the perimeter. The impact of shock depends upon the voltage, energy of the pulse, area of contact between the recipients, fence and ground, and the route of the current through the body. The intensity of shock can range from barely noticeable to uncomfortable or painful. It can also be solar powered. (*See* Fig. 18)

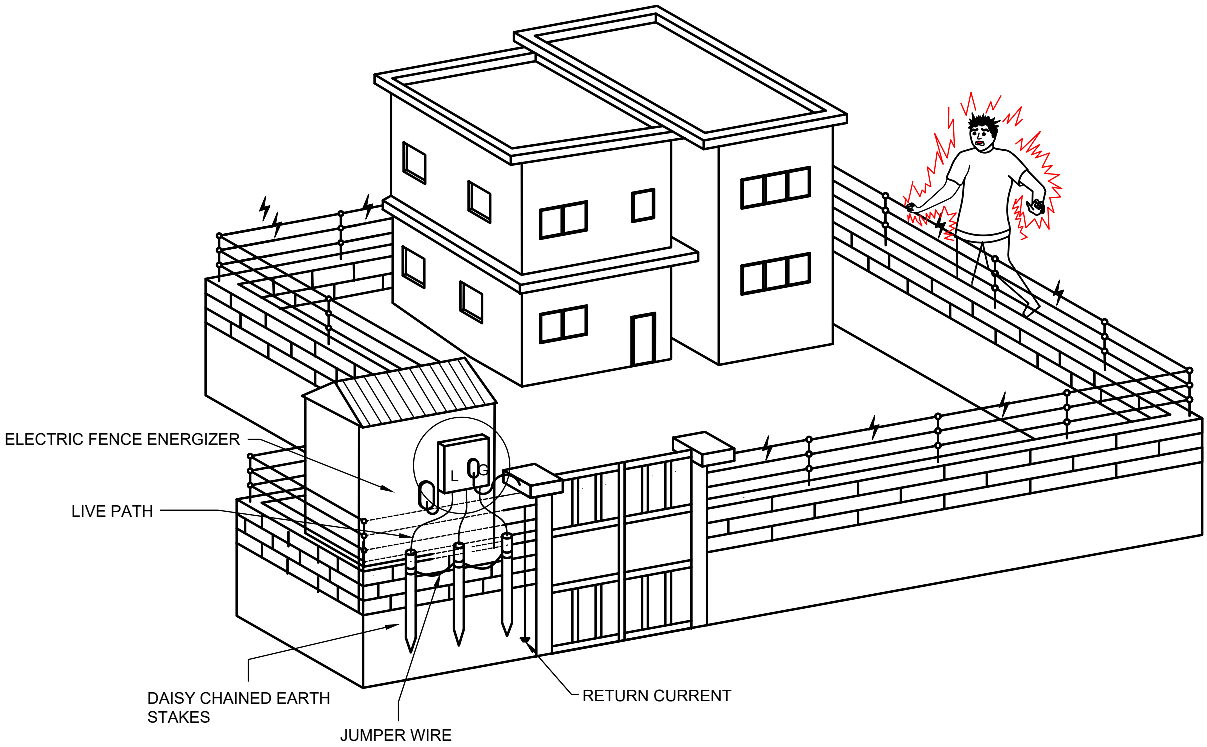


FIG. 18 POWER/ELECTRIC FENCE

10.11.3 *Compliance with Regulations and Standards*

It shall comply with specific safety and local regulatory standards. *See* accepted standard [D-2(72)] for safety and performance requirements. Prominent warning signs to alert people to the presence of the electric fence should also be displayed at regular intervals.

11 LIGHTNING PROTECTION OF BUILDINGS

11.1 General

Lightning flashes to, or nearby, structures (or lines connected to the structures) are hazardous to people, to the structures themselves, and to their contents and installations. Flashes of lightning discharges are of very high energy and can have devastating effects depending on the path of its discharge. Lightning strike is not predictable and is a random phenomenon both from the aspect of its occurrence and intensity or the energy discharge. There are no devices or methods capable of modifying the natural weather phenomena to the extent that they can prevent lightning discharges. Lightning protection measures therefore become essential. Lightning protection system (LPS) is the method of diversion of the lightning charges to the periphery of the building and to the ground so that the building, its occupants and sensitive equipment housed in the building, including connections from public systems to the building, are protected from the effects of lightning. The works carried out under this shall confirm to the relevant Indian Standards and the provisions of good practice [D-2(1)]. Brief details of the system are given hereunder.

NOTE — Reference is made to IEC 62305 (all parts) : 2024 instead of IS/IEC 62305 : 2010/11 since IEC 62305 : 2010/11 has been revised and is likely to be adopted by Bureau of Indian Standards shortly.

11.2 Steps for Deciding on Lightning Protection System

Lightning protection systems (LPS) are installed to avoid accidents, severe injuries and loss of life/deaths of humans and animals due to direct or indirect effects of lightning.

The following steps are to be followed to ensure protection from lightning in a building:

a) In order to utilize the building components such as reinforced cement concrete (RCC) columns and RCC foundation for embedded down conductor and earth termination system, the lightning protection system shall be considered and designed before starting the construction of the building;

b) Assess the need and level for lightning protection system based on risk and frequency of damage assessment as per IEC 62305-2 : 2024 'Protection against lightning — Part 2: Risk management' and the level of protection shall be identified along with coordinated SPDs to be connected to the power system and the telecommunication system;

c) Decide on the type of external LPS including usage of building components, corrosion problems, sizing of conductors and routing of conductors;

d) Calculate the separation distances, if isolated or electrically insulated LPS is used and find out the possibility of maintaining separation distance. Note that for high rise buildings, maintaining separation distance may not be practically possible. In such cases, alternate methods recommended in IEC 62305-3 : 2024 'Protection against lightning — Part 3: Physical damage to structures and life hazard' should be used. Equipotential bonding with the attached LPS shall be done at multiple levels and for exposed and extraneous metallic parts of the building;

e) Down conductors shall be placed to surround the building structure as uniformly as possible. Down conductors shall be installed vertically to provide the shortest and most direct path to the earth, and bends and joints should be avoided;

f) Decide on the type of earth termination system and the provisions for equipotential bonding at ground level. Type A earth termination (vertical or horizontal earth electrodes) is not efficient for large buildings. Lightning protection system without equipotential bonding (at ground level) to electrical installation is a safety hazard and shall be avoided;

g) In buildings where sensitive and large electronic systems are present such as datacentres, hospitals, telecommunication centres, etc, appropriate shielding measures shall be provided to mitigate the effects of electromagnetic disturbances; and

h) Measures to reduce touch and step potential outside the building, shall be adopted to ensure safety of the people.

While designing and execution of LPS, the following points shall be observed and implemented to prevent any unforeseen accidents due to lightning:

a) Where architectural or structural constraints exist, multiple down conductors shall not be routed collectively through vertical shafts or internal facades. In all such cases, appropriate separation distance between the conductors, continuous metallic bonding with accessibility for inspection and testing when required shall be ensured.

b) Equipotential bonding with the MET of the electrical installation and termination of SPDs shall be done.

c) Routing down conductors near metal installations such as facades, pipes, etc, without equipotential bonding should not be done.

11.3 Classification of Lightning Protection System

Class of LPS denotes the classification of an LPS according to the lightning protection level for which it is designed. Four classes of LPS I, II, III and IV are defined, based on the corresponding LPL I, II, III and IV. Each class of LPS is characterized by the rolling sphere radius, mesh size, protection angle, typical distance between down conductors, separation distance against dangerous sparking and minimum length of earth electrodes (IEC 62305-3 : 2024 'Protection against lightning — Part 3: Physical damage to structures and life hazard'). Acceptable method to determine the position of air termination system includes the protection angle method, rolling sphere method and the mesh method. The rolling sphere method is suitable for all classes. The protection angle method is suitable for simple shaped buildings but is subject to limits indicated in Table 3. The mesh method is suitable for plane surface protection.

11.4 Planning and Designing of Lightning Protection System

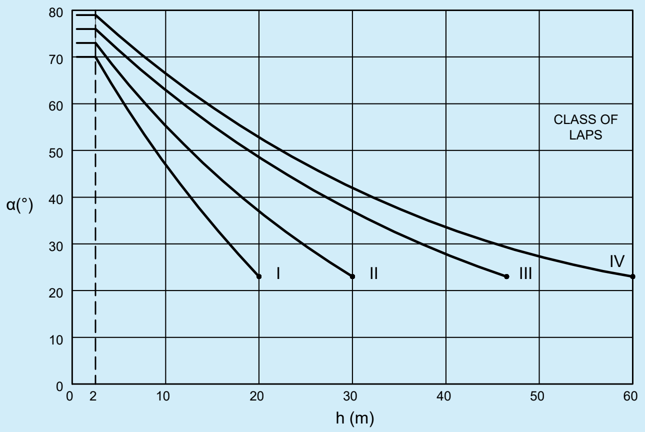
The lightning protection system (LPS) should be designed and installed by LPS designers or engineers experienced in LPS design. Planning, implementation and testing of an LPS encompasses a number of technical fields and demands for coordination by all parties involved with the construction and maintenance of the structure to ensure an efficient LPS.

It is essential to carry out the risk and frequency of damage assessment for a building based on IEC 62305-2 : 2024 'Protection against lightning — Part 2: Risk management' to decide the type of protection needed for lightning protection level and the level of coordinated SPDs required to be connected to the power line and telecommunication line. The lightning protection is divided into four levels (LPL I to IV) which helps in designing and implementing protection measures for an economical implementation. LPL I provides the maximum protection, whereas, LPL IV provides the least protection. Table 3 gives the values for different type of LPS.

Table 3 Maximum Values of Rolling Sphere Radius, Mesh Size and Protection Angle Corresponding to the Class of LPS

(*Clauses* 11.3, 11.4 *and* 11.6.1.7)

Sl No.	**Class of LPS**	**Protection Method**		
		Rolling Sphere Radius, *r* m	Mesh Size, W_m m	Protection Angle, α
(1)	(2)	(3)	(4)	(5)
i)	I	20	5 × 5	*See* Fig. 19 below
ii)	II	30	10 × 10	
iii)	III	45	15 × 15	
iv)	IV	60	20 × 20	



NOTES

1 NOT APPLICABLE BEYOND THE VALUES MARKED WITH • ONLY ROLLING SPHERE AND MESH METHODS APPLY IN THESE CASES.

2 h IS THE HEIGHT OF AIR-TERMINATION ABOVE THE REFERENCE PLANE OF THE AREA TO BE PROTECTED.

3 THE ANGLE WILL NOT CHANGE FOR VALUES OF h BELOW 2 m.

FIG. 19 PROTECTION ANGLE CORRESPONDING TO THE CLASS OF LPS

Complete system for protection of structures against lightning, including their internal systems and contents, be installed to avoid damages to structures, accidents, severe injuries to humans due to direct or indirect lightning. Both protection measures should complement each other.

The management of the LPS should be efficient if the steps given in **11.2** are followed. Quality assurance measures are of great importance, in particular, for structures including extensive electrical and electronic installations. *See* accepted standards [D-2(73)] and [D-2(74)].

During the planning, various parties involved shall deliberate and agree on the following points which influence lightning protection system:

a) Decide whether or not the structure needs protection and if so, the special requirements have to be decided by making necessary calculations {*see* accepted standards [D-2(75)]};

b) Special attention shall be provided by architects and civil engineers on routing of down conductors, separation distance, usage of natural components and foundation earthing (*see also* Note);

c) Electrical separation and equipotential bonding shall be carefully analysed. Equipotential bonding of electrical services by SPD is also mandatory to complete lightning protection;

d) Ensure a close liaison between the architect/engineer, the builder, the lightning protection system engineer and the appropriate authorities throughout the design stages (*see* Note); and

e) Agree the procedures and define the period for testing and future maintenance {*see* accepted standard [D-2(76)]}.

NOTE — Modern buildings with electronic equipment need protection from radiated surges of lightning. To achieve this, structural steel of the building is also used as a part of lightning protection system {*see* accepted standard [D-2(73)]}. In such cases, lightning protection measures shall be included in the structural steel, particularly in column foundation.

11.5 Use of Building Components in Lightning Protection System

Conductive components installed not specifically for lightning protection system which can be used in addition to LPS or in some cases could provide the functions of one or more parts of LPS like natural air termination, natural down conductor, natural earth electrode are known as natural components of LPS {*see* accepted standard [D-2(76)]}.

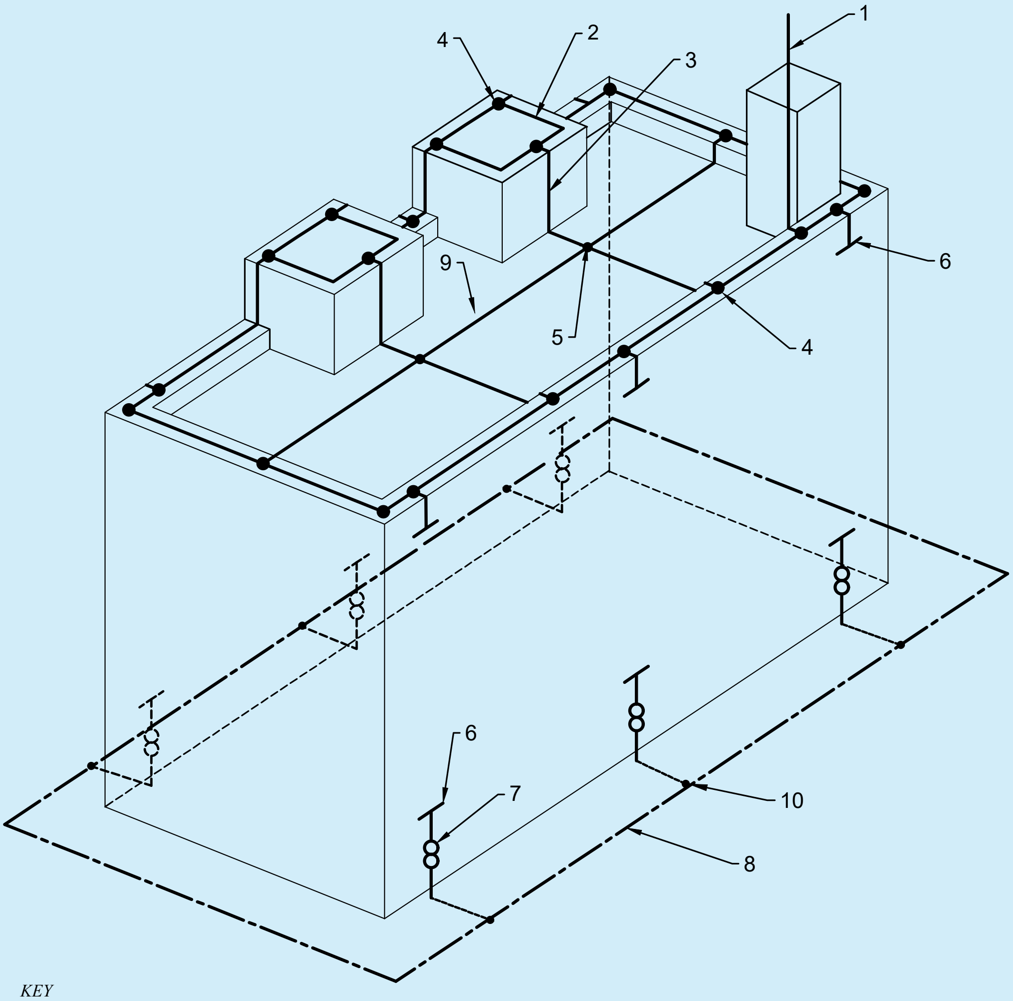
Steel work within RCC structure is considered to be electrically continuous provided that major interconnections of vertical and horizontal bars are welded or otherwise securely connected. For new structures the connections between the RCC elements in the columns of the building shall be easily achieved by the designer in cooperation with the builder and the civil engineer by providing one additional smoothly finished copper/copper coated steel/stainless steel conductor/rod of diameter as indicated in Table 8. From foundation to the terrace continuously welded with suitable clamping/welding to all intervening horizontal bars (in case if single welded rod is not possible then necessary lapping between two rods shall be made as per IEC 62305-3 : 2024 ‘Protection against lightning — Part 3: Physical damage to structures and life hazard’). Thus, all external columns can act as down conductors for LPS and there will be no need for provision of separate external down conductors especially in architectural facia and glazed facia of the buildings. The overall electrical resistance of the reinforcement provided should not be greater than 0.2 Ω using test equipment suitable for this purpose. Suitable test joints shall be brought out from the structure at/near ground level for test purposes.

Interconnected reinforcement steel in concrete foundation buried directly in ground can be used as earth electrode. Special care shall be taken at the termination to prevent mechanical splitting of the concrete. Normally, a concrete raft foundation or pile foundation with pile caps of a building, provides reinforcement rods of not less than 25 mm having interconnected reinforcement steel duly clamped/welded, will provide a proper earth electrode and in closed loop formation. This will give a very good earth resistance for the down conductors and the overall value shall be measured to be less than earth resistance achieved normally.

The additional reinforcement provided for LPS shall be connected through welding to the foundation reinforcement and also with the roof conductors connecting the air termination through welding and suitably epoxy painted to prevent rusting. Thus, the LPS for the building shall become homogeneous after provision of air termination at the roof level based on rolling sphere/mesh system by interconnecting the top of the reinforcement from the columns with the terrace conductors (*see* Fig. 20).

Use of building components namely the cement concrete foundation and the columns, reduces not only the work of providing down conductors and earthing sets for the LPS and the cost thereof but also saves the difficulties of placing down conductors of LPS in respect of architectural facia of modern buildings. Also, test joints are not required for these cases {*see* **5.3.6** of accepted standard [D-2(73)]}.

NOTE — When incorporating a structure's natural components, such as rebar within the concrete foundation, specialized mechanical couplers or clamps {*see* accepted standard [D-2(77)]} may be specified during design to create secure equipotential bonding as per IEC 62305-3 : 2024 'Protection against lightning — Part 3: Physical damage to structures and life hazard'.



KEY

1	AIR TERMINATION ROD
2	HORIZONTAL AIR TERMINATION CONDUCTOR
3	DOWN CONDUCTOR
4	T - TYPE JOINT
5	CROSS TYPE JOINT
6	CONNECTION TO STEEL REINFORCING RODS {*see* **E-4.3.3** AND **E-4.3.6** OF GOOD PRACTICE [D-2(73)]}
7	TEST JOINT
8	EARTH ELECTRODE TYPE B EARTHING ARRANGEMENT, RING EARTH ELECTRODE
9	FLAT ROOF WITH ROOF FIXTURES
10	T - TYPE JOINT - CORROSION RESISTANT

NOTE — THE STEEL REINFORCEMENT OF THE STRUCTURE SHOULD COMPLY WITH AVAILABLE INDIAN STANDARDS. ALL DIMENSIONS OF THE LPS SHOULD COMPLY WITH THE SELECTED PROTECTION LEVEL.

FIG. 20 CONSTRUCTION OF EXTERNAL LPS ON A STRUCTURE OF STEEL-REINFORCED CONCRETE USING THE REINFORCEMENT OF THE OUTER WALLS AS NATURAL COMPONENTS

11.6 Components of Lightning Protection System (LPS)

The main and most effective measure for protection of structures against physical damage is considered to be the lightning protection system (LPS). It usually consists of both external and internal lightning protection systems.

An external LPS which consists of air-termination system, down-conductor system and earthing system {*see* accepted standard [D-2(73)]} is intended to:

a) intercept a lightning flash to the structure (with an air-termination system);

b) conduct the lightning current safely towards earth (using a down-conductor system); and

c) disperse the lightning current into the earth (using an earth-termination system).

An internal LPS comprises equipotential bonding or a separation distance (and hence electrical insulation) between the external LPS components and other electrically conducting elements internal to the structure.

Both external and internal protection systems should complement each other.

Access to the ground and the proper use of foundation steelwork for the purpose of forming an effective earth-termination may well be impossible once construction work on a site has commenced. Therefore, soil resistivity and the nature of the earth electrode should be considered at the earliest possible preferably during the design stage of a project. This information is fundamental to the design of an earth-termination system and may influence the foundation design work for the structure.

Regular consultation between LPS designers and installers, architects/civil engineer and builders is essential in order to achieve the best result at minimum cost. If lightning protection is to be added to an existing structure, every effort should be made to ensure that it conforms to the principles of this NBCS. The design of the type and location of an LPS should take into account the features of the existing structure.

11.6.1 *Air-Termination System*

Air-termination system is a part of an external LPS using metallic elements such as rods, mesh conductors or catenary wires intended to intercept lightning flashes. The probability of penetration by a lightning current on a structure is considerably decreased by the presence of a properly designed air-termination system. Air-termination systems can be composed of any combination of the following elements:

a) vertical rods (offers certain angle of protection);

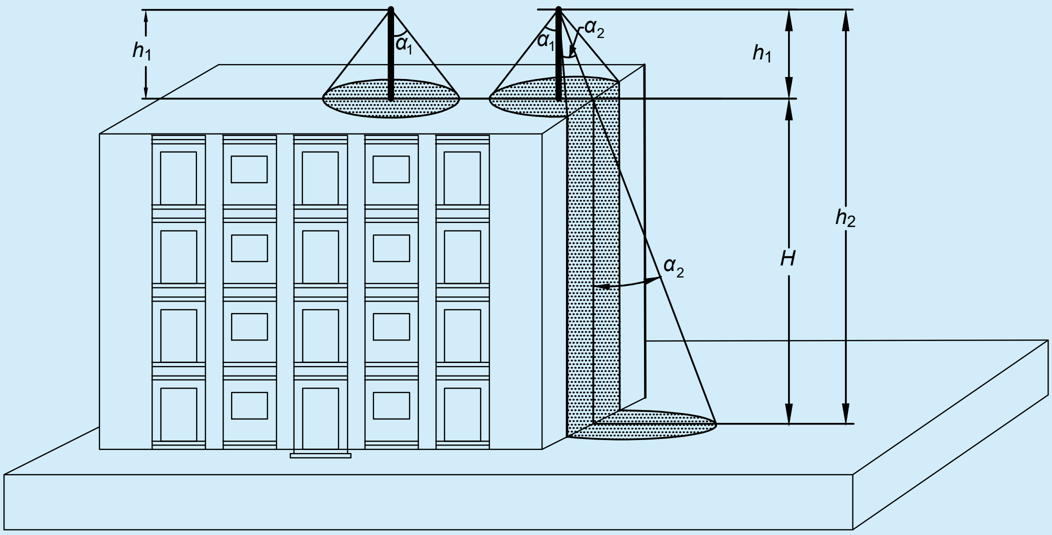
b) catenary wires; and

c) meshed/grid conductors.

Franklin rod (conventional) type of air-termination system shall be positioned in accordance with **11.6.1.1**. The individual air-terminations rods should be connected together at roof level to ensure current division. Radioactive air-terminals shall not be allowed. Any other kind of air-terminal like dissipation system/ESE air-terminal/CSE air-terminal or any other air terminal not approved by IEC 62305-3 : 2024 'Protection against lightning — Part 3: Physical damage to structures and life hazard' shall not be acceptable.

11.6.1.1 *Positioning*

Air-termination components installed on a structure shall be located at corners, exposed points and edges (especially on the upper level of any facades) in accordance with one or more of the following methods {*see also* Fig. 21 to Fig. 25 in conjunction with good practice [D-2(11)]}:



KEY

H HEIGHT OF BUILDING OVER THE GROUND REFERENCE PLANE

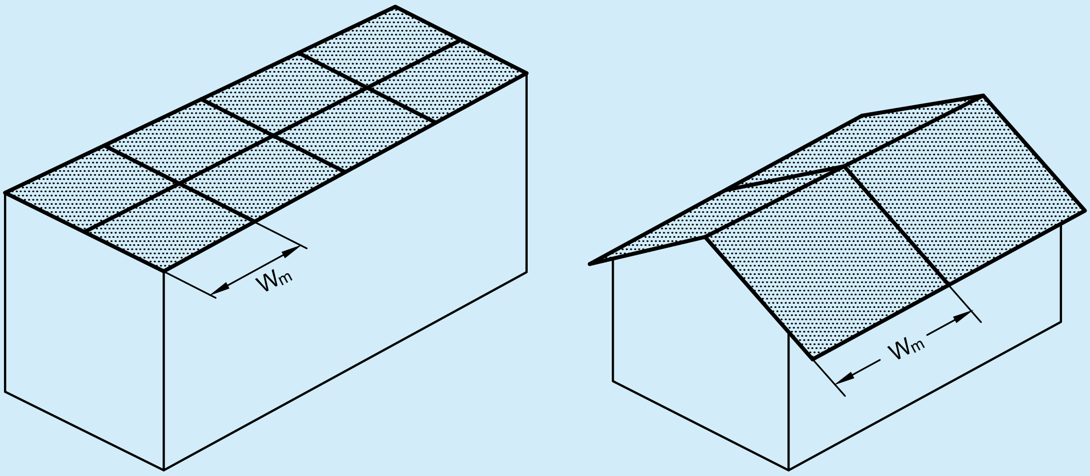
h_1 PHYSICAL HEIGHT OF AN AIR TERMINAL ROD

h_2 HEIGHT OF THE AIR TERMINATION ROD OVER THE GROUND = $h_1 + H$

α_1 THE PROTECTION ANGLE CORRESPONDING TO THE AIR TERMINATION HEIGHT, $h = h_1$, BEING THE HEIGHT ABOVE THE ROOF SURFACE TO BE MEASURED (REFERENCE PLANE)

α_2 THE PROTECTION ANGLE CORRESPONDING TO THE HEIGHT, $h_2 = H + h_1$

FIG. 21 PROTECTION ANGLE METHOD OF AIR TERMINATION DESIGN FOR DIFFERENT HEIGHTS



W_m – MESH SIZE

FIG. 22 DESIGN OF AIR-TERMINATION SYSTEM ACCORDING TO MESH METHOD

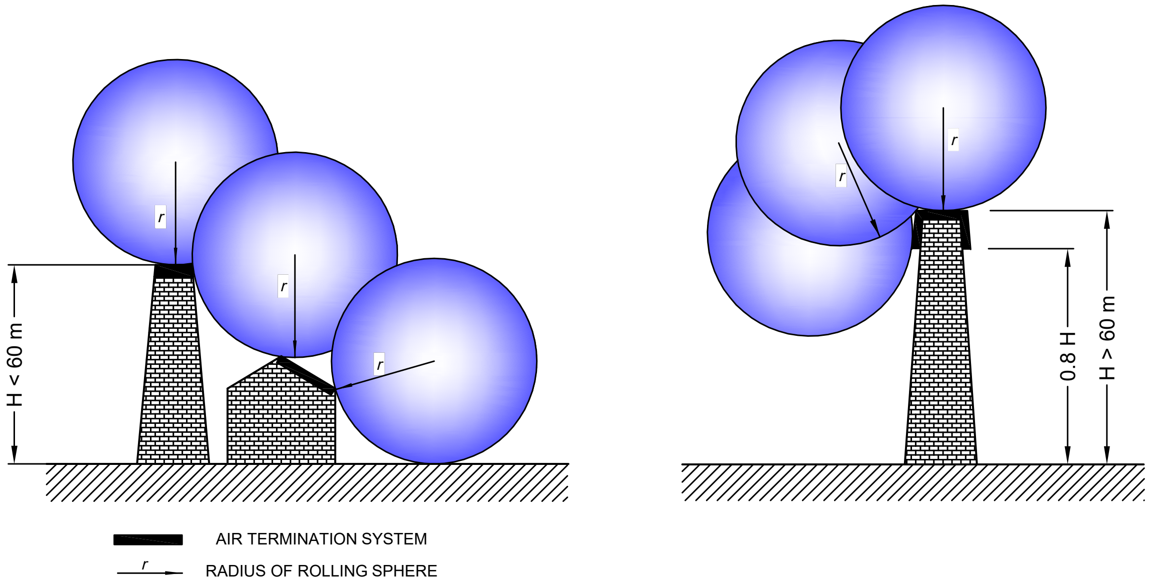
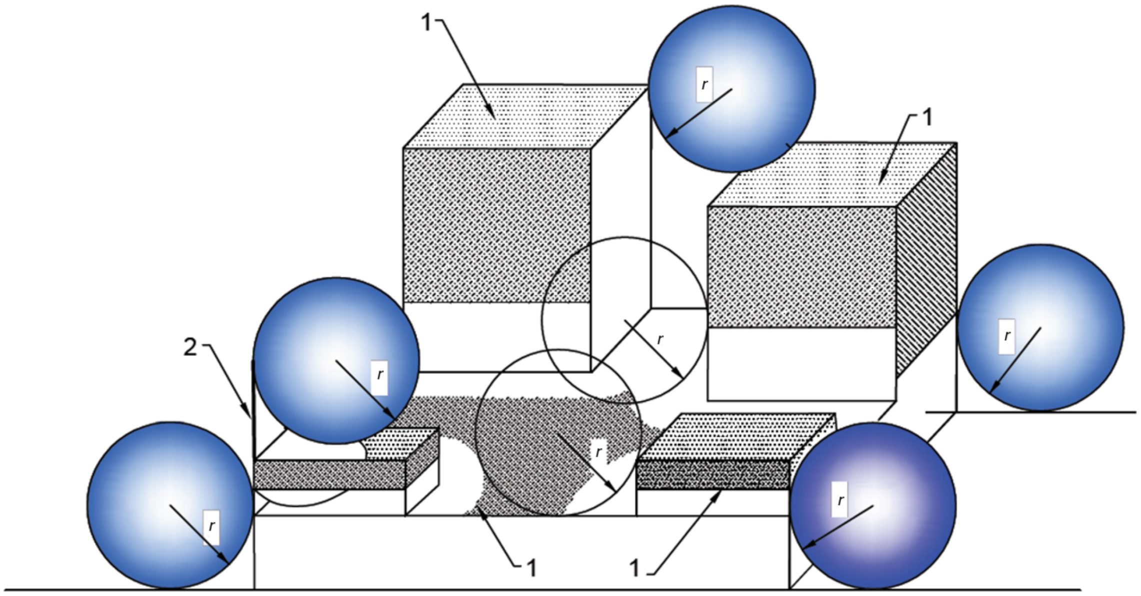

r
r
r
r
r
H < 60 m
0.8 H
H > 60 m
AIR TERMINATION SYSTEM
r
RADIUS OF ROLLING SPHERE

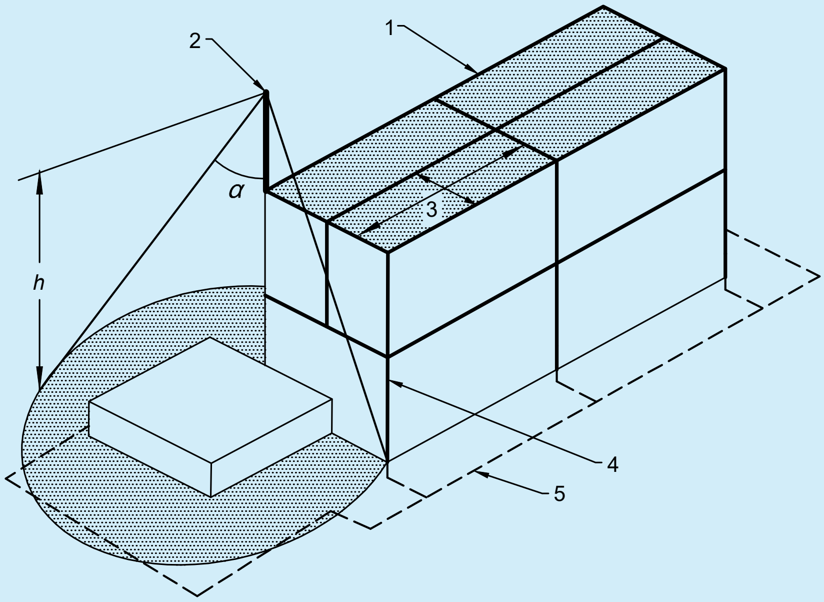
Fig. 23 Design of Air-Termination System According to the Rolling Sphere Method


1
r
1
2
r
r
r
r
r
r
r
1
1

Key

1 Shaded areas are exposed to lightning interception and need protection
2 Mast on the structure
r Radius of rolling sphere

Fig. 24 Design of Air-Termination Conductor Network for a Structure with Complicated Shape



KEY

1 AIR - TERMINATION CONDUCTOR (ALSO CALLED AS MESH/FARADAY CAGE)
2 AIR - TERMINATION ROD
3 MESH SIZE
4 DOWN CONDUCTOR
5 EARTHING SYSTEM WITH RING CONDUCTOR
h HEIGHT OF THE AIR TERMINAL ABOVE GROUND LEVEL
α PROTECTION ANGLE

FIG. 25 DESIGN OF AN LPS AIR-TERMINATION ACCORDING TO THE PROTECTION ANGLE METHOD, MESH METHOD AND GENERAL ARRANGEMENT OF AIR-TERMINATION ELEMENTS

11.6.1.2 Roof mounted electrical/electronic equipment (for example, chillers, antennas, cameras and bill boards) need vertical air-termination to avoid direct strike. Power and data connection to these equipment should have proper SPDs (*see* 11.7.4) to avoid failures. Overhead cables such as cable TV lines from one building to the other should be avoided.

11.6.1.3 Unearthed metallic roofs should be avoided. Metallic roofs shall be connected either to steel reinforcement or to other earthed steel parts of the building satisfying the requirements of number of down-conductors (*see* 11.6.2).

11.6.1.4 *Structures of height less than* 60 m *and more than* 60 m

Lateral impacts of flashes to the side of tall structures are considered as negligible for structures up to 60 m in height measured from ground level. However, elements significantly protruding the facade can be endangered (for example, balconies, cameras, antennas).

On structures taller than 60 m, flashes to the side can occur, especially to protruding parts and to corners and edges of facades.

All external metal parts that have a conductive connection with internal metal parts separated by a distance $d > s$ from a down conductor (or air terminations) should not be connected to the down conductor so as to keep any unnecessary partial lightning currents out of the structure.

If this is not possible, the metal part should be directly bonded to the LPS. The possibility of the occurrence of partial lightning current into the structure should be considered.

NOTE — In general, the risk due to these flashes is low because only a few per cent of all flashes to tall structures will be to the side and their parameters are significantly lower than those of flashes to the top of structures. However, electrical and electronic equipment on walls outside structures can be destroyed even by lightning flashes with low current peak values.

An air-termination system shall be installed to protect significant protrusions (such as balconies, viewing platforms) on vertical surfaces on the upper part of tall structures (that is, typically the topmost 20 percent of the height of the structure), as well as the equipment installed on them (*see* Annex D of IEC 62305-3 : 2024 'Protection against lightning — Part 3: Physical damage to structures and life hazard'). For parts of the upper 20 percent that do not exceed 60 m above ground level, protection of the vertical surface is optional.

NOTE — Elements protruding through the facade of structures up to 60 m in height are rarely endangered.

11.6.1.5 *Roof top solar PV and water heaters on Buildings*

Vertical air-terminals are required for protecting roof mounted installations such as solar PV, water heaters, chillers as well as water tanks. Vertical air-terminals need to be connected to the air-termination mesh/down-conductors. Metal support structure of these installations shall be bonded to the air-termination mesh/down-conductors. Class I/Class II surge protection devices (SPDs) (*see* **11.7.4**) should be installed in the electrical lines to protect the installations inside the building (typically d.c. SPD for solar PV output at inverter or junction box level and a.c. SPD for inverter output and mains input). The roof top PV system or 230 V a.c. water heaters or any other equipment should not pose any safety risk related to lightning protection and protection of overall building may be reviewed by the expert after installation of roof top PV system. Necessary measures may then be required to complete the lightning protection arrangement.

Vertical air-terminals for PV modules based on LPL III/IV connected directly to the frame shall protect against direct lightning impact in solar PV power plant. A design according to rolling sphere method should be done for zone of protection (for example, 1 m rod at 0.5 m height from panel at four corners provides protection to approximately 12 m × 9 m area). Maximum height of the air-termination rod above the panel should be calculated considering the falling of shadow or umbra region of shadow not falling on any PV module. To reduce step potential, structures should be interconnected with underground earth mats/isolating spark gaps, wherever necessary (*see* Fig. 26 and Fig. 27).

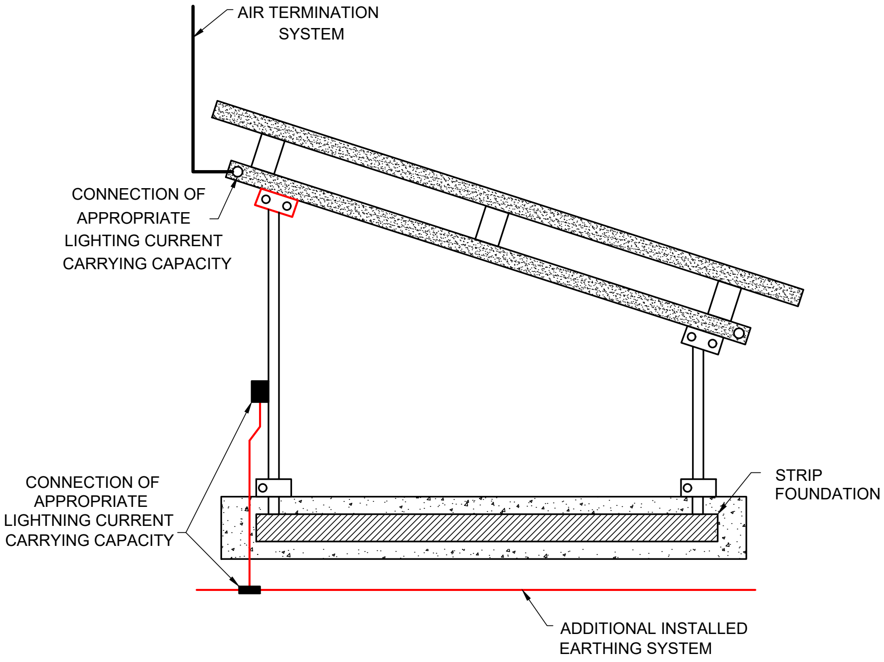

AIR TERMINATION SYSTEM
CONNECTION OF APPROPRIATE LIGHTING CURRENT CARRYING CAPACITY
CONNECTION OF APPROPRIATE LIGHTNING CURRENT CARRYING CAPACITY
STRIP FOUNDATION
ADDITIONAL INSTALLED EARTHING SYSTEM

FIG. 26 TYPICAL INSTALLATION OF LIGHTNING PROTECTION SYSTEM IN SOLAR PV INSTALLATION

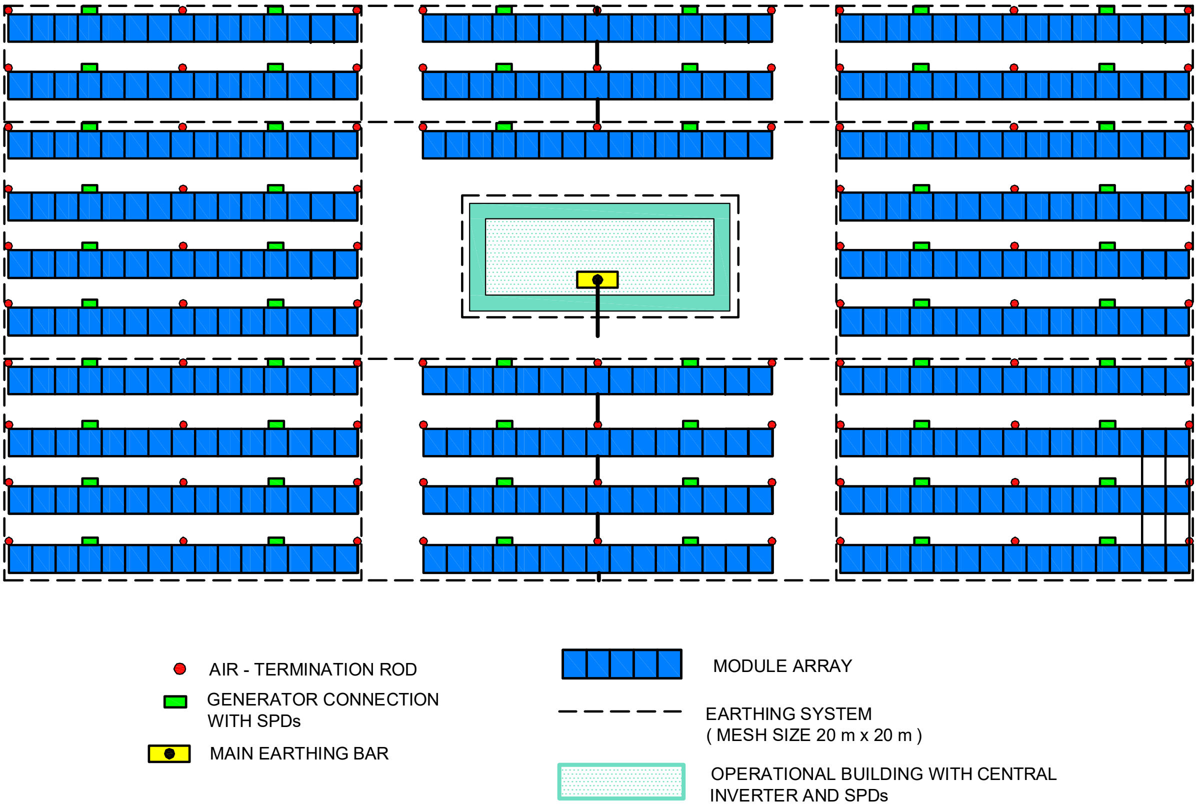

AIR - TERMINATION ROD
GENERATOR CONNECTION WITH SPDs
MAIN EARTHING BAR
MODULE ARRAY
EARTHING SYSTEM (MESH SIZE 20 m x 20 m)
OPERATIONAL BUILDING WITH CENTRAL INVERTER AND SPDs

FIG. 27 TYPICAL ARRANGEMENT OF EARTHING AND SURGE PROTECTION DEVICES IN SOLAR PV INSTALLATION

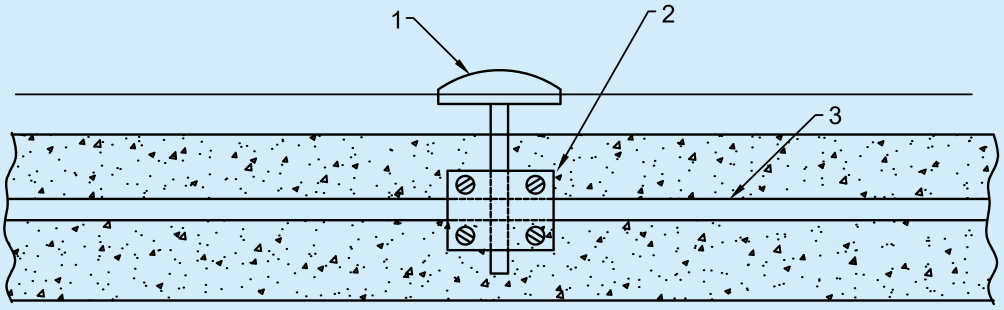
11.6.1.6 *Buildings with roof top telecom towers*

The metallic tower itself will act as air-termination. Antennas mounted above these towers need air-terminals connected to the main structure. The main structure shall be connected to the air-termination conductors for the balance of the building, if available. Two separate down-conductors with a size of minimum 150 mm^2 should be used in addition to regular down-conductors to make the bonding between tower and ring earthing. In order to avoid uncontrolled flash overs and also to protect equipment, which may be mounted on the tower itself, special cable with increased dielectric strength as down-conductor should be used in order to avoid separation distance. The area of cross section will be significantly lower than 50 mm^2 but not less than 28 mm^2, which is sufficient enough to discharge the lightning current where mechanical strength is not an essential requirement.

Every power, coaxial, data and other metallic lines connected between the telecom installation and the other parts of the building shall be protected with suitable SPD. It should be ensured that SPDs during their operation do not impede fire safety.

11.6.1.7 *Lightning protection for multi-storeyed car park roofs/helipads*

Air-termination studs (*see* Fig. 28) may be used for lightning protection for multi-storeyed car park roofs/helipads. Air-termination studs used can be connected to the reinforcement steel of a concrete roof. In the case of roofs where a connection to the reinforcement cannot be made, the roof conductors can be laid in the seams of the carriageway slabs and air-termination studs can be located at the mesh joints. The mesh width shall not exceed the value corresponding to the protection class given in Table 3. The persons and vehicles on this parking area are not protected against direct lightning.



KEY

1 AIR - TERMINATION STUD
2 STEEL CONDUCTOR CONNECTING TO SEVERAL BARS OF THE REINFORCEMENT STEEL
3 STEEL REINFORCEMENT TO CONCRETE

FIG. 28 TYPICAL AIR-TERMINATION STUDS USED ON CAR PARK ROOFS

11.6.2 *Down-conductor System*

Down-conductor system is a part of an external LPS intended to conduct lightning current from the air-termination system to the earth-termination system. The down conductor system shall confirm to 5.3 of accepted standard [D-2(73)]. In order to reduce the probability of damage due to lightning current flowing in the air-termination system, the down-conductors shall be arranged in such a way that from the point of strike to earth:

a) several parallel current paths exist;
b) the length of the current paths is kept to a minimum; and
c) equipotential bonding to conducting parts of the structure is performed.

11.6.2.1 Typical values of the distance between down-conductors are given in Table 4. These values can be used for horizontal ring conductors installed for a tall building more than 60 m height. The minimum number of down-conductors shall be 2 (diagonally opposite to each other) for building with an area less than 100 m^2.

Table 4 Minimum Distance between Down-Conductors

(*Clause* 11.6.2.1)

Sl No. (1)	Class of LPS (2)	Distance m (3)
i)	I	10
ii)	II	10
iii)	III	15
iv)	IV	20

11.6.2.2 Down-conductors shall be installed so that, as far as practicable, they form a direct continuation of the air-termination conductors. It shall be installed straight and vertical such that they provide the shortest and most direct path to earth. The formation of sharp bends and loops shall be avoided. Every down-conductor should be connected to a Type B ring/foundation earthing. Connection of down-conductor to a Type A earthing is allowed only in case of space constraints or existing buildings, where installation is difficult.

11.6.2.3 While routing the down-conductors, separation distance need to be calculated based on accepted standard [D-2(73)] and maintained from live parts/services.

11.6.2.4 Lateral connection of down-conductors at ground level and every 10 m to 20 m of height as a ring conductor, as per below table, is considered to be good practice. The installation of as many down-conductors as possible, at equal spacing around the perimeter interconnected by ring conductors, reduces the probability of dangerous sparking and facilitates the protection of internal installations {*see* accepted standard [D-2(73)]}. This condition is fulfilled in metal framework structures and in reinforced concrete structures in which the interconnected steel is electrically continuous.

11.6.2.5 Routing of down-conductors (insulated or uninsulated) through shafts with electrical and electronic system is not allowed. But routing of down conductors can be done through other service shafts by maintaining separation distance or with equipotential bonding of extraneous metal components.

11.6.2.6 Separation distance is the distance required between air-terminals/lightning down-conductor and any conductive/metallic/electrical/electronic part of a building to avoid uncontrolled flashover.

11.6.2.6.1 While calculating the separation distance, the parameter l (length, in m along the air-terminal and the down-conductor from the point where the separation distance is to be considered, to the nearest equipotential bonding point or earth termination system is not bonded to equipotential bonding point or the earth termination) is a major influencing factor. If the down conductors or the earth terminal system is not bonded to equipotential bonding system of the electrical installation in the building, the lightning protection system will be ineffective.

Cable with increased dielectric strength and tested for lightning current discharge may be used to avoid specific separation distance to live parts of the building {*see* accepted standard [D-2(73)]}.

11.6.2.7 The down-conductor shall be supported using suitable clamps or connectors or exothermic welding. The clamps or connectors or exothermic welding shall be tested for the lightning current as per selected LPL. Reference may be made to table given below and accepted standard [D-2(73)] for supporting details:

Sl No. (1)	*Arrangement* (2)	*Fixing Centres for Tape, Stranded and Soft Drawn Round Conductors* mm (3)	*Fixing Centres for Round Solid Conductors* mm (4)
i)	Horizontal conductors on horizontal surfaces	1 000	1 000
ii)	Horizontal conductors on vertical surfaces	500	1 000
iii)	Vertical conductors from the ground to 20 m	1 000	1 000
iv)	Vertical conductors from 20 m and thereafter	500	1 000

NOTES

1 This table does not apply to built-in type fixings, which may require special considerations.

2 Assessment of environmental conditions (that is, expected wind load) should be undertaken and fixing centres different from those recommended may be found to be necessary.

11.6.2.8 The wind speed shall be taken into account while mounting the air-termination and down-conductor system {*see* accepted standard [D-2(73)]}.

11.6.3 *Earth-termination System*

Earth-termination system is a part of an external LPS which is intended to conduct and disperse lightning current into the earth. When dealing with the dispersion of the lightning current (high frequency behaviour) into the ground, whilst minimizing any potentially dangerous overvoltages, the shape and dimensions of the earth-termination system are the important criteria. In general, a low earthing resistance (if possible lower than 10 Ω when measured at low frequency) is recommended. From the viewpoint of lightning protection, a single integrated structure earth-termination system is preferable and is suitable for all purposes (that is, lightning protection, power systems and telecommunication systems).

Type A earth-termination comprising of vertical/horizontal conductor or Type B earth-termination comprising of ring earthing/foundation earthing shall be used satisfying the requirements of this NBCS as well as accepted standard [D-2(73)]. In structures where only electrical systems are provided, a Type A earthing arrangement may be used, but a Type B earthing arrangement is preferable. In structures with electronic systems, a Type B earthing arrangement is recommended.

11.6.3.1 *Type A earthing*

Length of the earth electrode depends on the soil resistivity and class of LPS {*see* good practice [D-2(11)] for details and Table 5 for vertical earth electrode}.

Table 5 Minimum Length of Vertical Earth Electrode

(*Clauses* 11.6.3.1 *and* 11.6.3.2)

Sl No.	Class of LPS	Typical Length of Each Vertical Earth Electrode Based on Soil Resistivity m			
		Up to 500 Ω-m	1 000 Ω-m	2 000 Ω-m	3 000 Ω-m
(1)	(2)	(3)	(4)	(5)	(6)
i)	I	2.5	10	25	40
ii)	II	2.5	5	15	25
iii)	III	2.5	2.5	2.5	2.5
iv)	IV	2.5	2.5	2.5	2.5

11.6.3.2 *Type B earthing*

This type of arrangement comprises either a ring conductor external to the structure to be protected, in contact with the soil for at least 80 percent of its total length, or a foundation earth electrode. Such earth electrodes may also be meshed. For the ring earth electrode (or foundation earth electrode), the mean radius of the area enclosed by the ring earth electrode (or foundation earth electrode) shall be not less than the value of Type A earthing as given in Table 5 {*see* accepted standard [D-2(73)]}.

11.6.3.3 In industrial and commercial structures, the ring earth electrode around the structure or the ring earth electrode in the concrete at the perimeter of the foundation, should be integrated with a meshed network under and around the structure, having a mesh width of typically 5 m. This greatly improves the performance of the earth-termination system. If the basement's reinforced concrete floor forms a well-defined interconnected mesh and is connected to the earth-termination system, typically at every 5 m, the same will also be suitable {*see* accepted standard [D-2(73)]}.

11.6.3.4 Where large numbers of people frequently assemble in an area adjacent to the structure to be protected, further potential control for such areas should be provided. More ring earth electrodes should be installed at distances of approximately 3 m from the first and subsequent ring conductors. Ring electrodes further from the structure should be installed more deeply below the surface, that is, those at 4 m from the structure at a depth of 1 m, those at 7 m from the structure at a depth of 1.5 m and those at 10 m from the structure at a depth of 2 m. These ring earth electrodes should be connected to the first ring conductor by means of radial conductors.

11.6.3.5 For large buildings integrating structural steel as down-conductor and earth-termination, earth resistivity measurements are not required. Proper drawings should be made based on the actual installation and submitted to authorities if necessary {*see also* accepted standard [D-2(73)]}. However, provisions shall be provided for continuity resistance measurement.

11.6.3.6 Touch and step voltage safety measures outside structure shall be installed and maintained as per accepted standard [D-2(73)].

11.6.4 *Use of Natural Components*

11.6.4.1 Natural components installed not specifically for lightning protection system can be used in addition to LPS or in some cases could provide the functions of one or more parts of LPS, like natural air termination, natural down conductor, natural earth electrode. The use of building components such as columns and foundation have been explained in **11.5** separately, in order to give special attention for use of such systems in modern buildings.

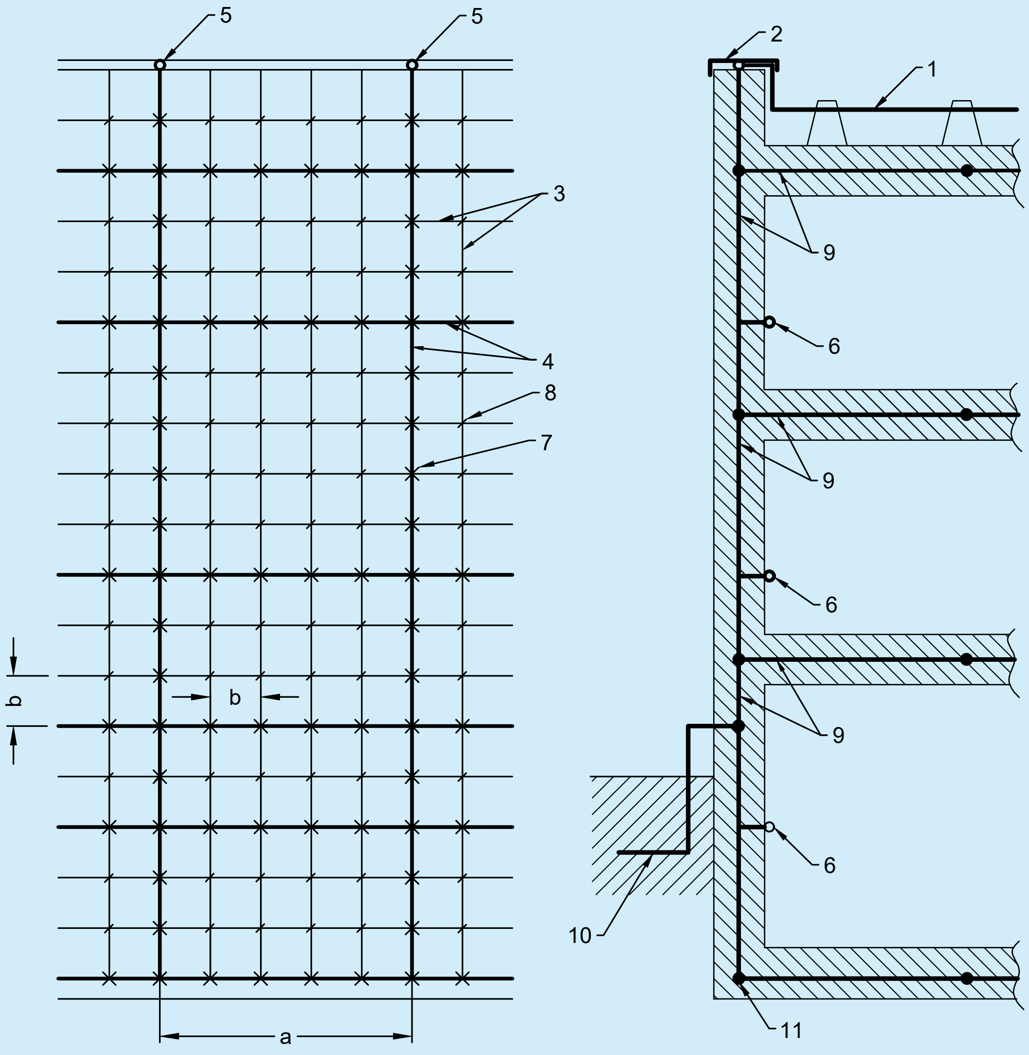
11.6.4.2 *Bonding network*

A low impedance bonding network is needed to avoid dangerous potential differences between all equipment inside the building. Moreover, such a bonding network also reduces the magnetic field, thereby reduces the radiated surges inside the building and provides more protection for electrical electronic equipment {*see* accepted standard [D-2(74)]}.

This can be realized by a meshed bonding network integrating conductive parts of the structure, or parts of the internal systems, and by bonding metal parts or conductive services at the boundary of each lightning protection zone (LPZ) directly or by using suitable SPDs.

The bonding network can be arranged as a three-dimensional meshed structure with a typical mesh width of 5 m (*see* Fig. 29 and Fig. 30). This requires multiple interconnections of metal components in and on the structure (such as concrete reinforcement, elevator rails, cranes, metal roofs, metal facades, metal frames of windows and doors, metal floor frames, service pipes and cable trays). Bonding bars (for example, ring bonding bars, several bonding bars at different levels of the structure) and magnetic shields of the LPZ shall be integrated in the same way.

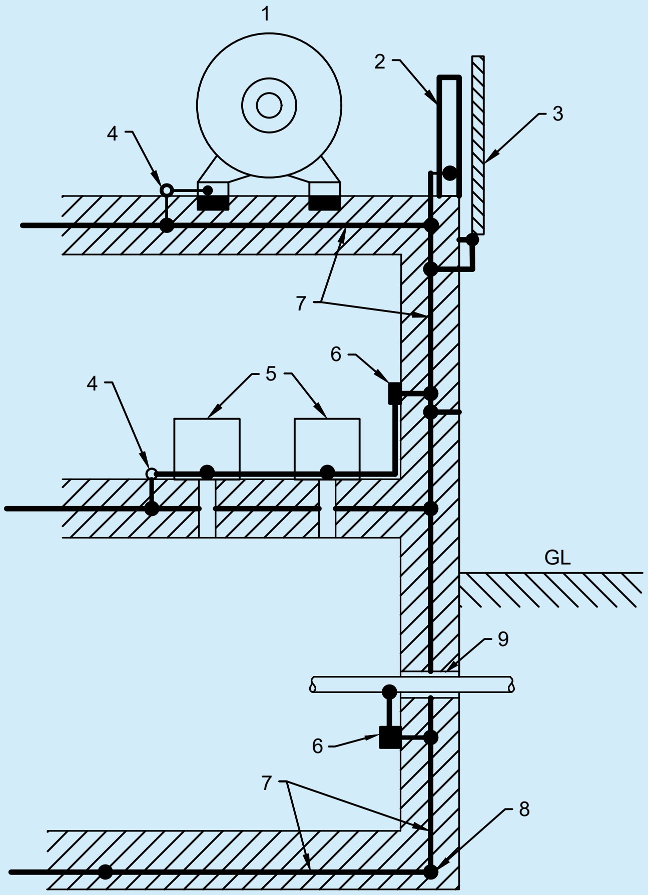
Conductive parts (for example, cabinets, enclosures, racks) and the protective earth conductor (PE) of the internal systems shall be connected to the bonding network {*see* accepted standard [D-2(74)]}.



KEY

1 AIR-TERMINATION CONDUCTOR
2 METAL COVERING OF THE ROOF PARAPET
3 STEEL REINFORCING RODS
4 MESH CONDUCTORS SUPERIMPOSED ON THE REINFORCEMENT
5 JOINT OF THE MESH CONDUCTOR
6 JOINT OF THE INTERNAL BONDING BAR
7 CONNECTION MADE BY WELDING OR CLAMPING
8 ARBITARY CONNECTION
9 STEEL REINFORCEMENT IN CONCRETE (WITH SUPERIMPOSED MESH CONDUCTORS)
10 RING EARTHING ELECTRODE (IF ANY)
11 FOUNDATION EARTHING ELECTRODE
a TYPICAL DISTANCE OF 5 m FOR SUPERIMPOSED MESH CONDUCTOR
b TYPICAL DISTANCE OF 1 m FOR CONNECTING THIS MESH WITH THE REINFORCEMENT

FIG. 29 UTILIZATION OF REINFORCING RODS OF A STRUCTURE FOR EQUPOTENTIAL BONDING



KEY

1 ELECTRIC POWER EQUIPMENT
2 STEEL GIRDER
3 METAL COVERING OF THE FACADE
4 BONDING JOINT
5 ELECTRICAL OR ELECTRONIC EQUIPMENT
6 BONDING BAR
7 STEEL REINFORCEMENT IN CONCRETE (WITH SUPERIMPOSED MESH CONDUCTORS)
8 FOUNDATION EARTHING ELECTRODE
9 COMMON INLET FOR DIFFERENT SERVICES

FIG. 30 EQUIPOTENTIAL BONDING IN A STRUCTURE WITH STEEL REINFORCEMENT

11.6.5 *Materials and Dimensions*

Copper and aluminium are recommended for exposed areas on installations required to have a long life. Galvanized steel may be preferred for temporary installations such as exhibition centres. Although it is a common practice to use material in the form of strip for horizontal air-terminations, down-conductors and bonds, it is more convenient to use round material, particularly as it facilitates the making of bends in any plane. *See* Table 6, Table 7 and Table 8 for details for different materials and conditions of use, refer accepted standard [D-2(74)] for minimum dimension of materials used in LPS.

Table 6 LPS Materials and Conditions of Use[1]

(*Clause* 11.6.5)

Sl No.	Material	Use			Corrosion		
		In Open Air	In Earth	In Concrete	Resistance	Increased by	May be Destroyed by Galvanic Coupling with
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	Copper	Solid	Solid	Solid	Good in many environments	Sulphur compounds Organic materials	–
		Stranded	Stranded	Stranded			
		–	As coating	As coating			
ii)	Hot galvanized steel[2], [3] and [4]	Solid	Solid	Solid	Acceptable in air, in concrete and in benign soil	High chlorides content	Copper
		Stranded[5]		Stranded[5]			
iii)	Steel with electro deposited copper	Solid	Solid	Solid	Good in many environments	Sulphur compounds	–
iv)	Stainless steel	Solid	Solid	Solid	Good in many environments	High chlorides content	–
		Stranded	Stranded	Stranded			
v)	Aluminium	Solid	Unsuitable	Unsuitable	Good in atmospheres containing low concentrations of sulphur and chloride	Alkaline solutions	Copper
		Stranded					

---

[1] This table gives general guidance only. In special circumstances more careful corrosion immunity considerations are required.

[2] Galvanized steel may be corroded in clay soil or moist soil.

[3] Galvanized steel in concrete should not extend into the soil due to possible corrosion of the steel just outside the concrete.

[4] Galvanized steel in contact with reinforcement steel in concrete may, under certain circumstances, cause damage to the concrete.

[5] Stranded conductors are more vulnerable to corrosion than solid conductors. Stranded conductors are also vulnerable where they enter or exit earth/concrete positions. This is the reason why stranded galvanized steel is not recommended in earth.

Table 7 Material, Configuration and Minimum Cross-Sectional Area of Air-Termination Conductors and Rods, Earth Lead-in Rods and Down-Conductors[1]

(*Clause* 11.6.5)

Sl No.	Material	Configuration	Minimum Cross-Sectional Area mm^2
(1)	(2)	(3)	(4)
i)	Copper, tin plated copper	Solid tape	50
		Solid round[2]	50
		Stranded[2]	50
		Solid round[3]	176
ii)	Aluminium	Solid tape	70
		Solid round	50
		Stranded	50
iii)	Aluminium alloy	Solid tape	50
		Solid round	50
		Stranded	50
		Solid round[3]	176
iv)	Copper coated aluminium alloy	Solid round	50
v)	Hot dipped galvanized steel	Solid tape	50
		Solid round	50
		Stranded	50
		Solid round[3]	176
vi)	Copper coated steel	Solid round	50
		Solid tape	50
vii)	Stainless steel	Solid tape[4]	50
		Solid round[4]	50
		Stranded	50
		Solid round[3]	176

---

[1] Mechanical and electrical characteristics as well as corrosion resistance properties shall meet the requirements as per accepted standard [D-2(78)].

[2] 50 mm^2 (8 mm diameter) may be reduced to 25 mm^2 in certain application where mechanical strength is not an essential requirement. Consideration should in this case, be given to reducing the space between fasteners.

[3] Applicable for air-termination rods and earth lead-in rods. For air-termination rods where mechanical stress such as wind loading is not critical, a 9.5 mm diameter, 1 m long rod may be used.

[4] If the thermal and mechanical considerations are important, then these values should be increased to 75 mm^2.

Table 8 Material Configuration and Minimum Dimensions of Earth Electrodes[1] and [2]

(*Clauses* 11.5 *and* 11.6.5)

Sl No.	Material	Configuration	Minimum Dimensions		
			Earth Rod Diameter mm	Earth Conductor mm^2	Earth Plate mm
(1)	(2)	(3)	(4)	(5)	(6)
i)	Copper, tin plated copper	Stranded	–	50	–
		Solid round	15	50	
		Solid tape	–	50	–
		Pipe	20	–	–
		Solid plate	–	–	500 × 500
		Lattice plate[3]	–	–	600 × 600
ii)	Hot dipped galvanized steel	Solid round	14	78	–
		Pipe	25	–	–
		Solid tape	–	90	–
		Solid plate	–	–	500 × 500
		Lattice plate	–	–	600 × 600
		Profile	[4]	–	–
iii)	Bare steel[5]	Stranded	–	70	–
		Sold round	–	78	–
		Solid tape	–	75	–
iv)	Copper coated steel	Solid round	14[6]	50	–
		Solid tape	–	90	–
v)	Stainless steel[7]	Solid round	15	78	–
		Solid tape	–	100	–

---

[1] Mechanical and electrical characteristics as well as corrosion resistance properties shall meet the requirements as per accepted standard [D-2(78)]

[2] In case of a Type B arrangement foundation earthing system, the earth electrode shall be correctly connected at least every 5 m with the reinforcement steel.

[3] Lattice plate constructed with a minimum total length of conductor of 4.8 m.

[4] Different profiles are permitted with a cross-section of 290 mm^2 and a minimum thickness of 3 mm, for example, cross profile.

[5] Shall be embedded in concrete for a minimum depth of 50 mm.

[6] 250 µm minimum radial copper coating, with 99.9 percent copper content.

[7] Chromium ≥ 16 percent, nickel ≥ 5 percent, molybdenum ≥ 2 percent, carbon ≤ 0.08 percent.

11.6.6 Protection measures against injury to living beings due to touch voltage and step voltage shall be provided in accordance with accepted standard [D-2(74)].

11.6.7 Inspection of the LPS shall be done as per IEC 62305-3 : 2024 'Protection against lightning — Part 3: Physical damage to structures and life hazard'.

11.7 Protection of Electrical/Electronic Systems within Structures

11.7.1 The internal LPS shall avoid the occurrence of dangerous sparking within the structure to be protected due to lightning current flowing in the external LPS or in other conductive parts of the structure. Dangerous sparking between different parts can be avoided by means of equipotential bonding or electrical insulation between the parts.

Permanent failure of electrical and electronic systems can be caused by the lightning electromagnetic impulse (LEMP) *via*:

a) conducted and induced surges transmitted to equipment *via* connecting wiring; and

b) the effects of radiated electromagnetic fields directly into equipment itself.

11.7.2 *Equipment Protection Principles*

11.7.2.1 For protection against the effects of radiated electromagnetic fields impinging directly onto the equipment, SPM consisting of spatial shields and/or shielded lines, combined with shielded equipment enclosures should be used.

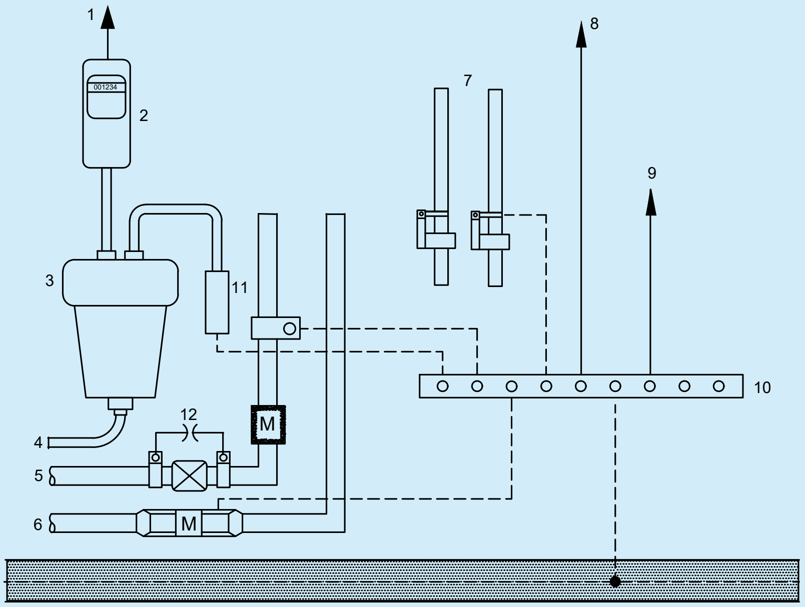
11.7.2.2 For protection against the effects of conducted and induced surges being transmitted to the equipment *via* connection wiring, SPM consisting of a coordinated SPD system should be used. SPD to be used according to their installation position are as follows:

a) At the line entrance into the structure (at the boundary of LPZ 1, for example at the main distribution panel):
   1) SPD tested with I_{imp} (typical waveform 10/350, for example, SPD tested according to class I); and
   2) SPD tested with I_n (typical waveform 8/20, for example, SPD tested according to class II).

b) Close to the apparatus to be protected (at the boundary of LPZ 2 and higher, for example, at secondary distribution board, or at a socket outlet):
   1) SPD tested with I_n (typical waveform 8/20 for example, SPD tested according to class II); and
   2) SPD tested with a combination wave (typical waveform 8/20 for example, SPD tested according to class II).

11.7.3 *Equipotentialization of Services to LPS*

Equipotentialization is achieved by interconnecting the LPS with structural metal parts, metal installations having no electrical power connection, internal systems, external conductive parts and lines connected to the structure. *See* Fig. 31.


1
2
001234
8
7
9
3
11
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12
M
4
5
6
M

KEY

1 POWER TO USER
2 POWER METER
3 HOUSE CONNECTION BOX
4 POWER FROM UTILITY
5 GAS
6 WATER
7 CENTRAL HEATING/COOLING SYSTEM
8 ELECTRONIC APPLIANCES
9 SCREEN OF ANTENNA CABLE
10 EQUIPOTENTIAL BONDING BAR
M METER

FIG. 31 EXAMPLE OF AN EQUIPOTENTIAL BONDING ARRANGEMENT

Interconnection can be done with bonding conductors, where the electrical continuity is not provided by natural bonding or by using surge protective devices (SPDs), where direct connections with bonding conductors is not feasible (for example, installation of SPDs for power, data, telecom lines, etc). It contains at least one non-linear component to ensure perfect equipotential bonding. All SPDs at the service entrance to an installation should be able to divert 10/350 µS impulse current depending upon selected level of protection. A three phase four wire system should be designed for 50 percent of the I_{imp} of selected LPS and single phase two wire system should be designed for 25 percent of the I_{imp} of selected LPS. The lightning current distribution for three phase four wire system is given in Fig. 32 {*see also* accepted standard [D-2(75)]}.

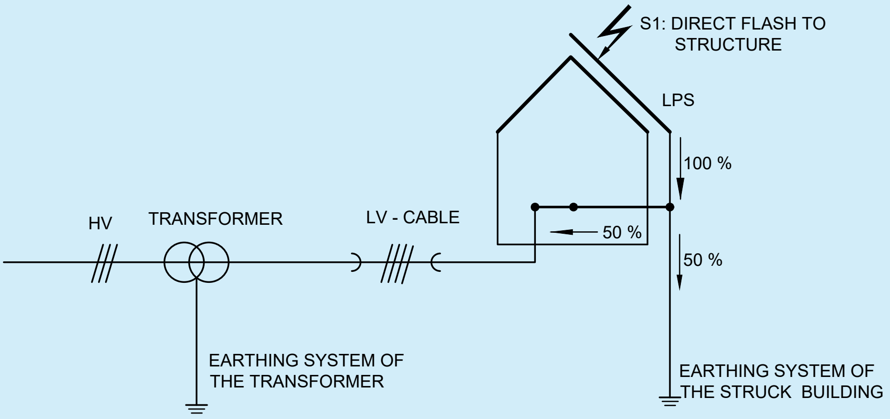

S1: DIRECT FLASH TO STRUCTURE
LPS
100 %
HV
TRANSFORMER
LV - CABLE
50 %
50 %
EARTHING SYSTEM OF THE TRANSFORMER
EARTHING SYSTEM OF THE STRUCK BUILDING

FIG. 32 BASIC EXAMPLE OF BALANCED CURRENT DISTRIBUTION

11.7.4 *Protection Measures with Surge Protection Devices* (*SPDs*)

11.7.4.1 Lightning surges frequently cause failure of electrical and electronic systems due to insulation breakdown or when overvoltages exceed the equipment's common mode insulation level. Power line protection is fundamental, however equal importance should be given to data, communication and instrumentation lines of the equipment that need protection. Equipment is protected if its rated impulse withstand voltage U_{W} at its terminals is greater than the surge overvoltage between the live conductors and earth. If not, an SPD shall be installed.

Implementing coordinated SPDs will provide protection against radiated surges for equipment {*see* accepted standard [D-2(74)]}. Shielding and routing of power and data lines, bonding of services and various lightning protection zones (LPZ) {*see* accepted standard [D-2(74)]} and earthing also plays a major role in protecting electrical and electronic equipment.

The SPDs are used to protect under specified conditions, electrical systems and equipment against various overvoltages and impulse currents such as lightning and switching surges. SPD shall be selected according to their environmental conditions and the acceptable failure rates of the equipment and the SPDs.

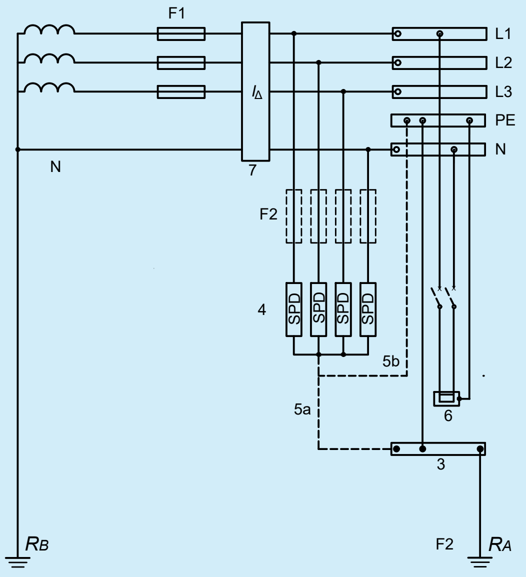
11.7.4.2 *Failure of SPDs*

Possibility of failure of any line to neutral or neutral to earth connected SPDs should not be ruled out, hence measures should be taken within the SPD for safe failure or withstand in worst conditions. SPD can fail in open or short modes. SPD should not create a fire hazard during failure. Safe failure mode is expected from the SPD.

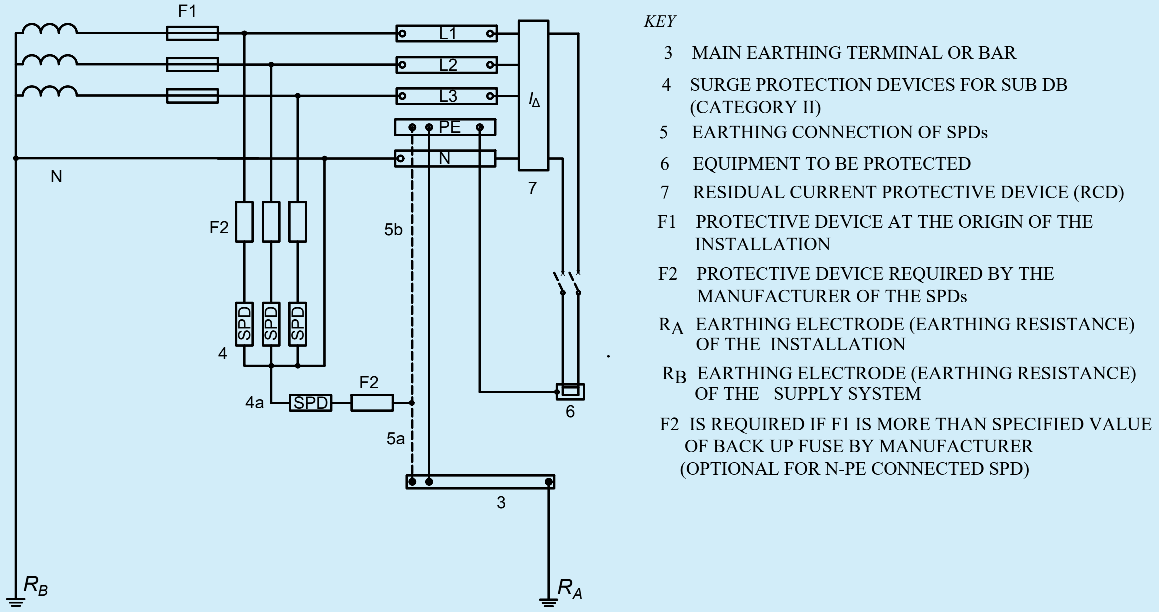
11.7.4.3 *Status indicators*

Each SPD should have inbuilt health indicator so as to show if protection is available. SPD should be installed in a way that visual inspection is easily possible. Failed SPD shall be replaced.

11.7.4.4 SPDs for power line need to be installed according to the type of service such as TN, TT, IT, etc. In general, the SPDs connected as per connection diagram given in Fig. 33 (informative) is suitable for TT connections. Reference may be made to relevant Indian Standard for such installations.



33A SPDs on the Load Side of RCD



KEY

3 MAIN EARTHING TERMINAL OR BAR

4 SURGE PROTECTION DEVICES FOR SUB DB (CATEGORY II)

5 EARTHING CONNECTION OF SPDs

6 EQUIPMENT TO BE PROTECTED

7 RESIDUAL CURRENT PROTECTIVE DEVICE (RCD)

F1 PROTECTIVE DEVICE AT THE ORIGIN OF THE INSTALLATION

F2 PROTECTIVE DEVICE REQUIRED BY THE MANUFACTURER OF THE SPDs

R_A EARTHING ELECTRODE (EARTHING RESISTANCE) OF THE INSTALLATION

R_B EARTHING ELECTRODE (EARTHING RESISTANCE) OF THE SUPPLY SYSTEM

F2 IS REQUIRED IF F1 IS MORE THAN SPECIFIED VALUE OF BACK UP FUSE BY MANUFACTURER (OPTIONAL FOR N-PE CONNECTED SPD)

33B SPDS ON THE SUPPLY SIDE OF RCD

FIG. 33 TYPICAL INSTALLATION OF SPDS IN TT SYSTEM

11.7.4.5 *Selection of SPDs*

SPD(s) need to be selected based on the place of installation as well the impulse voltage withstanding capacity of the equipment. I_{imp} and I_n, are test parameters used to categorize Class I and Class II SPD(s). They are related to the maximum values of discharge currents, which are expected to occur at the LPL probability level at the location of installation (LPZ) of the SPD in the system. I_n is associated with Class II tests and I_{imp} is associated with Class I tests.

11.7.4.5.1 If no risk analysis according to accepted standard [D-2(76)] has been carried out or if the current value of SPD cannot be established, Class I SPDs should be installed with an I_{imp} not less than 12.5 kA (10/350µS) for connection according to Fig. 33A or between L to N or PE. For connection according to Fig. 33B, I_{imp} shall not be less than 50 kA (10/350µS) between N and PE for three-phase systems and 25 kA (10/350 µS) between N and PE for single-phase systems. Otherwise, the currents shall be considered as per level of protection.

11.7.4.5.2 *Follow current extinguishing capability of the SPD*

Follow current is the peak current (rms value) supplied by the electrical power system and flowing through the SPD after a discharge current impulse. Follow current extinguishing capability and short circuit withstand capacity of SPD shall be as per accepted standard [D-2(74)].

11.7.4.5.3 Where Class II tested SPD {*see* accepted standard [D-2(76)]} are required at or near the origin of installation, the value of I_n shall be not less than 5 kA for connections according to Fig. 33A or between L to N or PE. For Class II tested SPDs connected between neutral and PE for connection in Fig. 33B, I_n shall not be less than 20 kA for three-phase systems and 10 kA for single-phase systems.

11.7.4.5.4 *Voltage protection level of SPD*

The voltage protection level of SPD is the maximum voltage to be expected at the SPD terminals due to an impulse stress with defined voltage steepness and an impulse stress with a discharge current with given amplitude and wave shape. The protection level of SPDs shall be selected in accordance with impulse withstand voltage category as per Table 9.

Table 9 Rated Impulse Voltage for the Equipment Energized Directly from the Low Voltages Mains

(*Clause* 11.7.4.5.4)

Sl No.	**Nominal Voltage of the Supply System[1] Based on on Accepted Standard [D-2(79)][2]**		**Voltage Line to Neutral Derived from Nominal Voltages a.c. or d.c. up to and Including** V	**Rated Impulse Voltage[3]**			
	Three Phase V	Single Phase V		Overvoltage Category [4]			
				I V	II V	III V	IV V
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)			50	330	500	800	1 500
ii)			100	500	800	1 500	2 500
iii)		120 to 240	150	800	1 500	2 500	4 000
iv)	230/400 277/480		300	1 500	2 500	4 000	6 000
v)	400/690		600	2 500	4 000	6 000	8 000
vi)	1 000		1 000	4 000	6 000	8 000	12 000

---

[1] *See* accepted standard [D-2(80)].

[2] The '/' mark indicates a four-wire three-phase distribution system. The lower value is the voltage line-to-neutral, while the higher value is the voltage line-to-line. Where only one value is indicated, it refers to three-wire, while the higher value is the voltage line-to-line. Where only one value is indicated, it refers to three-wire, three-phase systems and specifies the value line-to-line.

[3] Equipment with these rated impulse voltage can be used in installations in accordance with IEC 60364-4-44 'Low-voltage electrical installations — Part 4-44: Protection for safety — Protection against voltage disturbances and electromagnetic disturbances'.

[4] *See* **4.3.3.2.2** of accepted standard [D-2(80)].

11.7.4.5.5 The preferred values of voltage protection level of SPDs, U_p is given below (*see* accepted standard [D-2(81)]):

0.08 kV, 0.09 kV, 0.10 kV, 0.12 kV, 0.15 kV, 0.22 kV, 0.33 kV, 0.4 kV, 0.5 kV, 0.6 kV, 0.7 kV, 0.8 kV, 0.9 kV, 1.0 kV, 1.2 kV, 1.5 kV, 1.8 kV, 2.0 kV, 2.5 kV, 3.0 kV, 4.0 kV, 5.0 kV, 6.0 kV, 8.0 kV and 10 kV

Hence, for protecting a 240 V/415 V connected equipment, selecting a $U_p \leq 1.5$ kV will be a safer choice. The U_p may be tested and certified by a third party as per the laid down test procedures. *See* Fig. 34 on connection diagram for SPD.

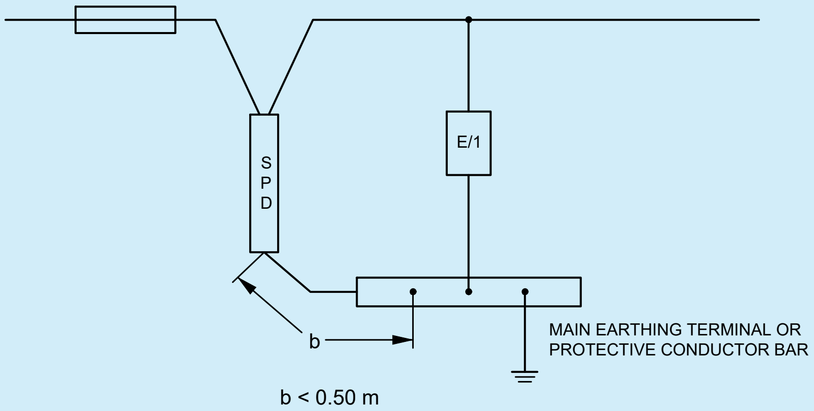


FIG. 34 EXAMPLE OF INSTALLATION OF SPDs AT OR NEAR ORIGIN OF INSTALLATION

11.7.4.6 For small residential buildings, power line SPD at the mains incoming panel will enhance the life of electronic equipment, such as TV, music system, refrigerators, LED lights, etc.

11.7.4.7 For large buildings, power line SPD is required at incoming panel as well as for sub distribution panels based on the LPZ principle {*see* accepted standard [D-2(74)]}.

11.7.4.8 For industrial and commercial buildings, critical and sensitive loads such as drives, PLC's, automation panels, etc, require protection with SPD in addition to SPD at incoming power panels and sub distribution boards. SPDs shall be selected to meet the requirements of relevant LPZs.

11.7.4.9 Lifts, escalators, moving walks and fire panels shall be protected with SPD in control panels. All electrical and control panels related to safety and security of building shall be protected with appropriate SPDs.

11.7.4.10 SPDs should be installed for outdoor equipment such as CCTV cameras, LED street lights, weighbridges, firefighting systems, roof top solar PV installations, etc. This will ensure availability of the vital services provided by these equipment as and when required.

11.7.4.11 Failure of equipment and chance of fire in electrical installations are more for buildings near tall structures (for example, telecom tower). These buildings should be protected with SPD at power incoming and ring earthing to avoid fire and equipment failure.

11.7.4.12 All SPDs should have status indication to show their healthy state for discharging the lightning current. The possibility of failure of L-N as well as N-PE connected SPD cannot be ignored.

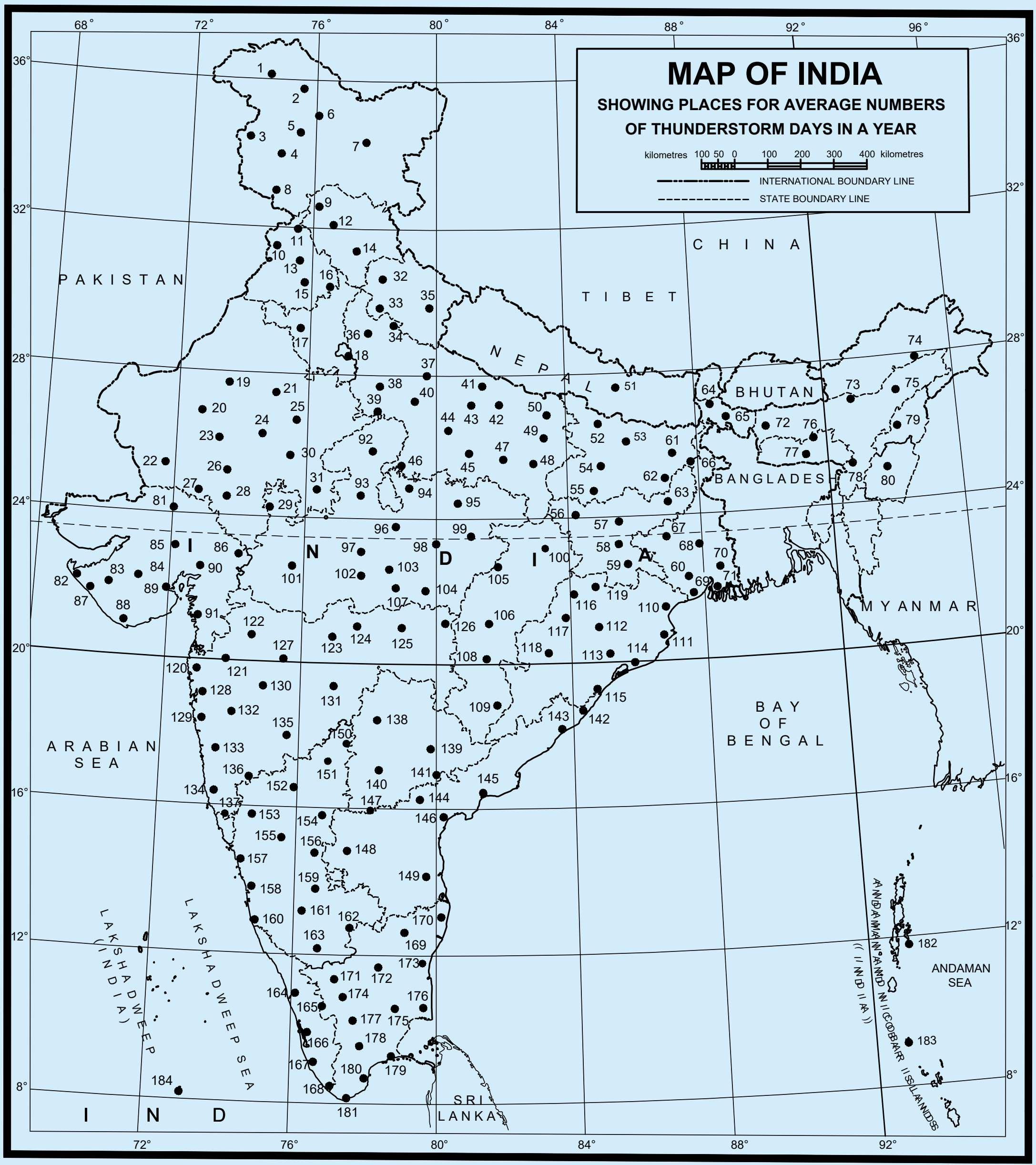
11.7.4.13 The SPD shall be installed at the entrance to ensure perfect bonding to the ground at the time of lightning {*see* good practice [D-2(11)] and accepted standard [D-2(74)]}. The let through energy of the protection system shall be less than the energy that equipment can withstand. As per accepted standard [D-2(74)], the energy coordination method is the best method to ensure the protection of the equipment. The let through energy details of the SPD shall be provided by manufacturer.

11.7.4.14 Maximum continuous operating voltage of the SPD (U_c) should not be less than 1.1 × U_{nominal} = 1.1 × 230 = 253 V; temporary overvoltage (TOV) withstand values shall be as per accepted standard [D-2(81)].

11.7.4.15 Low-voltage SPDs for connection to low-voltage power systems shall be conforming to the accepted standard [D-2(81)].

11.8 Average Number of Thunderstorm Days

For the purpose of risk assessment, annual thunderstorm days in various places are provided in the table below read with Fig. 35.


MAP OF INDIA
SHOWING PLACES FOR AVERAGE NUMBERS
OF THUNDERSTORM DAYS IN A YEAR
kilometres 100 50 0 100 200 300 400 kilometres
INTERNATIONAL BOUNDARY LINE
STATE BOUNDARY LINE
PAKISTAN
CHINA
TIBET
NEPAL
BHUTAN
BANGLADESH
MYANMAR
INDIA
ARABIAN SEA
BAY OF BENGAL
ANDAMAN SEA
LAKSHADWEEP (INDIA)
LAKSHADWEEP SEA
ANDAMAN AND NICOBAR ISLANDS (INDIA)
SRI LANKA
68°
72°
76°
80°
84°
88°
92°
96°
36°
32°
28°
24°
20°
16°
12°
8°

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BASED UPON SURVEY OF INDIA POLITICAL MAP PRINTED IN 2002.

THE TERRITORIAL WATERS OF INDIA EXTEND INTO THE SEA TO A DISTANCE OF TWELVE NAUTICAL MILES MEASURED FROM THE APPROPRIATE BASELINE.

THE INTERSTATE BOUNDARIES BETWEEN ARUNACHAL PRADESH, ASSAM AND MEGHALAYA SHOWN ON THIS MAP ARE AS INTERPRETED FROM THE NORTH-EASTERN AREAS (REORGANIZATION) ACT, 1971, BUT HAVE YET TO BE VERIFIED.

THE EXTERNAL BOUNDARIES AND COASTLINES OF INDIA AGREE WITH THE RECORD/MASTER COPY CERTIFIED BY SURVEY OF INDIA.

THE RESPONSIBILITY FOR THE CORRECTNESS OF INTERNAL DETAILS REST WITH THE PUBLISHER.

FIG. 35 MAP OF INDIA SHOWING PLACES FOR AVERAGE NUMBER OF THUNDERSTORM DAYS IN A YEAR

Sl No.	**Name of Place**	**Annual Thunder-storm Days**
1	Gilgit	7
2	Skardu	5
3	Gulmarg	53
4	Srinagar	54
5	Dras	3
6	Kargil	2
7	Leh	3
8	Jammu	26
9	Dharmsala	13
10	Amritsar	49
11	Pathankot	4
12	Mandi	46
13	Ludhiana	12
14	Simla	40
15	Patiala	26
16	Ambala	9
17	Hissar	27
18	Delhi	30
19	Bikaner	10
20	Phalodi	14
21	Sikar	17
22	Barmer	12
23	Jodhpur	23
24	Ajmer	26
25	Jaipur	39
26	Kankroli	36
27	Mount Abu	5
28	Udaipur	38
29	Neemuch	28
30	Kota	27
31	Jhalawar	40
32	Mussorie	61
33	Roorkee	74
34	Najibabad	36
35	Mukteswar	53
36	Meerut	–
37	Bareilly	34
38	Aligarh	30
39	Agra	24
40	Mainpuri	23
41	Bahraich	31
42	Gonda	22
43	Lucknow	18
44	Kanpur	26
45	Fatehpur	24
46	Jhansi	20
47	Allahabad	51
48	Varanasi	51
49	Azamgarh	1
50	Gorakhpur	11
51	Katmandu	74
52	Motihari	38
53	Darbhanga	10
54	Patna	33
55	Gaya	38
56	Daltonganj	73
57	Hazaribagh	73
58	Ranchi	34
59	Chaibasa	70
60	Jamshedpur	66
61	Purnea	52
62	Sabour	76
63	Dumka	63
64	Darjeeling	28
65	Jalpaiguri	68
66	Malda	59
67	Asansol	71
68	Burdwan	39
69	Kharagpur	76
70	Kolkata	70
71	Sagar Island	41
72	Dhubri	8
73	Tezpur	27
74	Dibrugarh	98
75	Sibsagar	103
76	Shillong	75
77	Cherrapunji	49
78	Silchar	33
79	Kohima	34
80	Imphal	49
81	Deesa	7
82	Dwarka	5
83	Jamnagar	8
84	Rajkot	12
85	Ahmedabad	11
86	Dohad	17
87	Porbandar	3
88	Veraval	3
89	Bhavnagar	11
90	Vadodara	8
91	Surat	4
92	Gwalior	53
93	Guna	33
94	Nowgong	59
95	Satna	41
96	Sagar	36
97	Bhopal	44
98	Jabalpur	50
99	Umaria	37
100	Ambikapur	29
101	Indore	34
102	Hoshangabad	37
103	Panchmarhi	30
104	Seoni	51
105	Pendadah	56
106	Raipur	34
107	Chhindwara	27
108	Kanker	37
109	Jagdalpur	35
110	Balasore	81
111	Chandbali	75
112	Angul	81
113	Bhubaneswar	46
114	Puri	33
115	Gopalpur	34
116	Jharsuguda	85
117	Sambalpur	67
118	Titlagarh	24
119	Rajgangpur	1
120	Dahanu	1
121	Nasik	17
122	Malegaon	13
123	Akola	20
124	Amraoti	32
125	Nagpur	45
126	Gondia	10
127	Aurangabad	34
128	Mumbai	16
129	Alibag	12
130	Ahmadnagar	10
131	Parbhani	32
132	Pune	22
133	Mahabaleshwar	14
134	Ratnagiri	6
135	Sholapur	23
136	Miraj	25
137	Vengurla	39
138	Nizambad	36
139	Hnamkonda	43
140	Hyderabad	28
141	Khammam	26
142	Kalingapatam	20
143	Vishakapatnam	46
144	Rentichintala	42
145	Masulipatam	20
146	Ongole	25
147	Kurnool	29
148	Anantpur	22
149	Nellore	18
150	Bidar	15
151	Gulbarga	34
152	Bijapur	9
153	Belgaum	31
154	Raichur	17

155	Gadag	21
156	Bellary	22
157	Karwar	27
158	Honavar	5
159	Chikalthana	24
160	Mangaluru	36
161	Hassan	26
162	Bengaluru	46
163	Mysuru	44
164	Kozhikode	39
165	Palghat	35
166	Kochi	69
167	Alleppey	51
168	Thiruvananthapuram	68
169	Vellore	25
170	Chennai	47
171	Udhagamandalam	24
172	Salem	69
173	Cuddalore	37
175	Trichchirapalli	41
176	Nagappattinam	15
177	Kodaikanal	82
178	Madurai	39
179	Pamban	5
180	Tuticorin	14
181	Cape Comorin	68
182	Port Blair	62
183	Car Nicobar 1	18
184	Minicoy 1	20

12 ELECTRICAL INSTALLATIONS FOR CONSTRUCTION AND DEMOLITION SITES

12.1 General

12.1.1 Electrical hazards are a major cause of serious injury and even death in construction sites. Accidents also cause loss of productivity and destroy the morale of workers. The need to use electricity and electrical/electronic equipment has been constantly increasing. Without these gadgets productivity and quality of work will suffer. Therefore, the use of electricity and the use of gadgets has to increase. Such increase requires a proper electrical distribution system in the work site.

12.1.2 To ensure continuous supply of power during the construction activity and maintain productivity, site security, etc the city power supply may be required to be supplemented by on-site standby power generation. Some gadgets require continuity of power supply without interruption, thereby requiring UPS systems. In a typical large construction site there may be a large temporary distribution network combined with more than one source of electricity, which can make the system quite complex from the safety point of view.

12.1.3 Problem may also arise in case of lack of required training to workers in the safe use of the tools and equipment that they are required to handle in a system with multiple sources of power supply. In case of use of imported equipment which may be manufactured to their own standards, problems may arise, such as, during connection and inter-connection of equipment and tools and mismatch of plugs and sockets. Appropriate action is to be taken by employing qualified/experienced electrical engineer.

12.1.4 Practical guidance to employers, designers, manufacturers, importers, suppliers (including hirers), electrical contractors and electricians on eliminating or reducing the risk of electrocution and electric shock to any person is necessary.

12.1.5 Even though awareness exist about good practices, the same may be compromised at times in the name of speed or economy or due to ignorance and neglect. The materials, equipment, tools, cables, switchgear used in the temporary installation face far more severe environmental working conditions because of use of discarded switchgear, cables, etc at the construction sites which compounds the risk to workmen from shock and fire. Hence, the laid down Indian Standards for permanent installations, need to be followed during construction and demolition meticulously. The complete installation shall be duly earthed as per *Central Electricity Authority* (*Measures related to safety and Electric Supply*) *Regulations*, 2023, good practice [D-2(11)] and [D-2(1)].

12.2 Installation and Removal of Construction Wiring

All construction wiring work shall be installed by an appropriately registered electrical contractor and by electrical workmen holding license of the appropriate level of competency depending on the voltage, local generation, etc, as provided in *Central Electricity Authority* (*Measures Related to Safety and Electric Supply*) *Regulations*, 2023 and *the Indian Electricity Act*, 2003. The installation should be inspected prior to commissioning and at regular intervals by the Engineer-in-Charge (if one is qualified to inspect electrical installations) or by representative, who should be competent to inspect an installation.

12.3 Provision of Indicating and Recording Instruments and Meters

Measurement is a prerequisite to analyse the performance. Construction site switchboards should have adequate instrumentation (such as, ammeters, PF meters, voltmeters, energy meters, etc) on different branches of the distribution system so that any abnormal condition or overload is noticed. Considering the nature of varying activity in a construction site, frequent visual, and instrument based inspections are necessary as well as keeping record of the same.

12.4 Residual-Current Circuit Breaker (RCCB)/Residual-Current Device (RCD)

The following shall be ensured in the construction and demolition sites:

a) Every electric supply to which electrical plant can be connected should incorporate an RCCB/RCD of appropriate capacity so as to protect persons who may come into contact with the electrical plant against electric shock;

b) The RCCB/RCD(s) should have a rated tripping current not exceeding 30 mA and should have the capacity to carry the load current required by the appliances permitted to be connected in that branch circuit or feeder;

c) Where construction work supply can only be obtained from a permanent wiring socket-outlet, RCCB/RCD should be connected at the socket-outlet;

d) Sub-mains supplying site sheds should incorporate an RCCB/RCD having a rated tripping current not exceeding 100 mA;

e) Every non-portable RCCB/RCD device on the worksite shall be trip tested by the built-in push button test every month, and performance tested for operation before being put into service and thereafter at least once every 12 months. It shall also be subjected to an imbalance of current not less than the rated residual current and shall trip in a time not exceeding 6 s;

f) Every portable RCCB/RCD device on the worksite shall be trip tested by the built-in push button test. The test shall be done prior to use and each day while in use; and it shall be performance tested for operation before being put into service and thereafter at least once every 3 months. It shall also be subjected to an imbalance of current not less than the rated residual current and shall trip in a time not exceeding 6 s;

g) Results of RCCB/RCD tests shall be recorded and kept on site or made available for audit and kept for a minimum period of 5 years or till the completion and handing over of the project, whichever is less [excluding the daily push button test for portable RCCB/RCD(s)];

h) Portable RCCB/RCD(s) when tested shall be fitted with a durable, non-reusable, non-metallic tag. The tag shall include the following information:

   1) The name of the person or company who performed the tests; and

   2) The test or retest date.

   The recommended colour coding for tags on tested RCCB/RCD, which is prescribed below should be indicated by its colour representing the period when the test was performed:

January to March	:	Red
April to June	:	Green
July to September	:	Blue
October to December	:	Yellow

j) Portable generators should be fitted with RCDs having a rated tripping current not exceeding 30 mA; and

k) Personal hoists used on construction sites shall be supplied from a separate final sub-circuit originating from the main switchboard; and be suitably identified by marking this supply on the RCD/MCB feeding it.

12.5 Temporary Supply Switchboards

All temporary supply switchboards used on building, construction and demolition sites shall be of robust construction and either securely attached to a pole, post wall or other structure which may be of stable freestanding design and:

a) where installed in outdoor locations, should be constructed and maintained to IP23 (or higher) rating so that safe operation is not affected by the weather;

b) switchboards should incorporate the support and elevation of cables and flexible extension cords;

c) switchboard enclosures shall be provided with an insulated or covered tie-bar or similar arrangement for the anchorage of the cables or flexible cords in order to prevent strain and mechanical damage at the termination of the cables or cords;

d) switchboards should be provided with a door and locking facility. The doors should be designed and attached in a manner that will not damage any flexible cord connected to the board and should protect the switches from mechanical damage;

e) the door should be provided with signs (in English, Hindi and at least one local language) stating, 'KEEP CLOSED – LEADS THROUGH BOTTOM';

f) switchboards should have an insulated slot (with edges suitably shaped or covered with plastic or rubber trims to avoid damaging the cable insulation/sheath) at the bottom for the passage of leads;

g) switchboards should be attached to a permanent wall or suitable portable or temporary structure in an elevated position suitable for easy access and having least interference with the activity in the area;

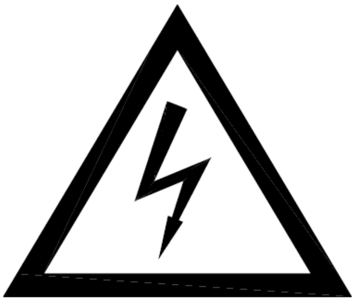
h) if the floor in that area is likely to be wet, additional precautions are necessary and an insulated platform should preferably be provided for access to operation of switches. Personal protective equipment such as helmet, electrician gloves, etc, should be available, placed near the switchboard, as an alternative;

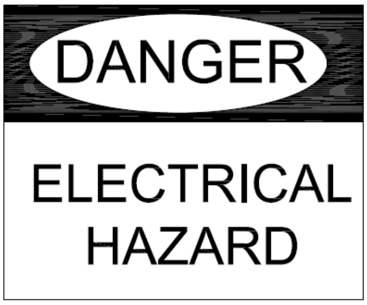
j) a clearance of at least 1.2 m should be maintained in front of all switchboards;

k) the contractor or nominated persons should ensure that all power circuits are isolated or made inaccessible so as to eliminate the risk of fire, electric shock or other injury to persons after completion of the daily work;

m) switchboards shall be legibly and indelibly marked with a set of numbers or letters or both which uniquely identify the switchboard from others on a site;

switchboards shall be marked to indicate the presence of live parts in accordance with symbols such as the following drawing:





p) chart indicating first aid measures for electric shock management should be placed near the switchboard;

q) ‘Lock Out and Tag Out’ procedures as adopted should be displayed;

r) the switchboard should be lighted properly to ensure its identification and safe working; and

s) all switchboards should have their identification names (or/and numbers) so that any communication/ instructions about them are unambiguous.

12.6 Cables Used in Worksite Installations

12.6.1 Worksite poses a number of hazards to the cables. The conditions are severe compared to those in permanent installations. Cables face dust, moisture, abrasives and even impact unlike those in permanent installations. Extra care should be taken to frequently inspect the cables and discard cables which show signs of damage as a damaged insulation combined with moisture can be dangerous.

12.6.2 Cables are likely to be run over by vehicles. Suitable protection is required by a steel pipe or hume pipe or steel plate, whichever is appropriate. Dragging of cables damages their sheath/insulation and may also cut a few strands of the conductor due to stretching, effectively reducing the current carrying capacity. Hence suitable care should be taken while laying the cables.

12.6.3 Overhead installation of cables is a common practice. Such installations should use a GI wire to carry the weight of the cable without causing the stretching of the cable. The carrier GI wire should be earthed. Unarmoured cables shall not be installed on metallic roofs or similar structures unless suitably protected against mechanical damage.

Overhead wiring should be positioned to avoid crossing roadways or accessways where cranes, high loads, or heavy machinery may travel. Where it is not possible to avoid accessways an effective means shall be provided to minimize the risk of the vehicular contact with the aerial wiring system. This condition may be satisfied by the placement of flagged catenary wires or cables of suitable material across the accessway, 6 m on either side of the overhead wiring and 0.6 m below the lowest point of the overhead electrical cables or lower.

All aerial conductors installed on construction and demolition sites shall be insulated. Cables supported by means of a catenary shall be stranded or shall be flexible cables affording double insulation or the equivalent of double insulation. Construction wiring (including switchboards) shall be visually inspected at intervals not exceeding 6 weeks.

12.7 Electrical Plant in Service Testing

Electrical plant shall be inspected and tested in accordance with the following:

a) Movable electrical plant that is hand held or portable during operation or moved between operations and is subject to damage or harsh environment shall be examined and tested every 3 months;

b) All other electrical plant used for construction purposes shall be inspected and tested at intervals not exceeding 6 months;

c) When any equipment inspected or tested in accordance with (a) and (b) is found to be unsatisfactory, it shall be withdrawn from service immediately and have a label attached to it, ‘Warning against Further Use’. Electrical plant found to be unsatisfactory shall not be returned to service until it has been repaired and retested;

d) The inspection and testing specified should be carried out by an authorized/qualified person; and

e) The results of the inspection of electrical plant should be recorded and kept on site or made available for inspection by authorities. Information recorded shall include:

    1) the name of the person or company who performed the tests;

    2) the test or retest date; and

    3) identification of faulty equipment and action taken to repair or remove it from use.

12.8 Lighting

Following in respect of lighting shall be ensured in construction and demolition sites:

a) *Access lighting* — Adequate artificial lighting should be installed to illuminate the work area if there is insufficient natural lighting. Lamps in luminaires shall be protected against mechanical damage. Luminaires installed as part of the permanent electrical installation in site accommodation, may not require further mechanical protection;

   Sufficient battery powered lighting shall be installed in stairways and passageways to allow safe access and exit from the area if there is insufficient natural lighting. If there is a loss of supply to the normal lighting in the area, it should be ensured that battery powered lighting has sufficient capacity to operate for one hour to allow persons to exit the building safely.

   Temporary wiring supplying lighting circuits should be connected to the designated lighting circuits of the switchboard.

b) *Task lighting* — Portable luminaires shall be provided with the appropriate ingress protection (IP) rating. Task lighting in many construction site may have to move continuously in steps as the work progresses. The lighting system should also be shifted in suitable steps instead of simply extending the cables without any consideration for safety. Hand held additional lights, if any, should be taken from a socket protected by a RCCB/RCD of 30 mA setting just like hand held tools;

c) *Lift and service shaft lighting* — Lift and service shaft lighting may have either construction wiring or permanent wiring. Fluorescent lighting should be used. The lights should be located on the floor above or below the work area. It shall be ensured that the emergency lighting has sufficient battery capacity to operate for a minimum of 1 h if there is a loss of supply to the normal lighting in the area;

d) *Lighting in means of egress* — Sufficient battery powered lighting shall be installed in stairways and passageways to allow safe access and exit from the area if there is insufficient natural lighting. If there is a loss of supply to the normal lighting in the area it shall be ensured that battery powered lighting has sufficient capacity to operate for 1 hr to allow persons to exit the building safely; and

e) *Illumination of signs and warning boards* — Sufficient lighting should be available to illuminate the sign boards and warning boards. These lights may also be a part of the lighting set for means of egress.

12.9 Transportable Construction Buildings (Site Sheds)

Electrical installations to transportable construction buildings shall comply with the following:

a) If supply is by means of a flexible cord, the same shall not be taken from one transportable building to another transportable building.

b) The flexible cord supplying a transportable building should not be more than 15 m in length.

c) Each amenity in the building shall be connected/supplied by a flexible cord to a final sub-circuit protected by an RCCB/RCD device with a rated tripping current not exceeding 30 mA; these flexible cords should be protected from mechanical damage and power outlets in site sheds should be used to supply power to the equipment and lighting within the shed only.

d) Socket-outlets installed on the outside of transportable building shall be used only to supply power to the following:

   1) Electrical equipment and lighting immediately adjacent to those transportable buildings.

   2) Other transportable buildings when the socket-outlet is part of an interconnecting system and the flexible cord supplying those transportable buildings has a maximum length of 15 m.

12.10 Lock-Out and Tag-Out Practices

Whenever an electrician is to work on a branch feeder from the switchboard it becomes necessary that the switch feeding the feeder on which work is done is to be switched-off and should be kept switched-off till the same electrician decides to switch on after completion of work either for testing or for putting the section back into service. To ensure that during the period an electrician is working on a feeder or the equipment it feeds, the practice is to put a ‘tag’ on the concerned switch. The tag will carry details about which authorized worker has put the tag and when and who is authorized to remove it. This is a very critical operating practice for maintenance of the electrical system and following it is of particular importance in the case of temporary installations, where such requirements arise more often than in permanent installations.

Lock-out procedure shall be similar to the above but the difference is that the relevant switch is kept locked in off position and the key is kept by the person or the team leader who will be working on the feeder. The system should also maintain a register where the activities of this nature and the details of action (repair, transfer of the end equipment to a new location, addition of a new appliance on the feeder, etc) are recorded.

12.11 Standard Operating and Maintenance Practices in Sites with More Than One Source of Electricity

12.11.1 In medium and large construction sites it is common to use local generation of electricity by a diesel generating set. The reasons may be lack of dependable local/city distribution system for continuous power supply, high cost of temporary connection charges, restrictions on use of certain equipment like welding transformers on temporary connection, etc. Apart from DG sets for power requirement of site construction equipment, there may be office equipment with computers and site laboratory equipment which require un-interruptible power supply. Shock hazards depend on the voltage of the system and the consequent current flow through the body. As such shock risk associated with all these sources is the same.

12.11.2 Wherever an alternative power supply is provided, proper protocols shall be adopted for the supply from different systems and the associated change-over switch or contactors. Risk increases due to existence of more than one source of power supply. System schematics, operating practice and essential interlock between the different sources of power should be displayed and followed systematically. Earthing for each system should be provided. Changeover switches should be of 4 pole in order to ensure that earth leakage protections operate properly with each one of the power sources. The system should also maintain a register where the activities related to each source of power is recorded and the actions to be taken are provided.

12.12 Earthing or Grounding

12.12.1 Earthing or grounding is an essential pre-requisite for any electrical system from the aspect of safety of personnel, equipment, appliances and for avoidance of fire due to short-circuit or of feeding energy to a short circuit originating from any other cause consequent to damage to insulation by the fire.

12.12.2 The standard earthing practice is applicable to temporary installations also. The earth sets installed at the initial development of the site can be planned to be retained as earthing sets for use even after the completion of the building for the permanent installation.

12.12.3 The minimum requirement of earthing for any temporary electrical installation is given hereunder for easy adherence to the basic minimum. It is recommended to follow the earthing requirements given in **8** and accepted standard [D-2(11)].

12.12.3.1 The neutral of the system of each source or generator shall be having two distinct connection to two distinct earthing sets. All metal parts associated with electrical equipment are required to be connected to earth. The minimum requirement is the provision of two pipe earthing sets each with a pipe of 4.2 m length and separated by at least 2.5 m between them in accordance with good practice [D-2(11)] and connected to the source neutral by a conductor of cross-section more than half the size used for the phase conductor.

12.12.3.2 Earth continuity shall be maintained all over the site wherever electricity is made available and the earth continuity conductor shall have a cross-section at least more than that used for the phase conductor.

12.12.3.3 Wherever the requirements of earthing and use of RCD or RCCB cannot be satisfactorily met with at any site and electrical hand tools are required to be used, low voltage (< 50 V) appliances or self-contained battery operated tools shall be used as a safe alternative. This applies to work under damp or water logged areas also.

13 PROTECTION OF HUMAN BEINGS FROM ELECTRICAL HAZARDS

13.1 General

Danger to persons due to contact with live parts is caused by the flow of the current through the human body. The effects on the human body are dependent on the amount of the current flow and the duration of the flow. The current flow through the human body depends on the voltage and the resistance in the path. The contact resistance forms an important or significant contributor to the total resistance for the current flow. The contact resistance reduces by a factor of 100 to 1 000 due to the body part being wet and also the touch pressure at the point of contact. The works under this clause shall cover the relevant Indian Standards and good practice [D-2(1)].

13.1.1 *Physiological Effects of Electric Shock*

The following are the physiological effects of electric shock:

a) *Tetanization* — The muscles affected by the current flow involuntarily contract and letting go of gripped conductive parts is difficult;

NOTE — Very high currents do not usually induce muscular tetanization because, when the body touches such currents, the muscular contraction is so sustained that the involuntary muscle movements generally throw the subject away from the conductive part.

b) *Breathing arrest* — If the current flows through the muscles controlling the lungs, the involuntary contraction of these muscles alters the normal respiratory process and the subject may die due to suffocation or suffer the consequences of traumas caused by asphyxia;

c) *Ventricular fibrillation* — The most dangerous effect is due to the superposition of the external currents with the physiological ones, which, by generating uncontrolled contractions, induce alterations of the cardiac cycle. This anomaly may become an irreversible phenomenon since it persists even when the stimulus has ceased; and

d) *Burns* — They are due to the heating deriving, by Joule effect, from the current passing through the human body.

13.1.2 On a time-current diagram (*see* Fig. 36), four zones to which the physiological effects of alternating current (15 Hz to 100 Hz) passing through the human body have been related as given below:

13.1.3 In general, 'special locations' involve one or more of the following environmental conditions or different risks, which in the absence of special arrangements, will give rise to an increased risk of electric shock:

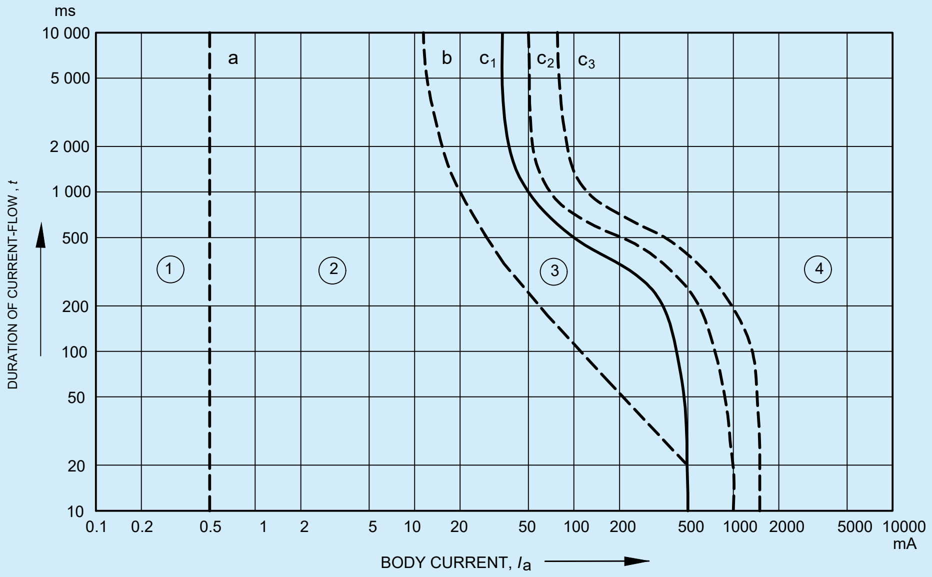
a) wetness or condensation, that is, reduced skin resistance;

b) absence of clothing, that is, greater opportunity to make direct or indirect contact through increased area of bare skin and bare feet;

c) proximity of earthed metalwork, that is, increased risk of indirect contact; and

d) arduous or onerous site conditions, that is, conditions of use that may impair the effectiveness of the protective measures.

13.1.3.1 The additional requirements for these 'special locations' have been devised by assessing the relevant risks under each of the above categories and making adjustments to the protective measures accordingly. The intention is to remove or minimize the additional risks to users presented by the electrical installations within these 'special locations'. Designers, installers and operators of such installations should consider the particular requirements of the installation and design and install or operate the installation to reduce or protect against risks from these requirements. It should be however recognized, that all installations require adequate regular periodic inspection and testing, and any necessary maintenance or repair works be properly carried out.



NOTES

1 AS REGARDS VENTRICULAR FIBRILLATION, THIS FIGURE RELATES TO THE EFFECTS OF CURRENT WHICH FLOWS IN THE PATH 'LEFT HAND TO FEET'. FOR OTHER CURRENT PATHS, SEE 5 AND TABLE III OF ACCEPTED STANDARD [D-2(82)].

2 THE POINT 500 MA/100 MS CORRESPONDS TO FIBRILLATION PROBABILITY IN THE ORDER OF 0.14 PERCENT.

Zones	Physiological effects
Zone 1	Usually no reaction effects.
Zone 2	Usually no harmful physiological effects.
Zone 3	Usually no organic damage to be expected. Likelihood of muscular contractions and difficulty in breathing, reversible disturbances of formation and conduction of impulses in the heart, including atrial fibrillation and transient cardiac arrest without ventricular fibrillation increasing with current magnitude and time.
Zone 4	In addition to the effects of Zone 3, probability of ventricular fibrillation increasing up to about 5 percent (curve c_2), up to about 50 percent (curve c_3) and above 50 percent beyond curve c_3. Increasing with magnitude and time, pathophysiological effects such as cardiac arrest, breathing arrest and heavy burns may occur.

FIG. 36 TIME/CURRENT ZONES OF THE EFFECTS OF a.c. CURRENTS (15 Hz TO 100 Hz)

13.2 Protection Against Electric Shocks

13.2.1 Protective measures against electric shock are based on following two common dangers:

a) Contact with an active conductor, which is live with respect to earth in normal circumstances; and is referred to as a 'direct contact' hazard;

b) Contact with a conductive part of an apparatus which is normally dead, but which has become live due to insulation failure in the apparatus; and is referred to as an 'indirect contact' hazard; and

The third type of shock hazard exists in the proximity of HV or LV (or mixed) earth electrodes which are passing earth-fault currents.

c) This hazard is due to potential gradients on the surface of the ground and is referred to as a 'step-voltage' hazard; shock current enters one foot and leaves by the other foot, and is particularly dangerous for four-legged animals. A variation of this danger, known as a 'touch voltage' hazard can occur, for instance, when an earthed metallic part is situated in an area in which potential gradients exist. Touching the part would cause current to pass through the hand and both feet. Animals with a relatively long front-to-hind legs span are particularly sensitive to step-voltage hazards.

NOTE — Cattle have been killed by the potential gradients caused by a low voltage (240/415 V) neutral earth electrode of insufficiently low resistance.

13.2.2 Potential-gradient problems as mentioned in **13.2.1** are not normally encountered in electrical installations of buildings, provided that equipotential conductors properly bond all exposed metal parts of equipment and all extraneous metal (that is, those which are not part of an electrical apparatus or the installation, for example structural steelwork, etc) to the protective-earthing conductor.

Potential-gradient problems do exist at the switchboards of electrical installations. Even where components, such as the metallic cubicle and operating handle are earthed, there is a possibility that for very short duration when a fault current is flowing through the metal part, the potential of the earthed metal part may be increased due to the current flow. The practice of using an insulating mat at places where the switches are to be operated, is for protection against such transient over-voltages in earthed metal parts (if the metal part is not earthed the transient overvoltage will be beyond safe limits).

With the increased use of pumped water in bathrooms for spa-baths, power showers, etc, there is a need, on occasions, to provide for motive power within the area of the bath. In order to protect against direct and indirect contact, supplies for such equipment shall be by extra-low-voltage-system with the nominal voltage not exceeding 12 V r.m.s.

It is a requirement to provide supplementary equipotential bonding by bonding all simultaneously accessible exposed and extraneous conductive parts. This should include all in-coming metallic services (including metal wastes) and any structural metalwork, including a metallic floor grid, if provided.

Protection measures as given in **13.2.3** to **13.2.5** shall also be provided for protection against electric shock.

13.2.3 *Direct-Contact Protection or Basic Protection*

The main form of protection against direct contact hazards is to contain all live parts in housings of insulating material or in metallic earthed housings, by placing out of reach (behind insulated barriers or at the top of poles) or by means of obstacles. Where insulated live parts are housed in a metal envelope, for example, transformers, electric motors and many domestic appliances, the metal envelope is connected to the installation protective earthing system. Protection classification and the details of the different levels of protection are designated by IP XX and IK X {*see* accepted standard [D-2(36)] and [D-2(10)]. The metallic enclosure has to demonstrate an electrical continuity, then establishing a good segregation between inside and outside of the enclosure. Proper grounding of the enclosure further participates the electrical protection of the operators under normal operating conditions. For LV appliances this is achieved through the third pin of a 3 pin plug and socket. Total or even partial failure of insulation to the metal, can raise the voltage of the envelope to a dangerous level (depending on the ratio of the resistance of the leakage path through the insulation, to the resistance from the metal envelope to earth). The minimum standard for any equipment has to be IP2X to limit the possibility of a finger touching a live part of an electrical system.

13.2.4 *Indirect-Contact Protection or Fault Protection*

A person touching the metal envelope of an apparatus with a faulty insulation is said to be making an indirect contact. An indirect contact is characterized by the fact that a current path to earth exists (through the protective earthing (PE) conductor) in parallel with the shock current through the person concerned. The hazard in such cases is dependent on the earth resistance and the resistance of the earth continuity conductor, which would effectively be in parallel to the path of flow of current through the human body.

Extensive tests have shown that, providing the potential of the metal envelope not greater than 50 V with respect to earth, or to any conductive material within reaching distance, no danger exists.

If the insulation failure in an apparatus is between a HV/LV conductor and the metal envelope, it is not generally possible to limit the rise of voltage of the envelope to 50 V or less, simply by reducing the earthing resistance to a low value. The solution in this case is to create an equipotential ‘earthing systems’. Insulation faults affecting the LV substation's equipment (internal) or resulting from atmospheric overvoltages (external) may generate earth currents capable of causing physical injury or damage to equipment.

a) Preventive measures essentially consist of all substation frames and connecting them to the earth bar;

b) Minimizing earth resistance; and

c) Fast tripping and isolation of the fault by the operation of the fuse or circuit breaker.

13.2.5 In order to provide protection against electric shock due to leakage current for human being, a 30 mA RCCB/RCD shall be installed at distribution board incomer of buildings, such as residential, schools and hospitals. For all other buildings, a 100 mA RCCB will suffice for protection against leakage current.

13.2.6 *Additional Protection Against Electric Shocks*

In a.c. systems, additional protection by means of a residual current protective device (RCD) with sensitivity not exceeding 30 mA shall be provided for:

a) socket-outlets with a rated current not exceeding 20 A that are for use by ordinary person and are intended for general use; and

b) mobile equipment with a current rating not exceeding 32 A for use outdoors.

The residual current devices shall be independent of the line voltage, except for installation operated, tested and inspected by skilled persons.

13.3 Hazards Due to Multiple Electrical Sources

The need for reliability of power supply and continued supply for different equipment leads to provision of redundant equipment chains as well as the provision of more than one source of power.

For critical installations it is normal to have more than one service connection, preferably from two different paths, so that at least one of the paths is in service at any time.

At the next level, to cover the failure of the area distribution network, local standby generating systems such as diesel generating sets are provided. For extremely critical loads which cannot tolerate even short break in service UPS systems which store energy in a battery bank and release it during the power failure become necessary.

As such, multiple sources have become a necessary common feature in most large buildings. Even in small buildings activities depending on computers, etc leads us to provide a standby system with an UPS or an inverter.

Where there is more than one source the shock hazards increase due to various reasons and a proper drill and display of instructions becomes necessary so that the users and in particular the operating and maintenance personnel are warned of the different sources and the associated protocol.

13.4 Care and Design of Electrical Installations for Human Safety

Location of switches and location of electrical equipment has to be done with a view to avoid electrical hazards to the users from the angle of human safety.

Most common hazard is of direct contact and that too when associated with wet surfaces. Wet surface reduces the contact resistance and thereby increases the current flow.

The second most common hazard comes up from old or/and damaged or under-sized flexible cords used for connection of portable equipment or devices.

The recommendations for typical areas requiring special attention are given in **13.4.1** to **13.4.5**.

13.4.1 *Bath Room Installations*

13.4.1.1 *Geyser*

The geyser or a storage water heater in not a portable device as it requires connection to the electricity line as well as to the water supply lines. The electrical connection will be from a 16 A socket-outlet located at least 500 mm away from the plumbing connections. The switch for the geyser should not be accessible from the bath area or the shower area, to avoid a person standing on the wet surface touching the switch. The switch should be located away from the wet floor area of a bath room and preferably outside near the entrance to the bath room. This switch should have a built in indicator to display the status.

13.4.1.2 *Shaver socket*

Shaver sockets are located near the mirror. The socket will be fed from an isolating transformer (which in addition to providing electrical isolation between the output to the shaver and the building electrical system, may also give a voltage choice selection) to avoid shock hazard.

Shaver sockets which do not have a built in isolating transformer should be protected at the back by a RCCB/RCD of 30 mA sensitivity.

13.4.1.3 *Protection against electric shocks in bathrooms*

All circuits in bathrooms shall be protected by a RCCB/RCD with a sensitivity of 30 mA. The RCCB/RCD shall be in compliance with its relevant Indian Standards.

13.4.1.4 *Protection against electric shocks in sauna heater*

All circuits in sauna shall be protected by a RCCB/RCD with a sensitivity of 30 mA. The RCCB/RCD shall be in compliance with the relevant Indian Standards.

13.4.2 *Bed Room Installations*

For the convenience of operating the lights, fan, nurses call bell system, etc from the bed, it is quite a common practice to provide a pendent switch wired with a flexible cord. The flexible cord used should be with an outer sheath and the sheath should be securely clamped at the pendent switch. Use of twisted flexible cables without double insulation is hazardous and should be avoided.

A bed-head control set for all outlets to be controlled, mounted either on the wall accessible from the bed or mounted on the head board of the bed would be a preferable and safer alternative. This alternative requires the termination of the permanently installed wiring at a box near the bed and a flexible multicore sheathed cable for connection from the wall termination box to the control switch set mounted on the bed-head.

13.4.3 *Kitchen Installations*

Today a large number of gadgets are in use in the kitchen and it would be desirable to provide a large number of combinations of 6 A/16 A sockets. As a general guideline any part of the kitchen counter should be within 1 m from a socket-outlet as most kitchen appliances come with a 1.5 m or 2 m flexible cord.

The sockets should be located on the basis of the equipment layout and the general-purpose outlets would be placed at 150 mm above the kitchen counter level.

For safety, all the socket-outlets should be from circuits with a RCCB/RCD protection of sensitivity 30 mA. If an instant geyser is provided the same has to be wired from circuit with a 100 mA RCCB/RCD as 30 mA may cause nuisance tripping for a geyser.

13.4.4 *Protection Against Electric Shocks in Swimming Pools and the Other Basins*

For swimming pools and other basins such as basins of swimming pools, paddling pools and their surrounding zones; areas in natural waters such as lakes in gravel pits, coastal and similar areas, specially intended to be occupied by persons for swimming, paddling and similar purposes and their surrounding zones, basins of fountains and their surrounding zones; all electrical systems provided shall be protected by residual current devices with a sensitivity not exceeding 30 mA. The RCD shall be in compliance with its product standard and the relevant Indian Standard. All circuits for lighting, etc in contact with water shall be at 24 V or less.

13.4.5 For protection against electric shock including those pertaining to medical and all other applications not mentioned above, reference shall be made to good practice [D-2(1)].

13.5 Earthing Requirements

Earthing is an essential need for protection against shock. Almost all devices require a proper earth connection through the earthing pin (and socket) and in turn through the protective earth conductor and shall comply with the requirements as per good practices [D-2(1)] and [D-2(11)].

13.6 Heating Appliances and Hot Appliances

Electrical appliance incorporating a heating element pose additional hazards from the possibility of overheating and inadvertent ignition of combustible material in the vicinity. While the installation by itself cannot be made failsafe, it is necessary to provide conspicuous indicators with the switches for the sockets used for such appliances, so that visible indication warns the user that the appliance is ON (many appliances which have their own built-in indication, may be in OFF position in their standby mode or in the cut-off mode. Under such conditions the indication associated with the switch would be a gentle reminder).

Almost all electrical appliances produce heat and require ventilation. The surface of the equipment is likely to be hot. Wherever the surface temperature is likely to be more than 45 °C, there should be a protection against the possibility of touching the surface and getting scalded or burnt.

13.7 Switches Getting Supply from Multiple Sources

Use of critical electrical equipment requiring continued power supply even in the absence of the commercial supply are on the increase both at home and in any general office, apart from special functional buildings where multiple or redundant sources is a necessity. Use of UPS systems has become common.

Where there are such points or switches fed from multiple sources, it is desirable to mark these switches or adopt a colour code so that they are identified readily.

Many UPS and inverters have the feature of tripping on overload followed by automatic restoration after a brief time delay. Such characteristics should be made known to the users, so that accidents do not happen by the uninformed user taking some action assuming that the power supply is not there. Shock hazards are dependent on the system voltage and the hazard level is the same whether it is from the power system or from a mini UPS of a few watts.

13.8 Protection Against Environmental Over-Voltages

Any building today has a number of metallic connections coming into the building or installed over (or near) the building such as lines for electricity, telephone, dish antenna, radio antenna, pipe lines for water supply, sewage, cable of cable TV, solar hot water system, solar photovoltaic array, cell phone tower, wind generator, etc. External disturbances such as lightning, faults in external systems, etc, can induce over-voltage in the installations within the building.

Buildings are to be provided protection from lightning strikes by a system of ‘Faraday cage’ on the basis of hazard assessment. But at the same time use of dish antenna for TV, cable TV (the cable for which is run from building to building on the top, apparently forming a line to catch a lightning stroke) are on the rise and are without any regulation. These installations pose hazards to the installations inside the building. Care should be taken while allowing such installations in buildings. In case the occupant is not in a position to avoid such incidence, suitable SPD should be provided in the circuit. Good practice [D-2(1)] may also be referred in this regard.

For sensitive and critical equipment, it is necessary to make a separate detailed study and build in appropriate protective device such as shield, suppressor or diverter, as may be appropriate for the equipment as well as the type of hazard assessed.

13.9 Flammable Atmosphere and Risk of Ignition by Electricity Leading to Fire or Explosion

13.9.1 Flammable atmospheres may result in electrical fire and explosion hazards. They are dealt with separately because of the complexities and problems peculiar to the subject. They occur when flammable gas, vapour, mist, aerosol or dust is present in a concentration in air between the upper (UEL) and lower (LEL) explosive limits. Such mixtures ignite if there is a source of ignition is present, such as incentive arcs or sparks from electrical equipment. The risk areas are divided into following zones for flammable gases/vapours:

a) *Zone* 0 Where the flammable atmosphere is always present;

b) *Zone* 1 Where the flammable material is present during normal operations and a flammable atmosphere is likely to occur; and

c) *Zone* 2 Where the flammable atmosphere is unlikely during normal operation and if it occurs, it will exist only for a short time.

13.9.2 A spark such as from a switch in an explosive atmosphere can trigger a fire or an explosion. In such areas special 'flame-proof' category switches, light fittings, cables, etc will have to be used. The installation practices are also precise. Zonal boundaries have to be determined by the occupier's specialist staff and marked on the site drawing in plan and elevation. It is a difficult task and requires a knowledge of the characteristics of the material and how it disperses from the source of emission.

To illustrate by an example, if LPG leaks from a domestic gas cylinder it creates a hazardous situation. LPG is heavier than air and will settle down at the bottom on the floor with gradually changing ratio of air/LPG mixture as you go up above the floor level and it would be an explosive mixture at a height of a few centimetres above the floor level, which can easily be ignited by a spark or a flame. LPG stored in a basement (particularly if it is without exhaust picked up from floor level) can be serious situation.

Armed with the zonal boundary plans, the next step is to determine the position of the electrical equipment. Wherever possible, the risk should be avoided or minimized by locating the electrical equipment outside the risk areas or in Zone 2 areas rather than in Zones 0 and 1.

Zone 0 is usually inside reaction vessels or storage tanks. There is not much electrical equipment available for use in Zone 0 and as the risk is high it should be avoided by locating the equipment outside, example, a container can have glazed port-holes so that the interior can be viewed through one and lit from a luminaire shining through another. Zone 1 areas often occur only in the immediate vicinity of where the flammable material is processed. They are invariably surrounded by Zone 2 areas where the electrical apparatus should preferably be situated. It is sometimes possible to light outside site zones by luminaires located at high level in safe areas above the vertical zone boundaries. For flammable interiors, lighting can often be provided by positioning the luminaires outside in a safe location and shining the light through glazed panels in the roof or walls. Again, motors can be outside and drive an internal machine through a long shaft extension passing through a gas-tight seal in the wall. In some plants, it is convenient to locate the motor starters together on a starter panel in a motor control room. This room may either be in a safe area or if within the flammable zone, fed with clean air, from outside the zone, maintained at a positive pressure to ensure that gas cannot enter. Conduits for wiring should be solid drawn or seam welded with screwed joints. Where flammable gases have to be excluded from equipment, barrier seals may be necessary. Flexible metallic conduit should be lined to prevent abrasion of the cable insulation. Aluminium and aluminium alloy conduits and accessories should not be used where frictional contact with oxygen-rich items such as rusty steel might occur and cause sparking.

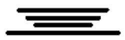
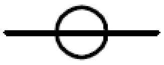
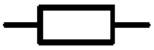
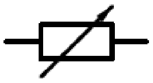
13.10 Protection against Fire Due to Leakage Current in the Building

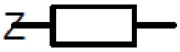
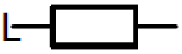
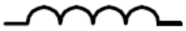
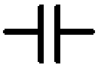
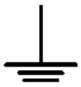
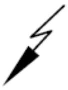
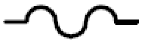
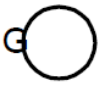
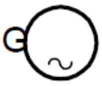
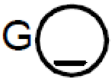
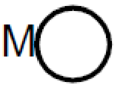
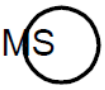
Large number of fires in the building occur due to faulty electrical installation. Mostly, the cause is assigned to over load or short-circuit fault. But there can be one more reason for causing the fire in the building. As the quality of insulation of the cables deteriorate due to ageing over a period of time, certain amount of leakage current flows in the system. This leakage current or tracking is difficult to detect and if it is allowed for a long period of time, say months or years, sparks occur which on a favourable condition, may lead to devastating fire in the building. Ignition of fire due to leakage current or tracking may be prevented by providing residual current devices of 300 mA as part of the main distribution board.

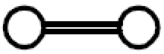
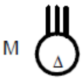
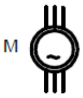
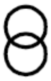
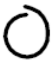
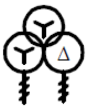
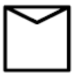
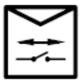
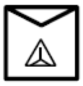
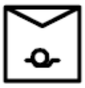
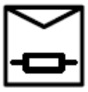
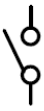
ANNEX A

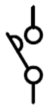
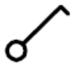
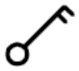
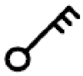
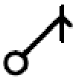
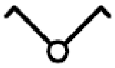
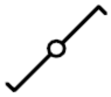
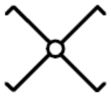
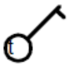
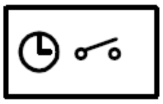
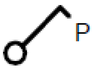
(*Clause* 2.2)

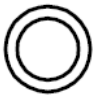
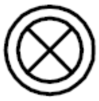
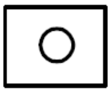
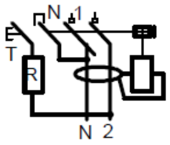
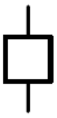
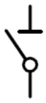
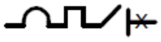
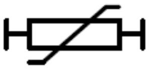
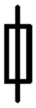
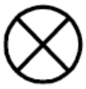
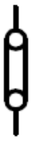
DRAWING SYMBOLS FOR ELECTRICAL INSTALLATIONS IN BUILDINGS

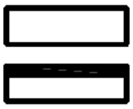
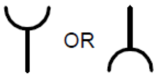
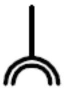
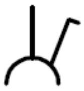
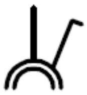
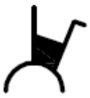
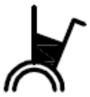
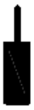
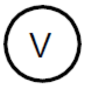
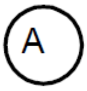
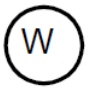
Sl No.	*Details*	*Symbol*
1.	Direct current	—
2.	Alternating current, general symbol	∼
3.	Alternating current, single-phase, 50Hz	∼ 50 Hz
4.	Alternating current, three phase, 415 V	3 ∼ 50 Hz 415 V
5.	Alternating current, three phase with neutral, 50 Hz	3N ∼ 50 Hz
6.	Neutral	N
7.	Positive polarity	+
8.	Negative polarity	−
9.	Direct current, 2 conductors 110 V	2 — 110 V
10.	Direct current 3 conductors including neutral 220 V	2N — 220 V
11.	Underground cable	
12.	Overhead Line	
13.	Winding, delta	△
14.	Winding, star	Y
15.	Terminals	○
16.	Resistance/Resistor	
17.	Variable resistor	

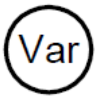
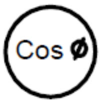
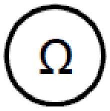
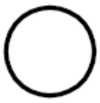
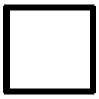
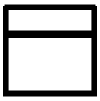
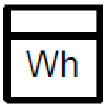
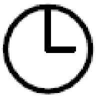
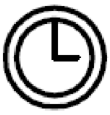
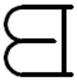
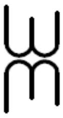
18.	Impedance	
19.	Inductance/Inductor	
20.	Winding	
21.	Capacitance, Capacitor	
22.	Earth	
23.	Fault	
24.	Flexible conductor	
25.	Generator	
26.	a.c. generator	
27.	d.c. generator	
28.	Motor	
29.	Synchronous motor	

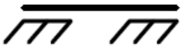
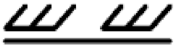
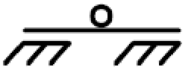
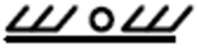
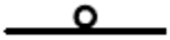
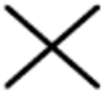
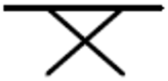
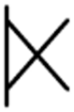
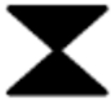
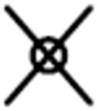
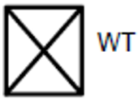
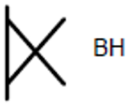
30.	Mechanically coupled Machines	
31.	Induction motor, Three-phase, squirrel cage	
32.	Induction motor with Wound rotor	
33.	Transformers with two separate windings	
34.	Auto-transformer	
35.	3-Phase transformer with three separate windings-star-star-delta	
36.	Starter	
37.	Direct-on-line-starter for reversing motor	
38.	Star-delta starter	
39.	Auto-transformer starter	
40.	Rheostatic starter	
41.	Switch	

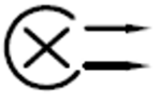
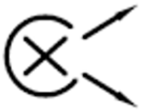
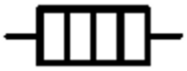
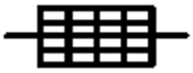
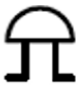
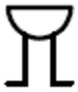
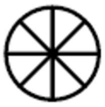
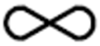
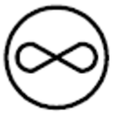
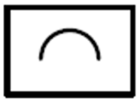
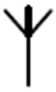
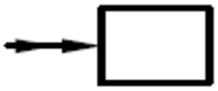
42.	Contactor	
43.	One - way switch, single pole	
44.	One - way switch, two pole	
45.	One - way switch, three pole	
46.	Single pole pull switch	
47.	Multiposition switch for different degrees of lighting	
48.	Two-way switch	
49.	Intermediate switch	
50.	Period limiting switch	
51.	Time switch	
52.	Pendant switch	

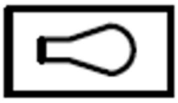
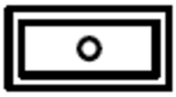
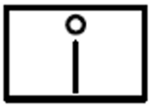
53.	Push button	
54.	Luminous push button	
55.	Restricted access push button	
56.	Relay	
57.	Circuit-Breaker	
58.	Isolator	
59.	Residual current circuit breaker	
60.	Surge protective device	
61.	Fuse	
62.	Signal lamp	
63.	Link	

64.	Distribution boards, cubicle box, main fuse board with switches	
65.	Socket outlet, 6A	
66.	Socket outlet, 16 A	
67.	Combined Switch and Socket Outlet, 6A	
68.	Combined switch and socket outlet, 16 A	
69.	Interlocking switch and socket outlet, 6A	
70.	Interlocking switch and socket outlet, 16A	
71.	Plug	
72.	Voltmeter	
73.	Ammeter	
74.	Wattmeter	

75.	Varmeter	
76.	Power factor meter	
77.	Ohmmeter	
78.	Indicating instrument (General symbol)	
79.	Recording instrument (General symbol)	
80.	Integrating meter	
81.	Watthour meter	
82.	Clock	
83.	Master clock	
84.	Current transformer	
85.	Voltage transformer	

86.	Wiring on the surface	
87.	Wiring under the surface	
88.	Conduit on surface	
89.	Concealed conduit	
90.	Wiring in conduit	
91.	Lamp	
92.	Lamp mounted on a ceiling	
93.	Lamp, mounted on a wall	
94.	Emergency lamp	
95.	Panic lamp	
96.	Water—tight lighting fitting	
97.	Batten lamp holder	

98.	Spot light	
99.	Flood light	
100.	Heater	
101.	Storage type water heater	
102.	Bell	
103.	Buzzer	
104.	Siren	
105.	Ceiling fan	
106.	Exhaust fan	
107.	Fan regulator	
108.	Aerial	
109.	Radio receiving set	

110.	Television receiving set	
111.	Manually operated fire alarm	
112.	Automatic fire detector switch	

ANNEX B

[*Clauses* 3.1.2.2 (Note) 3.3 (Note), 3.5.3(c), 4.2.1(q)(10), 4.9, 4.9.1.2, 4.9.1.4, 4.9.1.5, 4.9.3.1, 5.3.6.7, 5.4.1.1, 5.4.1.3, 6.4.6, 8.2.1, 8.3, 9.1.1, 9.3.2.6(d), 10.7.3 *and* 10.8.3]

EXTRACTS FROM *CENTRAL ELECTRICITY AUTHORITY (MEASURES RELATING TO SAFETY AND ELECTRIC SUPPLY) REGULATIONS*, 2023

B-1 The following are the extracts of some of the rules:

Regulation 3, Designated person to operate and carry out the work on electrical lines and apparatus

(1) The supplier or consumer, or owner of electrical installation, owner or agent or manager of a mine, or agent of any company operating in an oil-field or owner of a drilled well in an oil-field or a contractor who has entered into a contract with a supplier or a consumer, or owner of electrical installation, owner or agent or manager of a mine, or agent of any company operating in an oil-field or owner of a drilled well in an oil-field to carry out duties incidental to the generation, transformation, transmission, conversion, distribution or use of electricity shall designate person for the purpose to operate and carry out the work on electrical lines and apparatus.

(2) The supplier or consumer, or owner or agent or manager of a mine, or agent of any company operating in an oil-field or the owner of a drilled well in an oil-field or a contractor referred to in sub-regulation (1) shall maintain a record, in paper or electronic form, wherein the names of the designated person and the purpose for which they are designated, shall be entered.

(3) No person shall be designated under sub-regulation (1) unless-

(i) he possesses a certificate of competency or electrical work permit, issued by the Appropriate Government; and

(ii) his name is entered in the register referred to in sub-regulation (2).

Regulation 5, Electrical Safety Officer

(1) All suppliers of electricity including generating companies, transmission companies and distribution companies shall designate an Electrical Safety Officer for ensuring observance of safety measures specified under these regulations in their organisation for construction, operation and maintenance of electrical system of all generating stations, transmission lines, substations, distribution systems and supply lines.

(2) The Electrical Safety Officer shall possess a degree in Electrical Engineering with at least five years experience in operation and maintenance of electrical installations or a Diploma in Electrical Engineering with at least ten years experience in operation and maintenance of electrical installations:

Provided that the Electrical Safety Officer designated for mines shall possess educational qualification as mentioned in sub-regulation (2) with at least five years of experience in operation and maintenance of electrical installations relevant to mines.

(3) For every electrical installation including factory registered under the *Factories Act*, 1948 (63 of 1952) with more than 250 kW connected load and mines and oil-field as defined in the *Mines Act*, 1952 (35 of 1952), with more than 2 000 kW connected load, the owner of the installation or the management of the factory or mines, as the case may be, shall designate Electrical Safety Officer under sub-regulation (1) and having qualification and experience specified in sub-regulation (2), for ensuring the compliance of the safety provisions laid under the Act and the regulations made thereunder:

Provided that the Electrical Safety Officer shall carryout recommended periodic tests as per the relevant standards, and inspect such installations at intervals not exceeding one year, and keep a record thereof in Form I or Form II or Form III or Form IV, as the case may be, of Schedule II of these regulations; test reports and a register of recommendations in regard with safety duly acknowledged by owner; compliances made thereafter; and such records shall be made available to the Electrical Inspector, as and when required.

Regulation 6, Chartered Electrical Safety Engineer

(1) The Appropriate Government shall authorise Chartered Electrical Safety Engineer from amongst persons having the qualification and experience as per the guidelines issued by the Authority to assist the owner or supplier or consumer of electrical installations for the purpose of selfcertification under Regulation 32 and Regulation 45 of these regulations.

(2) The Appropriate Government shall upload the name of the Chartered Electrical Safety Engineer, as soon as any person is authorised as Chartered Electrical Safety Engineer, on the web portal of the Government or the Department dealing with matters of inspection of electrical installations for the information of the owner or supplier or consumer.

Regulation 8, Safety measures for operation and maintenance of transmission and distribution systems

(1) The Engineers or Supervisors engaged or appointed to operate or undertake maintenance of transmission and distribution systems shall hold degree or diploma in appropriate trade of Engineering from a recognised institute or university.

(2) The Engineers and Supervisors engaged or appointed to operate or undertake maintenance of transmission and distribution systems shall have successfully undergone the type of training specified in guidelines as per sub- regulation (4), within two years from the date of engagement or appointment.

(3) The Technicians to assist Engineers or Supervisors shall possess a certificate in appropriate trade, preferably with a two years course from an Industrial Training Institute recognised by the Central Government or State Government and should have successfully undergone the type of training as specified in guidelines as per sub- regulation (4), within two years from the date of engagement or appointment:

Provided that the existing employees, as on the date of notification of these regulations, who are extending technical assistance to Engineers or Supervisors and do not have requisite qualification as mentioned in this regulation, shall have to undergo the training either from Power Sector Skill Council or from training institute recognised by the Authority for carrying out trade specific course as per the guidelines issued by the Authority and get certificate as mentioned above within two years from the date of notification of these regulations.

(4) The Authority shall issue guidelines for the training for operation and maintenance of transmission, distribution systems within six months of the notification of these regulations:

Provided that the duration and content of the training course shall be as specified in the guidelines.

(5) Owner of every transmission or distribution system shall arrange for training of their personnel engaged or appointed to operate and undertake maintenance of transmission and distribution system, in his own institute or any other institute recognised by the Authority or State Government as per the guidelines and shall maintain records of the assessment of these personnel issued by the training institute in the format prescribed in guidelines and such records shall be made available to the Electrical Inspector, as and when required.

Regulation 14, General safety requirements pertaining to construction, installation, protection, operation and maintenance of electric supply lines and apparatus

(1) All electric supply lines and apparatus shall be of sufficient rating for power, insulation and estimated fault current and of sufficient mechanical strength, for the duty cycle which they may be required to perform under the environmental conditions of installation, and shall be constructed, installed, protected, worked and maintained in such a manner as to ensure safety of human beings, animals and property.

(2) Save as otherwise provided in these regulations, the relevant standards including National Electrical Code and National Building Code shall be followed to carry out the purpose of these regulations and where relevant Indian Standards are not available, International standards shall be followed and in the event of any inconsistency, the provisions of these regulations shall prevail.

(3) The material and apparatus used shall conform to the relevant standards.

(4) All electrical equipment shall be installed above the Highest Flood Level and where such equipment is not possible to be installed above Highest Flood Level, it shall be ensured that there is no seepage or leakage or logging of water.

Regulation 17, Identification of earthed and earthed neutral conductors and position of switches and switchgear therein

Where the conductors include an earthed conductor of a two-wire system or an earthed neutral conductor of a multi-wire system or a conductor which is to be connected thereto, the following conditions shall be complied with-

(i) an indication of a permanent nature shall be provided by the owner of the earthed or earthed neutral conductor, or the conductor which is to be connected thereto, to enable such conductor to be distinguished from any live conductor and such indication shall be provided as per relevant standards, namely: –

  (a) where the earthed or earthed neutral conductor is the property of the supplier, at or near the point of commencement of supply;

  (b) where a conductor forming part of a consumer's system is to be connected to the supplier's earthed or earthed neutral conductor, at the point where such connection is to be made; and

  (c) in all other cases, at a point corresponding to the point of commencement of supply.

(ii) no cut-out, link, switch or circuit breaker other than a linked switch arranged to operate simultaneously on the earthed or earthed neutral conductor and live conductors shall be inserted or remain inserted in any earthed or earthed neutral conductor of a two wire-system or in any earthed or earthed neutral conductor of a multi-wire system or in any conductor connected thereto:

Provided that the above requirement shall not apply in case of a link for testing purposes, or a switch for controlling a generator or transformer.

Regulation 18, Earthed terminal on consumer's premises

(1) The supplier shall provide and maintain on the consumer's premises for the consumer's use, a suitable earthed terminal in an accessible position at or near the point of commencement of supply as per relevant standards:

Provided that in the case of installation of voltage exceeding 250 V the consumer shall, in addition to the aforementioned earthing arrangement, provide his own earthing system with an independent electrode and the same shall be interlinked with the earthed terminal mentioned in sub-regulation (1) through a suitable link.

(2) The consumer shall take all reasonable precautions to prevent mechanical damage to the earthed terminal and its lead belonging to the supplier.

Regulation 20, Danger notices

The owner of every installation of voltage exceeding 250 V shall affix permanently in a conspicuous position a danger notice in Hindi or English and the local language of the district, with a sign of skull and bones of a design as per relevant standards on:

(a) every motor, generator, transformer and other electrical plant and equipment together with apparatus used for controlling or regulating the same;

(b) all supports of overhead lines of voltage exceeding 650 V which can be easily climbed upon without the aid of ladder or special appliances; and

(c) luminous tube sign requiring supply, X-ray and similar high frequency installations of voltage exceeding 650 V but not exceeding 33 kV:

Provided that where it is not possible to affix such notices on any generator, motor, transformer or other apparatus, they shall be affixed as near as possible thereto, or the word ‘danger’ and the voltage of the apparatus concerned shall be permanently painted on it:
Provided further that where the generator, motor, transformer or other apparatus is within an enclosure one notice affixed to the said enclosure shall be sufficient for the purposes of this regulation.

Explanation — For the purposes of clause (b) rails, tubular poles, wooden supports, reinforced cement concrete poles and pre stressed cement concrete poles without steps, I-sections and channels, shall be deemed as supports which cannot be easily climbed upon.

Regulation 21, Handling of electric supply lines and apparatus

(1) Before any conductor or apparatus is handled, adequate precautions shall be taken, by earthing or other suitable means, to discharge electrically such conductor or apparatus, and any adjacent conductor or apparatus if there is danger therefrom, and to prevent any conductor or apparatus from being accidentally or inadvertently electrically charged when persons are working thereon shall be followed as per the relevant standards.

(2) Every person who is working on an electric supply line or apparatus or both shall be provided with, –

(a) personal protective equipment, tools and devices such as rubber gloves and safety footwear suitable for working voltage, safety belts for working at height, nonconductive ladder, earthing devices of appropriate class, helmet, line tester, hand lines, voltage detector and hand tools as per the relevant standards; and

(b) any other device for protecting him from mechanical and electrical injury due to arc flash and such personal protective equipment, tools and devices shall conform to the relevant standards and shall always be maintained in sound working condition.

(3) No person shall operate and undertake maintenance work on any part or whole of an electrical plant or electric supply line or apparatus and no person shall assist such person on such work, unless he is designated in that behalf and observes the safety precautions given in Part-I, Part-II, Part-III and Part-IV, as the case may be, of Schedule I.

(4) Every telecommunication line on supports carrying an overhead line of voltage exceeding 650 V but not exceeding 33 kV shall, for the purpose of working thereon, be deemed to be a line of voltage exceeding 650 V:

Provided that prior permission shall be taken from the concerned licensee before laying telecommunication lines on electric supports.

(5) For the safety of operating personnel, all non-current carrying metal parts of switchgear and control panels shall be properly earthed and insulating floors or mat conforming to the relevant standards, of appropriate voltage level shall be provided in front and rear of the panels where such personnel are required to carry out operation, maintenance or testing work.

(6) All panels shall be painted with the description of its identification at front and at the rear.

Regulation 29, Provisions applicable to protective equipment

(1) Fire buckets filled with clean dry sand and ready for immediate use for extinguishing fires, in addition to fire extinguishers suitable for dealing with fires, shall be conspicuously marked and kept in all generating stations, enclosed substations and enclosed switching-stations in convenient location.

(2) Appropriate type of fire extinguisher conforming to the relevant standards, shall be installed, maintained, periodically inspected and tested as per the relevant standards for extinguishing and controlling fire and record of such tests shall be maintained.

(3) Sufficient number of first-aid boxes or cupboards conspicuously marked and equipped with such contents as the State Government may specify or as per the relevant standards, shall be provided and maintained at appropriate locations in every generating station, enclosed substation, enclosed switching

station and in vehicles used for maintenance of lines so as to be readily available and accessible at all the times and all such boxes and cupboards shall, except in the case of unattended substations and switching stations, be kept under the charge of responsible persons who are trained in first-aid treatment and one of such persons shall be available during working hours.

(4) Two or more gas masks shall be provided conspicuously and installed and maintained at accessible places in every generating station with capacity of five megawatt and above and enclosed substation with transformation capacity of five megavolt-ampere and above for use in the event of fire or smoke:

Provided that where more than one generator with capacity of five megawatt and above is installed in a power station, each generator shall be provided with at least two separate gas masks in an accessible and conspicuous place.

(5) In every generating station, substation or switching station, an artificial respirator, fire extinguishers, first-aid boxes and gas masks shall be provided and kept in good working condition and locations of the same shall be displayed in the control room and operator cabin.

(6) Address and contact number of the nearest Doctor, Hospital with a facility for first-aid treatment for electric shock and burns, ambulance service and fire service shall be prominently displayed near the electric shock treatment chart in control room and operator cabin.

Regulation 30, Display of instructions for resuscitation of persons suffering from electric shock

(1) Instructions, in English or Hindi and the local language of the District and where Hindi is the local language, in English and Hindi for the resuscitation of persons suffering from electric shock, shall be affixed by the owner in a conspicuous place in every generating station, enclosed substation, enclosed switching station, mines and in every factory as defined in the Factory Act, 1948 (63 of 1952) in which electricity is used and in such other premises where electricity is used as the Electrical Inspector may, by notice in writing served on the owner, direct.

(2) The owner of every generating station, enclosed substation, enclosed switching station and every factory or other premises to which these regulations apply, shall ensure that all designated persons or persons engaged or appointed to operate and maintain electrical plants or transmission or distribution systems are acquainted with and are competent to apply the instructions referred to in sub-regulation (1).

Regulation 31, Precautions to be adopted by consumers, owners, occupiers, electrical contractors, electrical workmen and suppliers

(1) No electrical installation work, including additions, alterations, repairs and adjustments to existing installations, except such replacement of lamps, fans, fuses, switches, domestic appliances of voltage not exceeding 250 V and fittings as in no way alters its capacity or character, shall be carried out upon the premises of or on behalf of any consumer, supplier, owner or occupier for the purpose of supply to such consumer, supplier, owner or occupier except by an electrical contractor licenced in this behalf by the State Government and on its behalf under the direct supervision of a person holding a certificate of competency and by a person holding a permit issued or recognised by the State Government:

Provided that in the case of works executed for or on behalf of the Central Government and in the case of installations in mines, oil-fields and railways, the Central Government and in other cases the State Government, may, by notification in the Official Gazette, exempt on such conditions as it may impose, any such work described therein either generally or in the case of any specified class of consumers, suppliers, owners or occupiers.

Provided further that in the case of works executed for or on behalf of the Central Government and in the case of installations in mines, oil-fields and railways, an electrical contractor having licence issued by any State Government or Union Territory administration shall not require licence from other State Government in which the works are to be executed.

(2) No electrical installation work which has been carried out in contravention of sub-regulation (1) shall either be energised or connected to the works of any supplier.

Regulation 32, Periodical inspection and testing of installations

(1) The periodic inspection and testing of installation of voltage above the notified voltage belonging to the owner or supplier or consumer, as the case may be, shall be carried out by the Electrical Inspector:

Provided that the electrical installation below or equal to the notified voltage shall be self-certified by the owner or supplier or consumer, as the case may be.

(2) The periodicity of electrical inspection by the Electrical Inspector or the self-certification by the supplier, owner or consumer shall be as directed by the Appropriate Government.

Provided that the periodicity of electrical inspection and self-certification shall not exceed five years.

Provided further that in respect of the electrical installation belonging to mines, oil-fields and railways, such direction shall be issued by the Central Government.

(3) The periodic inspection and testing of installation of voltage equal to or below the notified voltage belonging to the owner or supplier or consumer, as the case may be, shall be carried out by the owner or supplier or consumer and shall be self-certified for ensuring observance of safety measures specified under these regulations and the owner or supplier or consumer, as the case may be, shall submit the report of self-certification to the Electrical Inspector in the Form I or Form II or Form III or Form IV, as the case may be, of Schedule II:

Provided that the electrical installation so self-certified shall be considered as duly inspected and tested only after the report of self-certification is duly received by the office of Electrical Inspector and if not acknowledged by the Electrical Inspector within three working days, it shall be deemed to be received:

Provided further that the owner or supplier or consumer has the option to get his installation inspected and tested by the Electrical Inspector of the Appropriate Government.

(4) Notwithstanding anything contained in sub-regulation (3), every electrical installation covered under section 54 of the Act including every electrical installation of mines, oil-fields and railways shall be periodically inspected and tested by the Electrical Inspector of the Appropriate Government.

(5) Where the supplier is directed by the Central Government or the State Government, as the case may be, to inspect and test the installation, such supplier shall report on the condition of the installation to the consumer concerned in the Form I, Form II, Form III and Form IV as provided in Schedule II and shall submit a copy of such report to the Electrical Inspector.

(6) The Electrical Inspector may, on receipt of such report, accept the report submitted by the supplier or record variations as the circumstances of each case may require and may recommend that the defects may be rectified as per report.

(7) In the event of the failure of the owner of any installation to rectify the defects in his installation pointed out by the Electrical Inspector in his report and within the time indicated therein, such installation shall be liable to be disconnected under the directions of the Electrical Inspector after serving the owner of such installation with a notice for a period not less than forty eight hours:

Provided that the installation shall not be disconnected in case an appeal is made under sub section (2) of section 162 of the Act and appellate authority has stayed the orders of disconnection.

(8) It shall be the responsibility of the owner of all installations to maintain and operate the installations in a condition free from danger and as recommended by the manufacturer or by the relevant standards.

Regulation 33, Testing of consumer's installation

(1) Upon receipt of an application for a new or additional supply of electricity and before commencement of supply or recommencement of supply after the supply has been disconnected for a period of six months, the supplier shall either test the installation himself or accept the test results submitted by the consumer when same has been duly signed by the licenced electrical contractor:

Provided that in case of voltage level equal to or below the notified voltage, Chartered Electrical Safety Engineer can also test the installation on request of owner.

(2) The testing and verifications shall be carried out as per relevant standards.

(3) The testing equipment shall be calibrated by a Government authorised or National Accreditation Board for Testing and Calibration Laboratories accredited laboratory at periodical interval as per the periodicity specified by them.

(4) The supplier shall maintain a record of test results obtained at each supply point to a consumer, as per the forms provided in Schedule III.

(5) If as a result of such inspection and test, the supplier is satisfied that the installation is likely to be dangerous, he shall serve on the applicant a notice in writing requiring him to make such modifications as are necessary to render the installation safe and may refuse to connect or reconnect the supply until the required modifications have been completed.

Regulation 34, Generating units required to be inspected by electrical inspector

The capacity above which generating units including generating units producing electricity from renewable sources of energy shall be required to be inspected by the Electrical Inspector before commissioning, shall be as per the notification issued by the Appropriate Government in this regard.

Regulation 35, Precautions against leakage before connection

(1) The supplier shall not connect its works with the apparatus in the premises of any applicant seeking supply unless the supplier is satisfied that at the time of making the connection cause a leakage from that installation or apparatus of a magnitude detrimental to safety which shall be checked by measuring the installation or apparatus insulation resistance as stipulated in the relevant standards.

(2) If the supplier declines to make a connection under the provisions of sub-regulation (1) the supplier shall convey to the applicant the reasons thereof, in writing for so declining.

Regulation 36, Leakage on consumer's premises

(1) If the Electrical Inspector or the supplier has reasons to believe that there is leakage in the system of a consumer which is likely to affect injuriously the use of electricity by the consumer or by other persons, or which is likely to cause danger, he may give notice to the consumer in writing to inspect and test the consumer's installation.

(2) If after such notice, the consumer fails to provide access to its installation for inspection and testing, or an insulation resistance of the consumer's installation is so low as to prevent safe use of electricity, the supplier may, and if directed so by the Electrical Inspector shall discontinue the supply of electricity to the installation but only after giving to the consumer forty eight hours notice in writing for disconnection of supply and shall not recommence the supply until he or the Electrical Inspector is satisfied that the cause of the leakage has been removed.

Regulation 37, Supply and use of electricity

(1) The electricity shall not be supplied, transformed, converted, inverted or used or continued to be supplied, transformed, converted, inverted or used unless the conditions provided in sub- regulations (2) to (8) are complied with.

(2) The following controls of requisite capacity to carry and break the current shall be installed as near as possible after the point of commencement of supply so as to be readily accessible and capable of completely isolating the supply to the installation, such equipment being in addition to any control switch installed for controlling individual circuits or apparatus, namely:

Supplied at voltage	*Control*
Below 11 kV.	Switch fuse unit or a circuit breaker by consumers.
11 kV and above.	A circuit breaker by consumers.

(i) In case of every transformer the following shall be provided, namely: –on primary side of transformer, a linked switch with fuse or gang operated air break switch with fuse or circuit breaker of adequate capacity:

Provided that the linked switch with fuse on the primary side of the transformer may be of such capacity as to carry the full load current and to break only the magnetising current of the transformer:

Provided further that for transformer having capacity of 1 000 kVA and above, a circuit breaker shall be provided:

Provided also that the linked switch with fuse or gang operated air break switch with fuse or circuit breaker on the primary side of the transformer shall not be required for the unit auxiliary transformer and generator transformer;

(ii) on the secondary side of all transformers a circuit breaker of adequate rating shall be installed:

Provided that for supplier's transformers of capacity below 1 000 kVA, a linked switch with fuse or circuit breaker of adequate rating shall be installed on secondary side.

(4) Except in the case of composite controlgear designed as a unit each distinct circuit is to be protected against excess energy by means of a suitable fuse link or a circuit breaker of adequate breaking capacity, suitably located and so constructed as to prevent danger from overheating, arcing or scattering of hot metal when it comes into operation and to permit for ready renewal of the fuse link without danger.

(5) The supply of electricity to each motor or a group of motors or other apparatus meant for operating one particular machine shall be controlled by a suitable linked switch or a circuit breaker or an emergency tripping device with manual reset of requisite capacity placed in such a position as to be adjacent to the motor or a group of motors or other apparatus readily accessible to and easily operated by the person incharge and so connected in the circuit that by its means all supply of electricity can be cut off from the motor or group of motors or apparatus from any regulating switch, resistance of other device associated therewith.

(6) All insulating materials shall be as per their application and their mechanical strength shall be sufficient for the purpose so as to maintain adequately their insulating property under all working conditions in respect of temperature, moisture, salinity and pollution.

(7) Adequate precautions shall be taken to ensure that no live parts are exposed as to cause danger.

(8) Every consumer shall use all reasonable means to ensure that where electricity is supplied by the supplier, no person other than the supplier shall interfere with service lines and apparatus placed by the supplier on the premises of the consumer.

Regulation 38, Provisions for supply and use of electricity in multi-storeyed building more than 15 metres in height

(1) The connected load and voltage of supply above which inspection is to be carried out by an Electrical Inspector for a multi-storeyed building of more than fifteen metre height shall be notified by the Appropriate Government.

(2) Before making an application for commencement of supply or recommencement of supply after an installation has been disconnected for a period of six months or more, the owner or occupier of a multi-storeyed building shall give not less than thirty days notice in writing to the Electrical Inspector specifying therein the particulars of installation and the supply of electricity shall not be commenced or recommenced within this period, without the approval in writing of the Electrical Inspector.

(3) The following safety measures shall be provided in the multi-storeyed buildings of more than fifteen metre height and other premises such as airports, hospitals, hotels, places of entertainment, places of worship, cultural centres, stadium, academic buildings, test labs, industrial installations, installation with explosive or flammable material, railway or metro stations and other public buildings, namely:

(i) the supplier or owner of the installation shall provide at the point of commencement of supply a suitable isolating device with cut-out or breaker to operate on all phases except neutral in the three-phase, four-wire circuit and fixed in a conspicuous position at not more than 1.70 metre above the ground so as to completely isolate the supply to the building in case of emergency;

(ii) the owner or occupier of a multi-storeyed building shall ensure that electrical installations and works inside the building are carried out and maintained in such a manner as to prevent danger due to shock and fire hazards, and the installation is carried out as per the relevant standards;

(iii) no other service pipes and cables shall be taken through the ducts provided for laying of power cables and all ducts provided for power cables and other services shall be provided with fire barrier at each floor crossing;

(iv) the Fire Retardant Low Smoke and Low Halogen power cables shall be used in building of more than fifteen metre height as per relevant standards;

(v) Provided that Halogen Free Flame Retardant power cables as per the relevant standards shall be used in airports, hospitals and hotels irrespective of height;

(vi) distribution of electricity to the floors shall be done using busbar trunking system;

(vii) lightning protection of the building shall be as per the relevant standards;

(viii) verification of electrical wiring of the building shall be carried out as per the relevant standards; and

(ix) electricity meter shall not be installed in the passage of staircase.

Regulation 39, Conditions applicable to installations of voltage exceeding 250 Volts

The following conditions shall be compiled with where electricity of voltage above 250 V is supplied, converted, transformed or used, namely:

(i) all conductors, other than those of overhead lines, shall be completely enclosed in mechanically strong metal casing or metallic covering which is electrically and mechanically continuous and adequately protected against mechanical damage unless the said conductors are accessible only to a designated person or are installed and protected so as to prevent danger:

Provided that non-metallic conduits conforming to the relevant standards may be used for installations of voltage not exceeding 650 V;

(ii) all metal works, enclosing, supporting or associated with the installation, other than that designed to serve as a conductor shall be connected with an earthing system as per relevant standards and the provisions of regulation 43;

(iii) every switch board shall comply with the following, namely:

  (a) a clear space of not less than one metre in width shall be provided in front of the switchboard;

  (b) if there are any attachments or bare connections at the back of the switchboard, the space, if any, behind the switchboard shall be either less than twenty centimetre or more than seventy five centimetre in width, measured from the farthest protruding part of any attachment or conductor; and

  (c) if the space behind the switchboard exceeds seventy five centimetre in width, there shall be a passage way from either end of the switchboard, clear to a height of 1.8 metre;

(iv) in case of installations provided in premises where inflammable materials including gases and chemicals are produced, handled or stored, the electrical installations, equipment and apparatus shall comply with the requirements of flame proof, dust tight, totally enclosed or any other suitable type of electrical fittings depending upon the hazardous zones as per the relevant standards;

(v) where an application has been made to a supplier for supply of electricity to any installation, the supplier shall not commence the supply or where the supply has been discontinued for a period of six months or more, recommence the supply unless the consumer has complied with the relevant provisions in these regulations;

(vi) where a supplier proposes to supply or use electricity at or to recommence supply of voltage exceeding 250 V but not exceeding 650 V after it has been discontinued for a period of six months, he shall, before connecting or reconnecting the supply, give notice in writing of such intention to the Electrical Inspector; and

(vii) if at any time after connecting the supply, the supplier is satisfied that any provision of these regulations have not been complied with, the supplier shall give notice of the same in writing to the consumer and the Electrical Inspector, specifying the defects and to rectify such defects in a reasonable time:

Provided that if the consumer fails to rectify such defects the supplier may discontinue the supply after giving the consumer a reasonable opportunity of being heard and recording reasons in writing and the supply shall be discontinued only on written orders of an officer duly notified by the supplier in this behalf and shall be restored with all possible speed after such defects are rectified by the consumer to the satisfaction of the supplier.

Regulation 40, Appeal to electrical inspector in regard to defects

(1) If any applicant for a supply or a consumer is aggrieved by the action of the supplier in declining to commence, to continue or to recommence the supply of electricity to his premises on the grounds that the installation is defective or is likely to be dangerous, he may appeal to the Electrical Inspector to test the installation and the supplier shall not, if the Electrical Inspector intimates that the installation is free from the defect or danger complained of, refuse supply to the consumer on the grounds aforesaid, and shall, within twenty four hours after the receipt of such intimation from the Electrical Inspector, commence, continue or recommence the supply of electricity.

(2) Any test for which application has been made under sub-regulation (1), shall be carried out within seven days after the receipt of such application.

Regulation 41, Precautions against failure of supply and notice of failures

(1) The layout of the electric supply lines of the supplier for the supply of electricity throughout his area of supply shall under normal working conditions be sectionalised and so arranged, and provided with switchgear or circuit-breakers, so located, as to restrict within reasonable limits the extent of the portion of the system affected by any failure of supply.

(2) The supplier shall take all reasonable precautions to avoid any accidental interruptions of supply, and also to avoid danger to the public or to any employee or designated person when engaged on any operation during and in connection with the installation, extension, replacement, repair and maintenance of any works.

(3) The supplier shall send to the Electrical Inspector a notice of failure of supply of such kind as the Electrical Inspector may from time to time require to be notified to him, and such notice shall be sent by the earliest mode of communication after the failure occurs or after the failure becomes known to the supplier and shall be in the Form given in Schedule IV.

(4) For the purpose of testing or for any other purpose connected with the efficient working of the supplier's installations, the supply of electricity may be discontinued by the supplier for such period as may be necessary, subject to not less than twenty four hours notice being given by the supplier to all consumers likely to be affected by such discontinuance:

Provided that no such notice shall be given in cases of emergency.

Regulation 42, Test of insulation resistance

Where any electric supply line for use at voltages not exceeding 650 V has been disconnected from a system for the purpose of addition, alteration or repair, such electric supply line shall not be reconnected to the system until the supplier or the owner has carried out the test.

Regulation 43, Connection with earth

The following conditions shall apply to the connection with earth of systems at voltage exceeding 50 V but not exceeding 650 V, namely:

(i) neutral conductor of a three phase, four-wire system and the middle conductor of a two-phase, three-wire system shall be earthed as per the relevant standards;

(ii) neutral conductor shall also be earthed at one or more points along the distribution system or service line in addition to any connection with earth which shall be at the consumer's premises;

(iii) in the case of a system comprising electric supply lines having concentric cables, the external conductor or armour of such cables shall be earthed by two separate and distinct connections with earthing system;

(iv) in a direct current system, earthing and safety measures shall be as per the relevant standards;

(v) every building shall have protective equipotential bonding by interconnecting the exposed and extraneous conductive parts as per the relevant standards;

(vi) the alternating current systems which are connected with the earth as provided in this regulation shall be electrically interconnected:

Provided that each connection with the earth is bonded to the metal sheathing and metallic armouring, if any, of the electric supply lines;

(vii) the frame of every generator, stationary motor, portable motor, and the metallic parts, not intended as conductors, all transformers and any other apparatus used for regulating or controlling electricity, and all electricity consuming apparatus, of voltage exceeding 250 V but not exceeding 650 V shall be earthed by two separate and distinct connections with earth by the owner as specified in the relevant standards;

(viii) all metal casing or metallic coverings containing or protecting any electric supply line or apparatus shall be connected with the earth and shall be so joined and connected across all junction boxes and other openings as to provide good mechanical and electrical connection throughout the length:

Provided that the conditions mentioned in this regulation shall not apply, where the supply voltage does not exceed 250 V and the apparatus consists of wall tubes or brackets, electroliers, switches, ceiling fans or other fittings, other than portable hand lamps and portable and transportable apparatus, unless provided with the earth terminal and to class-II apparatus and appliances of the relevant standards:

Provided further that where the supply voltage is not exceeding 250 V and where the installations are either new or renovated, all plug sockets shall be of the three pin type, and the third pin shall be permanently and effectively earthed;

(ix) All earthing systems shall:

(a) consist of equipotential bonding conductors capable of carrying the prospective earth fault current without exceeding the allowable temperature limits as per relevant standards in order to maintain all non- current carrying metal works reasonably at earth potential and to avoid dangerous contact potentials being developed on such metal works;

(b) have earth fault loop impedance sufficiently low to permit adequate fault current for the operation of protective device within the time stipulated in the relevant standards; and

(c) be mechanically strong, withstand corrosion and retain electrical continuity during the life of the installation and all earthing systems shall be tested to ensure effective earth bonding as per the relevant standards, before the electric supply lines or apparatus are energised.

(x) all earthing systems belonging to the supplier shall in addition, be tested for resistance on dry day during the dry season at least once in a year;

(xi) earth fault loop impedance shall be tested to ensure the automatic operation of the protective device and a record of every earth test made and the result thereof shall be kept by the supplier for a period of not less than two years after the day of testing and shall be available to the Electrical Inspector when required;

(xii) earth fault loop impedance of each circuit shall be limited to a value determined by the type and current rating of the protective device used such that, on the occurrence of an earth fault, disconnection of the supply shall occur before the prospective touch voltage reaches a harmful value; and

(xiii) the neutral point of every generator and transformer shall be earthed by connecting it to the earthing system not by less than two separate and distinct connections.

Regulation 46, Use of electricity at voltage exceeding 650 V.

(1) The Electrical Inspector where the supply voltage exceeds the notified voltage shall not authorise the supplier to commence supply or recommence the supply, where the supply has been discontinued for a period of six months or more, or the supplier, where the supply voltage is equal to or below the notified voltage but exceeds 650 V, shall not commence supply or recommence the supply where supply has been discontinued for a period of six months or more, to any consumer unless:

(a) all conductors and apparatus situated on the premises of the consumer are so placed as to be inaccessible except to the designated person;

(b) the consumer has provided and agreed to maintain a separate building or a locked weather proof and fire proof enclosure of agreed design and location, to which the supplier at all times shall have access for the purpose of housing his apparatus and metering equipment, or where the provision for a separate building or enclosure is impracticable, the consumer has segregated the aforesaid apparatus of the supplier from any other part of his own apparatus:

Provided that the segregation shall be made by the fire walls, if the Electrical Inspector considers it to be necessary:

Provided further that in the case of an outdoor installation the consumer shall suitably segregate the aforesaid apparatus belonging to the supplier from his own;

(c) all pole type substations are constructed and maintained in accordance with regulation 52.

(2) Where electricity at voltage exceeding 650 V is supplied, converted, transformed or used, the owner shall:

(i) maintain safety clearances for electrical apparatus as per relevant standards specification so that sufficient space is available for easy operation and maintenance without any hazard to the operating and maintenance personnel working near the equipment and for ensuring adequate ventilation:

Provided that in case of mines, the safety clearances for electrical apparatus to be as per relevant mining regulations;

(ii) not allow any encroachment below such installation:

Provided that where the Electrical Inspector comes across any such encroachment, he shall direct the owner to remove such encroachments;

(iii) maintain minimum safety working clearances specified in Schedule V for the bare conductors or live parts of any apparatus in outdoor substations excluding overhead lines of installations of voltage exceeding 650 V;

(iv) ensure that the live parts of all apparatus within the reach from any position in which a person may require to be, are suitably protected to prevent danger;

(v) ensure that where the transformer is used, suitable provision shall be made, either by connecting with earth, a point of the circuit at the lower voltage or otherwise, to guard against danger by reason of the said circuit becoming accidentally charged above its normal voltage by leakage from or contact with the circuit at the higher voltage;

(vi) not install a substation or a switching station with apparatus having more than 2 000 litres of oil in the basement where proper oil draining arrangement cannot be provided;

(vii) undertake the following measures, where a substation or a switching station with oil-filled apparatus, such as transformer, static condenser, switchgear or oil circuit breaker having more than 2 000 litres of oil is installed, whether indoor or outdoors:

(a) the separation wall or fire barrier walls of thickness and dimensions as specified in the relevant standards shall be provided between the apparatuses and between the apparatus and adjacent building if building wall adjacent to the apparatuses is not rated for four hours fire withstand rating;

(b) provisions shall be made for suitable oil soakpit and where use of more than 9000 litre of oil in any one oil tank, receptacle or chamber is involved, provision shall be made for the draining away or removal of any oil which may leak or escape from the tank, receptacle or chamber containing the same, and special precautions shall be taken to prevent the spread of any fire resulting from the ignition of the oil from any cause and adequate provision shall be made for extinguishing any fire which may occur;

(c) spare oil shall not be stored in the vicinity of any oil filled equipment in any such substation or switching station; and

(d) all the transformers and switchgears shall be maintained in accordance with the maintenance schedules prepared in accordance with the relevant standards;

(viii) without prejudice to the above measures, undertake adequate fire detection and protection arrangement for quenching the fire of the apparatus;

(ix) ensure that every transformer of 10 MVA or reactor of 10 MVAR and above rating shall be provided with automatic firefighting system as per relevant standards;

(x) undertake the following measures, where it is necessary to locate the substation, or switching station in the basement, namely:

  (a) the transformer room be in the first basement at the periphery;

  (b) the direct access to the transformer room be provided from outside and the surrounding walls of four hours fire withstand rating be provided as per relevant standards;

  (c) the entrances to the transformer room be provided with fire resistant doors of two hour fire rating and the door shall always be kept closed and a notice of this effect be affixed on outer side of the door;

  (d) a curb of a suitable height be provided at the entrance in order to prevent the flow of oil from a ruptured transformer into other parts of the basement;

  (e) the cables to primary side and secondary side have sealing at all floors and wall opening of atleast two hours fire withstand rating; and

  (f) Fire Retardant Low Smoke Low Halogen cable as per relevant standards be used;

(xi) ensure that oil filled transformers installed indoors in other than residential or commercial buildings are placed on the ground floor or not below the first basement;

(xii) ensure that only dry type transformer shall be used inside the residential and commercial buildings;

(xiii) ensure that cable trenches inside the substations and switching stations containing cables are filled with sand, pebbles or similar non-inflammable materials or completely covered with non-inflammable slabs; and

(xiv) ensure that unless the conditions are such that all the conductors and apparatus may be made dead at the same time for the purpose of cleaning or for other work, the said conductors and apparatus shall be so arranged that these may be made dead in sections, and that work on any such section may be carried on by the person designated or appointed or engaged or permitted under these regulations without danger.

(3) The minimum clearances specified in Schedule VI shall be maintained for bare conductors or live parts of any high voltage direct current apparatus in outdoor substations, excluding high voltage direct current overhead lines.

(4) There shall not be tapping of another transmission line from the main line for 66 kV and above class of lines:

Provided that during natural calamities, tapping may be allowed to ensure emergency power supply to affected areas till normalcy is restored.

Regulation 47, Inter-locks and protection for use of electricity at voltage exceeding 650 volts

(1) The owner shall ensure the following, namely-

(i) isolators and the controlling circuit breakers shall be inter-locked so that the isolators cannot be operated unless the corresponding breaker is in open position;

(ii) isolators and the corresponding earthing switches shall be inter-locked so that no earthing switch can be closed unless and until the corresponding isolator is in open position;

(iii) where two or more supplies are not intended to be operated in parallel, the respective circuit breakers or linked switches controlling the supplies shall be inter-locked to prevent possibility of any inadvertent paralleling or backfeed;

(iv) when two or more transformers are operated in parallel, the system shall be so arranged as to trip the secondary breaker of the transformer in case the primary breaker of that transformer trips;

(v) all gates or doors which provide access to live parts of an installation shall be inter-locked in such a way that these cannot be opened unless the live parts are made dead and proper discharging and earthing of these parts shall be ensured before any person comes in close proximity of such parts; and

(vi) where two or more generators operate in parallel and neutral switching is adopted, inter-lock shall be provided to ensure that the generator breaker cannot be closed unless one of the neutrals is connected to the earthing system.

(2) The following protection shall be provided in all systems and circuits to automatically disconnect the supply under abnormal conditions, namely:

(i) overcurrent protection to disconnect the supply automatically if the rated current of the equipment, cable or supply line is exceeded for a time which the equipment, cable or supply line is not designed to withstand;

(ii) earth fault or earth leakage protection to disconnect the supply automatically, if the earth fault current exceeds the limit of current for keeping the contact potential within the reasonable values;

(iii) buchholz relay, pressure relief device and winding and oil temperature protection with alarm and trip contacts shall be provided on all transformers of ratings 1 000 kVA and above;

(iv) transformers of capacity 10 MVA and above shall be protected against incipient faults by differential protection;

(v) all generators with rating of 100 kVA and above shall be protected against earth fault or leakage;

(vi) all generators of rating 1 000 kVA and above shall be protected against faults within the generator winding using restricted earth fault protection or differential protection or by both;

(vii) high speed busbar differential protection along with local breaker back up protection shall be commissioned and shall always be available at all 132 kV and above voltage substations and switching stations and generating stations connected with the grid:

Provided that in respect of existing 132 kV substations and switching stations having more than one incoming feeders, the high speed busbar differential protection along with local breaker back up protection, shall be commissioned and shall always be available; and

(viii) in addition to above, all electrical protection system for generating stations, substations and transmission lines shall be as per the regulations notified by the Authority under clause (e) of sub-section (2) of section 177 of the Act.

Regulation 48, Testing, operation and maintenance

(1) Before the approval is accorded by the Electrical Inspector under regulation 45, the manufacturer's test certificates shall, if required, be produced for all the type, acceptance and routine tests as required under the relevant standards.

(2) No new apparatus, cable or supply line of voltage exceeding 650 V shall be commissioned unless such apparatus, cable or supply line are subjected to site tests as per relevant standards.

(3) No apparatus, cable or supply line of voltage exceeding 650 V which has been kept disconnected for a period of six months or more from the system for alterations or repair, shall be connected to the system until such apparatus, cable or supply line are subjected to the site tests as per relevant standards.

(4) Notwithstanding the provisions of this regulation, the Electrical Inspector may require certain tests to be carried out before or after charging the installations.

(5) All apparatus, cables and supply lines shall be maintained in healthy conditions and tests shall be carried out periodically as per the relevant standards.

(6) Records of all tests, trippings, maintenance works and repairs of all apparatus, cables and supply lines shall be duly kept in such a way that these records can be compared with the past records.

(7) It shall be the responsibility of the owner of all installations of voltage exceeding 650 V to maintain and operate the installations in a condition free from danger and as recommended by the manufacturer or by the relevant standards.

(8) Failures of any 220 kV and above voltage level transformer, reactor and transmission line towers shall be reported by the owner of electrical installation, within forty eight hours of the occurrence of the failure, to the Authority and the reasons for failure and measures to be taken to avoid recurrence of failure shall be sent to the Authority within one month of the occurrence in the forms provided in Schedule VII:

Provided that in case of mines and oil-fields, the failure of 10 MVA or above transformers shall be reported to Electrical Inspector of mines.

Regulation 50, Connection with earth for apparatus exceeding 650 volts

(1) The entire switchyard or substation equipment and buildings including all non-current carrying metal parts associated with an installation shall be effectively earthed to an earthing system or mat which shall –

(i) limit the touch and step potential to tolerable values as per relevant standards;

(ii) limit the earth potential rise to tolerable values as per relevant standards, so as to prevent danger due to transfer of potential through ground, earth wires, cable sheath, fences, pipe lines or other such equipment; and

(iii) maintain the resistance of the earth connection to such a value as to make operation of the protective device effective.

(2) In the case of star connected system with earthed neutrals or delta connected system with earthed artificial neutral point:

(i) the neutral point of every generator and transformer shall be earthed by connecting it to the earthing system not by less than two separate and distinct connections:

Provided that the neutral point of a generator may be connected to the earthing system through an impedance to limit the fault current:

Provided further that in the case of multi-machine systems, neutral switching may be resorted to, for limiting the injurious effect of harmonic current circulation in the system;

(ii) the generator or transformer neutral shall be earthed through a suitable impedance where an appreciable harmonic current flowing in the neutral connection causes interference with the communication circuits; and

(iii) in case of the delta connected system, the neutral point shall be obtained by the insertion of a earthing transformer and current limiting resistance or impedance wherever considered necessary at the commencement of such a system.

(3) In case of generating stations, substations and other installations of voltage exceeding 33 kV, the system neutral earthing and protective frame earthing may be, if system design so warrants, integrated into common earthing grid provided the resistance to earth of combined mat does not cause the step and touch potential to exceed the values as per relevant standards.

(4) Single phase systems of voltage exceeding 650 V shall be effectively earthed.

(5) In the case of a system comprising electric supply lines having concentric cables, the external conductor shall be connected with the earth.

(6) Where a supplier proposes to connect with earth an existing system for use at voltage exceeding 650 V which has not hitherto been so connected with earth, he shall give not less than fourteen days notice in writing together with particulars of the proposed connection with earth to the telegraph authority established under the *Indian Telegraph Act*, 1885 (13 of 1885).

(7) Where the earthing lead and earth connection are used only in connection with earthing guards laid under overhead lines of voltage exceeding 650 V but not exceeding 33 kV where they cross a telecommunication line or a railway line, and where such lines are equipped with earth leakage protective device, the earth resistance shall not exceed 25 Ω and the project authorities shall obtain no objection certificate from Railway Authorities and Power and Telecommunication Coordination Committee before energisation of the facilities.

Every earthing system belonging to either the supplier or the consumer shall be tested for its resistance to earth on a dry day during dry season not less than once in a year and records of such tests shall be maintained and produced, if so required, before the Electrical Inspector.

Regulation 60, Clearance in air of the lowest conductor of overhead lines

(1) The minimum clearance above ground and across road surface of National Highway or Expressway or State Highway or other road or highest traction conductor of railway corridor or navigational or non-navigational river of the lowest conductor of an alternating current overhead line, including service lines, of nominal voltage shall have the values specified in Schedule VIII A.

(2) The minimum clearances regarding high voltage direct current line shall be as per Schedule VIII B.

(3) In case of Electric lines of 33 kV and below passing through the protected areas (National Parks, Wildlife Sanctuaries, Conservation Reserves, Community Reserves), Eco-sensitive zones around the protected areas and Wildlife Corridors, only underground cable shall be used.

(4) No tower footing or structure of an overhead line of voltage 33 kV or above or high voltage direct current, shall be closer than twenty five metre from the edge of the right of way of a Petroleum or Natural Gas pipeline.

(5) Wherever overhead line of voltage 33 kV or above or high voltage direct current intending to cross the right of way of a Petroleum or Natural Gas pipeline, the angle of crossing of the overhead line with respect to the pipelines shall preferably be at right angles and, in any case, the crossing angle shall not be less than seventy five degrees.

Regulation 62, Clearance from buildings of lines of voltage and service lines not exceeding 650 Volts

(1) An overhead line shall not cross over an existing building as far as possible and no building shall be constructed under an existing overhead line.

(2) Where an overhead line of voltage not exceeding 650 V passes above or adjacent to or terminates on any building, the following minimum clearances from any accessible point, on the basis of maximum sag, shall be observed, namely–

(i) for any flat roof, open balcony, *verandah* roof and lean-to-roof:

(a) when the line passes above the building, a vertical clearance of 2.5 metre from the highest point; and

(b) when the line passes adjacent to the building, a horizontal clearance of 1.2 metre from the nearest point;

(ii) for pitched roof:

(a) when the line passes above the building, a vertical clearance of 2.5 metre immediately under the line; and

(b) when the line passes adjacent to the building, a horizontal clearance of 1.2 metre.

(3) Any conductor so situated as to have a clearance less than that specified in sub-regulation (2) shall be replaced with Aerial Bunched Cable and to be attached at suitable intervals to a bare earthed bearer wire having a breaking strength of not less than 350 kgf.

(4) The horizontal clearance shall be measured when the line is at a maximum deflection from the vertical due to wind pressure.

(5) The vertical and horizontal clearances shall be measured as per illustration provided in Schedule VIII C.

Explanation — For the purposes of this regulation, the expression ‘building’ shall be deemed to include any structure, whether permanent or temporary.

Regulation 63, Clearance from buildings of lines of voltage exceeding 650 V

(1) An overhead line shall not cross over an existing building as far as possible and no building shall be constructed under an existing overhead line.

(2) Where an overhead line of voltage exceeding 650 V passes above or adjacent to any building or part of a building it shall have on the basis of maximum sag a vertical clearance above the highest part of the building immediately under such line, of not less than:

(i)	for lines of voltage exceeding 650 Volts up to and including 33kV	-	3.7 m
(ii)	for lines of voltage exceeding 33 kV	-	3.7 m plus 0.30 m for every additional 33 kV or part thereof.

(3) The horizontal clearance between the nearest conductor and any part of such building shall, on the basis of maximum deflection due to wind pressure, be not less than:

(i)	for lines of voltage exceeding 650 V up to and including 11 kV	-	1.2 m
(ii)	for lines of voltage exceeding 11 kV and up to and including 33 kV	-	2.0 m
(iii)	for lines of voltage exceeding 33 kV	-	2.0 m plus 0.3 m for every additional 33 kV or part thereof.

(4) For high voltage direct current systems, the vertical and horizontal clearances, on the basis of maximum deflection due to wind pressure, from buildings shall be maintained as below:

Sl No.	*High Voltage Direct Current*	*Vertical Clearance* m	*Horizontal Clearance* m
1.	100 kV	4.6	2.9
2.	200 kV	5.8	4.1
3.	300 kV	7.0	5.3
4.	400 kV	7.9	6.2
5.	500 kV	9.1	7.4
6.	600 kV	10.3	8.6
7.	800 kV	12.4	10.7

(5) The vertical and horizontal clearances shall be as measured as illustrated in Schedule VIII C.

Regulation 66, Transporting and storing of material near electric lines

(1) No rods, pipes or similar materials shall be taken below, or in the vicinity of any bare overhead conductors or lines:

Provided that if these materials contravene the Regulations 62 and 63, such materials shall be transported under the direct supervision of a person designated or appointed or engaged or permitted under these regulations.

(2) No rods, pipes or other similar materials shall be brought within the flash over distance of bare live conductors or overhead lines.

(3) No material or earth work or agricultural produce shall be dumped or stored, no trees grown below or in the vicinity of bare overhead conductors or lines in contravention to the Regulations 62 and 63.

(4) No flammable material shall be stored under the electric line.

(5) No fire shall be allowed below overhead lines and above the demarcated underground cables.

Regulation 67, General clearances

(1) For the purpose of computing the vertical clearance of an overhead line, the maximum sag of any conductor shall be calculated on the basis of the maximum sag in still air and the maximum temperature as specified under Regulation 59 and computing any horizontal clearance of an overhead line the maximum deflection of any conductor shall be calculated on the basis of the wind pressure specified under Regulation 59.

(2) No blasting for any purpose shall be done within three hundred metre from the boundary of a substation or from the electric supply lines of voltage exceeding 650 V or tower structure thereof without the written permission of the owner of such substation or electric supply lines or tower structures; and in case of mining lease hold area, without the written permission of the Electrical Inspector of mines.

(3) No cutting of soil within ten metre from the tower structure of 110 kV and above voltage level shall be permitted without the written permission of the owner of tower structure.

(4) No person shall construct brick kiln or other polluting units near the installations or transmission lines of 220 kV and above within a distance of 500 metre.

Regulation 76, Safety and Protective Devices

(1) Every overhead line which is not being suspended from a dead bearer wire, not being covered with insulating material and not being a trolley-wire, is laid over any part of a street or other public place or in any factory or mine or on any consumer's premises shall be protected with earth guarding for rendering the line electrically harmless in case its conductor breaks.

(2) An Electrical Inspector may, by notice in writing, require the owner of any such overhead line, wherever it may be laid, to protect it in the manner specified in sub-regulation (1) of this regulation.

(3) To prevent bird dropping on the suspension insulator strings, suitable bird guards as per relevant standards, shall be provided on cross arms of suspension tower or suspension pole structures, over the suspension insulator strings.

Regulation 119, Additional safety requirements for renewable generating stations

The regulations under this chapter shall be applicable to renewable generating stations which shall be in addition to the regulations provided from chapter I to VII.

Regulation 121, Safety Requirements for Solar Installations

(1) The following general safety requirement for solar installations shall be ensured, namely –

(i) clear pathways of minimum seventy five centimetre in width with hand rails for roof access and emergency exit shall be provided for roof top system;

(ii) there shall be clear pathways, walkways between the rows or columns of solar panels which is necessary for cleaning and maintenance;

(iii) cables shall be laid in trenches for ground based photovoltaic installation;

(iv) ground mounted solar installations shall be protected by fencing or other means not less than 1.8 metre in height so as to prevent unauthorised entry;

(v) disconnection switches or circuit breakers provided in combiner boxes to disconnect the photovoltaic system from all other conductors of the system shall be located at a readily accessible location;

(vi) three phases on the alternating current side, and positive and negative conductor on the direct current side shall be marked and identified with different colours;

(vii) inverter unit for solar photovoltaics shall be installed in the periphery of the building and as near as the solar panel:

Provided that the direct current cable shall be ultraviolet protected or routed through ultraviolet protected pipe;

(viii) there shall be a manual disconnection switch to isolate the system from grid and shall be situated outside the alternating current combiner box; and

(ix) protection shall be deployed (for both input and output) on site for overload, surge current, surge voltage, short circuit, high temperature, over voltage, under voltage and over frequency, under frequency, reverse polarity and lightning.

(2) The following earthing requirements for solar installations shall be ensured, namely –

(i) solar earthing shall be as per the relevant standard;

(ii) the frame of inverter cabinet shall be connected with the earthing bus bar through the earthing terminals using flexible braided copper wire;

(iii) all metal casing and shielding of the plant, each array structure of the photovoltaic yard, equipment, inverters and control systems shall be earthed through proper earthing;

(iv) earthing system shall connect all non-current carrying metal receptacles, electrical boxes, appliance frames, chasis and photovoltaic module mounting structures in one long run and the earth strips shall be interconnected by proper welding and shall not be bolted;

(v) there shall be adequate number of interconnected earth pits provided in each location and minimum required gap shall be provided in between earth pits as per relevant standard.

(3) The following protection, testing and interlocking requirement for solar installations shall be ensured; namely:

(i) the solar photovoltaic power plant shall be provided with lightning and over voltage protection by deploying required number of lightning arresters as per the relevant standards;

(ii) every combiner box shall be provided with suitable surge protective device with arc extinguishing capability as per the relevant standards to avoid any risk of fire;

(iii) the input circuits of combiner box shall be provided with over current protection as per the relevant standards;

(iv) the output circuits of combiner box shall be provided with isolation protection;

(v) earth fault protection and insulation monitoring for photovoltaic arrays and inverters shall be provided;

(vi) all photovoltaic modules safety qualification shall comply with relevant standards.

(4) *Requirement to prevent fire for solar installations* — A fire detection system and automatic fire suppression system shall comply with the relevant standards.

(5) *Additional safety requirements for floating solar photovoltaic energy installations* — Photovoltaic modules and associated structure of floating solar power plant shall comply with the relevant standards for tests such as salt mist, ammonia corrosion, environmental stress cracking of High Density Poly Ethylene, stress cracking resistance of High Density Poly Ethylene and standard test method for tensile properties of plastics.

Regulation 123, Additional safety requirements for electric vehicle charging station

The regulations under this chapter shall be applicable to electric vehicle charging stations which shall be in addition to the regulations provided from chapter I to VII.

Regulation 124, General safety requirements for electric vehicle charging station

(1) Electric vehicle charging stations shall be provided with separate protection against the overload of input supply and output supply as per relevant standards.

(2) Socket-outlet of supply of electric vehicle charging points shall be installed at least 800 millimetre above the finished ground level.

(3) A cord extension set or second supply lead shall not be used in addition to the supply lead for the connection of the electric vehicle to the charging point and shall not be used as a cord extension set.

(4) No adaptor shall be used to connect a vehicle connector to a vehicle inlet.

(5) The distance between the charging point and the connection on the electric vehicle shall not be more than five metre during charging.

(6) The portable socket outlets shall not be permitted for electric vehicle charging.

(7) The lightning protection system shall be provided for the electric vehicle charging stations as per relevant standards.

(8) The electric vehicle charging station shall be equipped with a protective device against the uncontrolled reverse power flow from electric vehicle to the charging point.

(9) One second after disconnecting the electric vehicle from the supply mains, the voltage between accessible conductive parts or any accessible conductive part and earth shall be less than or equal to 42.4 Vpeak (30 Vrms), or 60 V DC, and the stored energy available shall be less than 20 J:

(10) Provided that, if the voltage is greater than 42.4 Vpeak (30 Vrms) or 60 V DC, or the energy is 20 J or more, a warning label shall be attached in a conspicuous position on the charging stations.

(11) A vehicle connector used for direct current charging shall be locked on the vehicle inlet if the voltage is higher than 60 V DC and in case of charging system malfunction, a means for safe disconnection shall be provided.

(12) The electric vehicle charging point shall disconnect supply of electricity to prevent overvoltage at the battery, if the output voltage exceeds maximum voltage limit permissible for the vehicle.

(13) The electric vehicle charging points shall not energise the charging cable when the vehicle connector is in unlock position.

(14) The electric vehicle connector shall not unlock if the voltage between the vehicle connector and the earth is more than 60 V.

(15) Safety clearance between the oil or gas dispenser and electric vehicle charging point shall be as per the order issued by the Authority.

(16) Only four core cable shall be used for charging points which require three phase power supply.

(17) Underground cables shall not cross the underground oil tank or oil pipeline.

(18) Underground cables through the charging area or vehicles passage shall be avoided and if provided shall be at a minimum depth of one metre from the finished ground surface.

Regulation 125, Earth Protection System for the Charging Station

(1) Each electric vehicle charging points shall be supplied individually by a dedicated sub-circuit protected by an overcurrent protective device complying with the relevant standards and the overcurrent protective device shall be part of a switchboard.

(2) Co-ordination of all protective devices in the charging stations shall be ensured.

(3) All electric vehicle charging stations shall be provided with an earth continuity monitoring system that disconnects the supply in the event of the earthing connection to the vehicle becomes ineffective.

(4) The charging lead shall be fitted with an earth-connected metal shielding and the cable insulation shall be wear resistant and maintain flexibility over the operating temperature range.

(5) A protective earth conductor shall be provided to establish an equipotential connection between the earth terminal of the supply and the conductive parts of the vehicle which shall be as per the relevant standards.

Regulation 126, Requirement to Prevent Fire for Electric Vehicle Charging Station

(1) The enclosure of electric vehicle supply equipment shall be made of fire retardant material with self-extinguishing property and free from halogen.

(2) The fire detection, alarm and control system shall be provided as per relevant standards.

Regulation 127, Testing of Charging Station

The owner of the charging station shall ensure that the tests as specified in the manufacturer's instructions for the residual current devices and the charging station have been carried out.

Regulation 128, Maintenance of records

(1) The owner of the charging station shall keep records of design, construction and labelling to be compatible with a supply of standard voltage at a nominal frequency of 50 Hz of the charging station.

(2) The owner of the charging station shall keep records of the relevant test certificates as indicated in these regulations and as per the relevant standards.

(3) The owner of the charging station shall keep records of the results of every inspection, testing and periodic assessment and details of any issues observed during the assessment and any actions required to be taken in relation to those issues.

(4) The owner of the charging station shall retain a copy of all records, as specified in sub-regulation (1), (2) and (3) of above, either in hard form or in electronic form, for at least seven years and shall provide a copy of the records to the officials during the inspection.

ANNEX C

[*Clauses* 4.2.1(ff), 4.2.2.2 *and* D-1 (Note)]

AREA REQUIRED FOR TRANSFORMER ROOM AND SUBSTATION FOR DIFFERENT CAPACITIES

C-1 The requirement for area for transformer room and substation for different capacities of transformers is given below for guidance:

Sl No. (1)	*Capacity of Transformer*(*s*) kVA (2)	*Total Transformer Room Area*, *Min* m^2 (3)	*Total Substation Area* (*Incoming*, *HV Panels*, *MV Panels*, *Transformer Roof but Without Generators*), *Min* m^2 (4)	*Suggested Minimum Face Width* m (5)
i)	1 × 160	14.0	90	9.0
ii)	2 × 160	28.0	118	13.5
iii)	1 × 250	15.0	91	9.0
iv)	2 × 250	30.0	121	13.5
v)	1 × 400	16.5	93	9.0
vi)	2 × 400	33.0	125	13.5
vii)	3 × 400	49.5	167	18.0
viii)	2 × 500	36.0	130	14.5
ix)	3 × 500	54.0	172	19.0
x)	2 × 630	36.0	132	14.5
xi)	3 × 630	54.0	176	19.0
xii)	2 × 800	39.0	135	14.5
xiii)	3 × 800	58.0	181	14.0
xiv)	2 × 1 000	39.0	149	14.5
xv)	3 × 1 000	58.0	197	19.0

NOTES

1 The areas given in respect of the different categories of rooms hold good, if they are provided with independent access doors in accordance with local regulations.

2 The minimum height of substation room/HV switch room/MV switch room shall be arrived at considering 1200 mm clearance requirement from top of the equipment to the below of the soffit of the beam. In case cable entry/exit is from above the equipment (transformer, HV switchgear, MV switchgear), height of substation room/HV switch room/MV switch room shall also take into account requirement of space for turning radius of cable above the equipment height

3 Additional space will be required in cases where the load requirement calls for redundancy for enhanced reliability through addition of switchgear, such as, bus couplers, etc.

4 For transformers of other capacity, it may lead to some minor changes in dimensioning.

ANNEX D

(*Clauses* 3.5.2(h) *and* 4.3.2)

ADDITIONAL AREA REQUIRED FOR GENERATOR IN ELECTRIC SUBSTATION

D-1 The requirement of additional area for generator in electric substation for different capacities of generators is given in the table below for guidance.

NOTES

1 The space requirements vary for specific installations due to factors such as derating due to site conditions (temperature, altitude, etc); type of cooling (radiator, heat exchanger, cooling tower, etc); type of ventilation; noise suppression system and special characteristics of loads, if any.

2 If the generator is located away from the substation, then additional switchgear will be required, area requirement for which can be estimated from the norms given in Annex C.

3 The area requirement suggested below covers the space requirement for day-tank and not the space for the bulk fuel storage.

Sl No. (1)	*Capacity* kVA (2)	*Area* m^2 (3)	*Clear Height below the Soffit of the Beam* m (4)
i)	25	56	3.6
ii)	48	56	3.6
iii)	100	65	3.6
iv)	150	72	3.6
v)	248	100	4.2
vi)	350	100	4.2
vii)	480	100	4.2
viii)	600	110	4.6
ix)	800	120	4.6
x)	1 010	120	6.5
xi)	1 250	120	6.5
xii)	1 600	150	6.5
xiii)	2 000	150	6.5

NOTE — The area and height required for generating set room given in the above table are for general guidance only and may be finally fixed according to actual requirements.

ANNEX E

(*Clauses* 9.3.1 *and* 9.4)

CHECKLIST FOR INSPECTION, HANDING OVER AND COMMISSIONING OF VARIOUS EQUIPMENT OF SUBSTATION

E-1 Typical format for checklist for inspection, handing over and commissioning of HV cables is given below:

NOTE — Format given below covers a basic minimum check list; it should be augmented for specific and special cases. The checklist has to be repeated for each HV cable.

HV CABLE INSPECTION, HANDING OVER AND COMMISSIONING DETAILS

A. DETAILS OF WORK

1) Scope of works :
2) Handed over by :
3) Taken over by :
4) Date of commissioning :
5) Date of handing over :
6) Details of enclosures :

Sl No.	*Description*	*Applicable*	*Not Applicable*
(1)	(2)	(3)	(4)
i)	Quality check list		
ii)	Site test report		
iii)	As built GA drawing/layout		
iv)	Manufacturer’s test certificates		
v)	Operation and maintenance manual		

Handed Over By

Taken Over By

Authorized Signatory

Authorized Signatory

B. QUALITY CHECK LIST

Item: Installation of HV Cables				
Make:				
Sl No.	*Tests Parameters*	*Bench Mark*	*Actual Observations*	*Remark*
(1)	(2)	(3)	(4)	(5)
i)	Cable size			
ii)	Voltage grade			
iii)	Type of material			
iv)	Check for routing			
v)	Meggering using 2.5 kV insulation tester			
	R-Y			
	Y-B			
	B-R			
	R-E			
	Y-E			
	B-E			
vi)	Minimum width of trench			
vii)	Minimum depth of trench			
viii)	Hume pipes used			
ix)	Hume joints with collar properly aligned and packed with 75 mm of cement concrete			
x)	Cable laying with suitable rollers			
xi)	Bending radius			
xii)	Cable tagging			
xiii)	Hi-Pot test (18 kV)			
xiv)	Sealing of cable ends, if not being terminated immediately			
xv)	Trench closing			

C. HI-POT TEST REPORT

1) Date of testing:

2) Equipment details:

Cable details

Location :
Panel No. :
Size :

3) Insulation Resistance Test (Value in MΩ, using 5 kV Megger):

Reference	*Measured Values* MΩ	
	Before	After
R-E		
Y-E		
B-E		
R-Y		

Y-B		
B-R		

4) Winding Resistance Test:

Applied Voltage kV	*Measured Current* mA
R = Y + B + E	
Y = B + R + E	
B = R + Y + E	

5) Remarks

E-2 Typical format for checklist for handing over and commissioning of HV panels is given below:

NOTE — Format given below covers a basic minimum check list; it should be augmented for specific and special cases. The checklist has to be repeated for each HV panel.

HV PANEL INSPECTION, HANDING OVER AND COMMISSIONING DETAILS

Project:

Owner:

Package:

Contractor:

A. HANDING OVER DETAILS

1) Scope of works :
2) Panel name and number :
3) Location :
4) Handed over by :
5) Taken over by :
6) Date of commissioning :
7) Date of handing over :
8) Details of enclosures :

Sl No.	Description	Applicable	Not Applicable
(1)	(2)	(3)	(4)
i)	Quality check list		
ii)	Site test report		
iii)	As built GA drawing/layout		
iv)	Manufacturer's test certificates		
v)	Operation and maintenance manual		

Handed Over By

Taken Over By

Authorized Signatory

Authorized Signatory

B. QUALITY CHECK LIST

Item: HV panel
Make:
Relevant Indian Standard:
As-built Drawing No:

Sl No.	*Test Parameters*	*Bench Mark*	*Actual Observations*
(1)	(2)	(3)	(4)
	Physical Checks for:		
	Circuit Breaker		
i)	Dimension enclosure		
ii)	Gauge		
iii)	Paint		
iv)	Degree of protection		
v)	Front doors		
vi)	Back cover		
vii)	Extension type enclosure		
viii)	Type of circuit breaker		
ix)	Number of circuit breakers		
x)	Type of surge arresting device included in the circuit breakers		
xi)	Earthing terminal		
xii)	Front plate with view glass		
xiii)	Space for mounting of current transformers		
xiv)	Space for mounting of potential transformers		
xv)	Cable entry		
xvi)	Interlocking with isolator		
xvii)	Earthing switch for cable in cable chamber		
xviii)	Earthing switch interlock with circuit breaker only it can be operated in ‘OFF’ condition		
xv)	Low voltage plug and socket		
xvi)	Vents for breaker/busbar/cable chambers		
xvii)	Insulation level		
xviii)	Toggle switch		
xix)	Ammeter selector switch		
xx)	Voltmeter selector switch		
xxi)	Trip/Neutral/Close		
xxii)	Local/remote selector switch		
xxiii)	LED lamps		
xxiv)	Mechanical operation		
xxv)	Remote operation		
xxvi)	Local operation		
xxvii)	Interlocking with isolator		
	Meters		
xxviii)	Voltmeter		

Sl No.	*Test Parameters*	*Bench Mark*	*Actual Observations*
(1)	(2)	(3)	(4)
xxix)	Ammeter		
xxx)	Tri vector meter		
xxxi)	Power factor meter		
xxxii)	Frequency meter		
	Specification Checks for		
xxxiii)	Rated current		
xxxiv)	Rated voltage		
xxxv)	Rated short circuit breaking capacity		
xxxvi)	Contact resistance		
xxxvii)	Control wiring		
xxxviii)	All control circuits Alarm and trip for OTI/WTI/Buchholz/ PRV		
xxxix)	SF6 pressure alarm and trip operation test		

C. COMMISSIONING REPORT

Customer:	
Project:	
Contractor:	
Panel Name:	
Location:	
Breaker Details:	

INSULATION TEST (MΩ)

R-Y	Y-B	B-R	R-E	Y-E	B-E	R-N	Y-N	B-N

RELAY SETTINGS

Overcurrent, Earth Fault and Undervoltage Relay	
CT ratio: Earth fault >Settings: I_o> Settings: Under voltage relay:	

GENERAL CHECKS

Breaker ‘ON’/‘OFF’	
Meters reading	
Indicating lamps	
Control supply	

E-3 Typical format for checklist for handing over and commissioning of transformers is given below:

NOTE — Format given below covers a basic minimum check list; it should be augmented for specific and special cases. The checklist has to be repeated for each transformer.

TRANSFORMER INSPECTION, HANDING OVER AND COMMISIONING DETAILS

Project:
Owner:
Package:
Contractor:

A. HANDING OVER DETAILS

1) Scope of works :
2) Transformer No. :
3) Location :
4) Handed over by :
5) Taken over by :
6) Date of commissioning :
7) Date of handing over :
8) Details of enclosures :

Sl No.	*Description*	*Applicable*	*Not Applicable*
(1)	(2)	(3)	(4)
i)	Quality check list		
ii)	Site test report		
iii)	As built GA drawing/layout		
iv)	Manufacturer's test certificates		
v)	Operation and maintenance manual		

Handed Over By

Authorized Signatory

Taken Over By

Authorized Signatory

B. QUALITY CHECK LIST

Item: Transformer
Make:
Relevant Indian Standard:
As-built Drawing No:

Sl No.	*Test Parameters*	*Bench Mark*	*Actual Observation*
(1)	(2)	(3)	(4)
a)	*Physical Checks for:*		
	i) Transformer Sl No.		
	ii) Dimension of enclosure		
	iii) Enclosure – Degree of protection		
	iv) Gauge		
	v) Paint		
	vi) Provision for lifts and jacking		
	vii) Wheels		
	viii) Locking facility for wheel		
	ix) Enclosure door (if applicable)		
	x) Enclosure door interlock wiring		
	xi) Removable case for access of taps		
	xii) Earthing terminal		
	xiii) Disconnecting type chamber for cable termination		
	xiv) LT side flanges (Bus ducts/Cables/ Overhead)		
	xv) Oil temperature indicator (relay unit)		
	xvi) Winding temperature indicator (relay unit)		
	xvii) Marshalling box winding and door switch		
	xviii) Thermistors for alarm and trip		
	xix) Separate neutral earthing chamber		
	xx) Rating and diagram plate		
	xxi) Tap changing options name plate		
	xxii) Oil level in conservator tank		
	xxiii) Oil level in breather cup		
	xxiv) Operation of PRV		
	xxv) Oil leakage (if applicable)		
	xxvi) Clearances around transformer		
	xxvii) Body earthing resistance		
	xxviii) Neutral earthing resistance		
b)	*Specification checks for*:		
	i) Rating of transformer		
	ii) Type		
	iii) Winding conductor		
	iv) Primary voltage		
	v) HV winding connections		

Sl No.	*Test Parameters*	*Bench Mark*	*Actual Observation*
(1)	(2)	(3)	(4)
	vi) Secondary voltage		
	vii) LV side connections		
	viii) Vector symbol		
	ix) System of supply		
	x) Impedance percentage		
	xi) Oil temperature rise		
	xii) Winding temperature rise		
	xiii) Tap changing		
	xiv) Tapping range		
	xv) Insulation type		
	xvi) Type of cooling		
	xvii) Vector group test		
	xviii) Polarity test		
	xix) Magnetizing test		
	xx) Tan delta test (as per capacity)		
	xxi) Breakdown voltage test: *Oil sample – I* (*Top*) *Oil sample – II* (*Bottom*)		

C. COMMISSIONING REPORT

Customer:	
Project:	
Contractor:	
Transformer Number:	
Location:	
Rating:	

INSULATION TEST (MΩ)

R-Y	Y-B	B-R	R-E	Y-E	B-E	R-N	Y-N	B-N

RELAY SETTINGS

Transformer Protection Relay (*WTI Scanner*): Winding temperature alarm set Winding temperature trip set (*OTI Scanner*): Oil temperature alarm set Oil temperature trip set	
Buchholz Relay	

GENERAL CHECKS

Breaker 'ON'/'OFF'	
Meters reading	
Indicating lamps	
Control supply	

E-4 Typical format for checklist for handing over and commissioning of MV/LV panel is given below:

NOTE — Format given below covers a basic minimum check list; it should be augmented for specific and special cases. The checklist has to be repeated for each MV/LV panel.

MV/LV PANEL INSPECTION, HANDING OVER AND COMMISIONING DETAILS

Project:
Owner:
Package:
Contractor:

A. HANDING OVER DETAILS

1) Scope of works :
2) Panel name :
3) Location :
4) Handed over by :
5) Taken over by :
6) Date of commissioning :
7) Date of handing over :
8) Details of enclosures :

Sl No.	*Description*	*Applicable*	*Not Applicable*
(1)	(2)	(3)	(4)
i)	Quality check list		
ii)	Site test report		
iii)	As built GA drawing		
iv)	Manufacturer's test certificates		
v)	Operation and maintenance manual		

Handed Over By

Taken Over By

Authorized Signatory

Authorized Signatory

B. QUALITY CHECK LIST

Item: MV/LV Panel
Make:
Relevant Indian Standard:
As-built Drawing No:

Sl No.	*Test Parameters*	*Bench Mark*	*Actual Observation*
(1)	(2)	(3)	(4)
a)	*Physical Checks for:*		
	i) Dimension enclosure		
	ii) Paint		
	iii) Degree of protection		
	iv) Front doors		
	v) Back cover		
	vi) Earthing terminal		
	vii) Front plate with view glass		
	viii) Cable entry		
	ix) Indication lamps		
	x) Check for any damages		
	xi) Check for rubber beading for the panel sections		
	xii) Coupling of panel		
	xiii) Coupling of busbars		
	xiv) Coupling of earth bus		
	xv) Number of shipping sections		
	xvi) Fish plate tightening		
	xvii) Any damages in busbar supports		
	xviii) Make of MCCB		
b)	*Specification Checks for:*		
	i) Rated current		
	ii) Rated voltage		
	iii) Rated short circuit capacity		
c)	*Circuit Breaker*:		
	i) Current rating		
	ii) Interlocks with other CB/relay		
	iii) Compartment		
	iv) End terminals segregation		
d)	*Busbar*:		
	i) Earth busbar		
	ii) Main busbar		
	iii) Link busbar		
	iv) Busbar sleeve		
e)	3 *Phase – Potential transformer*:		
	i) Make		
	ii) Ratio		

Sl No.	*Test Parameters*	*Bench Mark*	*Actual Observation*
(1)	(2)	(3)	(4)
	iii) Class		
	iv) Serial Nos.		
f)	*Current transformer*:		
	i) Make		
	ii) Ratio		
	iii) Class		
	iv) Serial No’s		
g)	*Multi digital meter*:		
	i) Make		
	ii) Input voltage		
	iii) Input current		
	iv) Wiring		
	v) For potential transformer		
	vi) For current transformer		
	vii) Incomer		
	viii) Outgoing		

C. COMMISSIONING REPORT

Customer:	
Project:	
Contractor:	
Panel Name:	
Location:	
Breaker Details:	

INSULATION TEST (MΩ)

R-Y	Y-B	B-R	R-E	Y-E	B-E	R-N	Y-N	B-N

RELAY SETTINGS

GENERAL CHECKS

Breaker ‘ON’/‘OFF’	
Meters reading	
Indicating lamps	
Control supply	

ANNEX F

(*Clause* 9.5)

FORM OF COMPLETION CERTIFICATE

I/ We certify that the installation detailed below has been installed by me/us and tested and that to the best of my/our knowledge and belief, it complies with *Central Electricity Authority* (*Measures Relating to Safety and Electricity Supply*) *Regulations*, 2023 as amended up-to-date and also the relevant provisions of Indian Standards and National Electrical Code of India, 20xx.

Electrical Installation at ____

A. INSTALLATION DATA

Voltage and system of supply _______________________________________

a) *Particulars of Works*:

1) Internal electrical installation:

Sl No.	*Description*	*No.*	*Total Load*	*Type of System of Wiring*
i)	Light point			
ii)	Fan point			
iii)	Plug point			
	3-pin 6 A			
	3-pin 16 A			
	5-pin 6 A			
	6-pin 16 A			

2) Others:

Sl No.	*Description*	*HP/kW*	*Type of Starting*
i)	Motors		
	1)		
	2)		
	3)		
ii)	Other plants		
	1)		
	2)		
	3)		

3) If the work involves installations of overhead line and/or underground cable:

i)	1) Type and description of over headline	
	2) Total length and No. of spans	
	3) No. of street lights and its description	
ii)	1) Total length of underground cable and its size	
	2) No. of joints:	
	End joint:	
	Tee joint:	
	Straight through joint:	

b) *Earthing*:

i)	Description of earthing electrode	
ii)	No. of earth electrodes	
iii)	Size of main earth lead	
iv)	Earth electrode resistance	

The date on which the measurements for item (iv) was taken has to be recorded.

NOTE — The above data should be supported by an appropriate drawing and tables indicating the reference points at which the measurements were taken at the construction/installation stage.

B. PRE-COMMISSIONING TEST DATA

a) *Test Results*:

1) Appropriate drawings showing the points at which the measurements were taken should accompany this report.

2) Environmental notes pertaining to the day on which the tests are conducted:

    i) Temperature:

    ii) Date and time:

    iii) Previous day/days history from the aspect of rain (in as much as it would affect the test results):

3) List of test instruments used:
(Please record the calibration certificate date, calibration authority and the validity date of each instrument listed.)

    i) -------------------

    ii) -------------------

4) Results:

    i) Insulation resistance

a)	Insulation resistance of the whole system of conductors to earth	……….. Megaohms
b)	Insulation resistance between the phase conductor and neutral:	
	Between phase R and neutral	……….. Megaohms
	Between phase Y and neutral	……….. Megaohms
	Between phase B and neutral	……….. Megaohms
c)	Insulation resistance between the phase conductors in case of polyphase supply	
	Between phase R and phase Y	……….. Megaohms
	Between phase Y and phase B	……….. Megaohms
	Between phase B and phase R	……….. Megaohms
d)	Insulation resistance between neutral conductor and earth in case of systems with neutral solidly earthed at the source	……….. Megaohms

ii) Polarity test:

Polarity of non-linked single pole branch switches:

iii) Earth continuity test:

Maximum resistance between any point in the earth continuity conductor including metal conduits and main earthing lead ……………Ohms.

iv) Earth electrode resistance:

a) Resistance of each earth electrode:

1) …………….. Ohms
2) …………….. Ohms
3) …………….. Ohms
4) …………….. Ohms

b) Resistance of each earth grid:

1) …………….. Ohms
2) …………….. Ohms
3) …………….. Ohms
4) …………….. Ohms

v) Lightning protective system:

a)	Designed lightning protection level (LPL)	…..
b)	Total roof area (L X W)	….. m^2
c)	Air-termination mesh size (L X W)	….. m x m
d)	Number of vertical rods/terminal (Down-conductors)	…..
e)	Distance between down-conductors	….. m
f)	Impulse current rating of SPD, if any	…… kA
g)	Voltage protection level of incoming SPD	…….kV
h)	Resistance of down-conductor for reinforced concrete structure/PEB structures, if natural components are used as per NBCS (Part D/ Section 2) 'Building Services, Electrical and Allied Installations'	……. ohms
j)	Resistance of the whole of lightning protective system to earth before any bonding is effected with earth electrode and metal in/on the structure	……. ohms

Signature of Supervisor	Signature of Contractor
Name and Address	Name and Address
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----------------------------------	-------------------------------
----------------------------------	-------------------------------

Persons witnessing the test:

Name	Designation/Address	Signature	Remarks
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ANNEX G

(*Clause* 3.5)

DECLARATIONS

G-1 DECLARATION FOR DESIGN

I/We being the person(s) responsible for the design of the electrical installation (as indicated by my/our signatures below), particulars of which are described below, having exercised reasonable skill and care when carrying out the design, hereby DECLARE that the design work for which I/we have been responsible is to the best of my/our knowledge and belief conform to the *CEA* (*Measures Relating to Safety and Electric Supply*) *Regulations*, 2023 and in accordance with the National Electrical Code of India, 20xx, National Building Construction Standards, 2026 and relevant standards of the products used and except for the departures, if any, detailed as follows:

Departures

Project/Site details

(Sign)
Electrical Consultant
Name and Address

(Sign)
Electrical Engineer on site

G-2 DECLARATION FOR CONSTRUCTION

I/We being the person(s) responsible for the construction of the electrical installation (as indicated by my/our signatures below), particulars of which are described below, having exercised reasonable skill and care when carrying out the construction, hereby DECLARE that the construction work for which I/we have been responsible is to the best of my/our knowledge and belief conform to the *CEA* (*Measures relating to Safety and Electric Supply*) *Regulations,* 2023 and in accordance with the relevant Indian Standards, National Electrical Code of India, 20xx, and National Building Construction Standards, 2026 and except for the departures, if any, detailed as follows:

Departures

Project/Site details

(Sign)
Electrical Contractor
Name and Address

(Sign)
Electrical Engineer on site

G-3 DECLARATION FOR INSPECTION AND TESTING

I/We being the person(s) responsible for the inspection and testing of the electrical installation (as indicated by my/our signatures below), particulars of which are described below, having exercised reasonable skill and care when carrying out the inspection and testing, hereby DECLARE that the construction work for which I/we have been responsible is to the best of my/our knowledge and belief conform to the *CEA* (*Measures Relating to Safety and Electric Supply*) *Regulations*, 2023 and in accordance with the relevant Indian Standards, National Electrical Code of India, 20xx and National Building Construction Standards, 2026 and except for the departures, if any, detailed as follows:

Departures

Project/Site details

(Sign)
Electrical Safety Verifier
L. No./Registration No.
Name and Address

(Sign)
Electrical Engineer on site

LIST OF STANDARDS

The following list records those standards which are acceptable as ‘good practice’ and ‘accepted standards’ in the fulfilment of the requirements of this NBCS. The latest version of a standard shall be adopted at the time of enforcement of this NBCS. The standards listed may be used for conformance with the requirements of the referred clauses in the NBCS.

In the following list, the number appearing in the first column within parenthesis indicates the number of the reference in this Section.

	IS No.	*Title*
(1)	SP 30 : 2023	National Electrical Code of India, 2023 (*second revision*)
(2)	IS 8270 (Part 1) : 2023/ IEC 61082-1 : 2014	Preparation of documents used in electrotechnology: Part 1 Rules (*first revision*)
	IS 1885 (Part 16) : 2023/ IEC 60050-845 : 2020	Electrotechnical — Vocabulary: Part 16 Lighting
	IS 1885	Electrotechnical vocabulary:
	(Part 17) : 2024/ IEC 60050-441 : 1984	Switchgear and control gear (*second revision*)
	(Part 32) : 2019/ IEC 60050-461 : 2008	Electrical cables (*second revision*)
	(Part 78) : 1993/ IEC Pub 50 (601) : 1985	Generation, transmission and distribution of electricity — General
	IS 19127 : 2025/ IEC 60617 : 2024	Graphical symbols for diagrams in the field of electrotechnology
(3)	IS 17505 (Part 1) : 2021	Specification for thermosetting insulated fire survival cables for fixed installation having low emission of smoke and corrosive gases when affected by fire for working voltages upto and including 1 100 V a.c. and 1500 V d.c.: Part 1 Requirements for armoured cables
(4)	IS 694 : 2010	Polyvinyl chloride insulated unsheathed and sheathed cables/cords with rigid and flexible conductor for rated voltages up to and including 1 100 V (*fourth revision*)
(5)	IS 17048 : 2018	Halogen free flame retardant (HFFR) cables for working voltages up to and including 1 100 volts — Specification
(6)	IS/IEC 61537 : 2006	Cable management — Cable tray systems and cable ladder systems
(7)	IS/IEC 62271-202 : 2022	High-voltage switchgear and controlgear: Part 202 a.c. prefabricated substations for rated voltages above 1 kV and up to and including 52 kV (*first revision*)
(8)	IS/IEC 60947-1 : 2020	Low-voltage switchgear and controlgear: Part 1 General rules (*second revision*)
	IS/IEC 60947-2 : 20xx	Low-voltage switchgear and controlgear: Part 2 Circuit-breakers (*under publication*)

	IS/IEC 60947-3 : 2020	Low-voltage switchgear and controlgear: Part 3 Switches, disconnectors, switch-disconnectors and fuse-combination units (*second revision*)
	IS/IEC 60947-4-1 : 2023	Low-voltage switchgear and controlgear: Part 4 Contractors and motor-starters, Section 1 Electromechanical contactors and motors-starters (*third revision*)
	IS/IEC 60947-4-2 : 2020	Low-voltage switchgear and controlgear: Part 4 Contractors and motor-starters, Section 2 Semiconductor motor controllers, starters and soft-starters (*second revision*)
	IS/IEC 60947-4-3 : 2020	Low-voltage switchgear and controlgear: Part 4 Contactors and motor-starters, Section 3 Semiconductor controllers and semiconductor contactors for non-motor loads (*third revision*)
	IS/IEC 60947-5-1 : 2016	Low-voltage switchgear and controlgear: Part 5 Control circuit devices and switching elements, Section 1 Electromechanical control circuit devices (*second revision*)
	IS/IEC 60947-5-2 : 2019	Low-voltage switchgear and control gear: Part 5 Control circuit devices and switching elements, Section 2 Proximity switches (*first revision*)
(9)	IS/IEC 60309-1 : 2021	Plugs, fixed or portable socket-outlet and appliance inlets for industrial purposes: Part 1 General requirements (*second revision*)
	IS/IEC 60309-2 : 2021	Plugs, fixed or portable socket-outlets and appliance inlets for industrial purposes: Part 2 Dimensional compatibility requirements for pin and contact-tube accessories (*second revision*)
(10)	IS 17050 : 2023/ IEC 62262 : 2021 +AMD1 2021	Degrees of protection provided by enclosures for electrical equipment against external mechanical impacts (IK code) (*first revision*)
(11)	IS 3043 : 2018	Code of practice for earthing (*second revision*)
(12)	IS 17036 : 2018	Distribution system supply voltage quality
(13)	IS 18732 : 2023	Guide for implementation of electrical installation standards in building
(14)	IS 7752 (Part 1) : 1975	Guide for improvement of power factor in consumers' installation: Part 1 Low and medium supply voltages
(15)	IS 5216	Recommendations on safety procedures and practices in electrical work:
	(Part 1) : 1982	General (*first revision*)
	(Part 2) : 1982	Life saving techniques (*first revision*)
(16)	IS 10028 (Part 2) : 1981	Code of practice for selection, installation and maintenance of transformers: Part 2 Installation

(17)	IS 10118 (Part 3) : 1982	Code of practice for selection, installation and maintenance of switchgear and controlgear: Part 3 Installation
(18)	IS 732 : 2019	Code of practice for electrical wiring installations (*fourth revision*)
(19)	IS 16996 : 2018/ IEC 60364-8-1 : 2014	Low-voltage electrical installations — Energy efficiency
(20)	IS 10118 (Part 2) : 1982	Code of practice for the selection, installation and maintenance of switchgear and controlgear: Part 2 Selection
(21)	IS 1646 : 2015	Fire safety of buildings (general): Electrical installations — Code of practice (*third revision*)
(22)	IS/IEC 61439 – All parts/ Sections	Low-voltage switchgear and controlgear assemblies — All parts/Sections
(23)	IS 1255 : 1983	Code of practice for installation and maintenance of power cables (up to and including 33 kV rating) (*second revision*)
(24)	IS 8084 : 2025	Interconnecting bus-bars for a.c. voltage above 1 kV up to and including 36 kV — Specification (*first revision*)
(25)	IS 1180 (Part 1) : 2014	Outdoor type oil immersed distribution transformers upto and including 2 500 kVA, 33kV — Specification: Part 1 Mineral oil immersed (*fourth revision*)
	IS 2026	Power transformers:
	(Part 1) : 2011	General (*second revision*)
	(Part 2) : 2010	Temperature-rise (*first revision*)
	(Part 3) : 2018/ IEC 60076-3 : 2000	Insulation levels, dielectric tests and external clearances in air (*fourth revision*)
	IS 2026 (Part 4) : 1977	Specification for power transformers: Part 4 Terminal marking, tappings and connections (*first revision*)
	IS 2026	Power transformers:
	(Part 5) : 2011	Ability to withstand short circuit (*first revision*)
	(Part 7) : 2009/ IEC 60076-7 : 2005	Loading guide for oil-immersed power transformers
	(Part 8) : 2009/ IEC 60076-8 : 1997	Applications guide
	(Part 10) : 2025/ IEC 60076-10 : 2016	Determination of sound levels (*first revision*)
	(Part 11) : 2021 IEC 60076-11 : 2018	Dry-type transformers
(26)	IS/IEC 61439-2 : 2020	Low-voltage switchgear and controlgear assemblies: Part 2 Power switchgear and controlgear assemblies (*first revision*)

	IS/IEC 60947-1 : 2020	Low-voltage switchgear and controlgear: Part 1 General rules (*second revision*)
	IS/IEC 60947-2 : 20xx	Low-voltage switchgear and controlgear: Part 2 Circuit-breakers (*under publication*)
	IS/IEC 60947-3 : 2020	Low-voltage switchgear and controlgear: Part 3 Switches, disconnectors, switch-disconnectors and fuse combination units (*second revision*)
	IS/IEC 60947-4-1 : 2018	Low-voltage switchgear and controlgear: Part 4 Contractors and motor-starters, Section 1 Electromechanical contactors and motors-starters (*second revision*)
	IS/IEC 60947-4-2 : 2020	Low-voltage switchgear and controlgear: Part 4 Contractors and motor-starters, Section 2 Semiconductor motor controllers starters and soft-starters (*second revision*)
	IS/IEC 60947-4-3 : 2020	Low-voltage switchgear and controlgear: Part 4 Contractors and motor-starters, Section 3 Semiconductor controllers and Semiconductor contactors for non-motor loads (*third revision*)
	IS/IEC 60947-5-1 : 2024	Low-voltage switchgear and controlgear: Part 5 Control circuit devices and switching elements, Section 1 Electromechanical control circuit devices (*third revision*)
	IS/IEC 60947-5-2 : 2019	Low-voltage switchgear and control gear: Part 5 Control circuit devices and switching elements, Section 2 Proximity switches (*first revision*)
	IS/IEC 61439 (Part 0) : 2014	Low-voltage switchgear and controlgear assemblies: Part 0 Guidance to specifying assemblies
	IS/IEC 61439-1 : 2020	Low-voltage switchgear and controlgear assemblies: Part 1 General rules (*first revision*)
(27)	IS 11353 : 2023/ IEC 60445 : 2021	Basic and safety principles for man-machine interface, marking and identification — Identification of equipment terminals, conductor terminations and conductors (*first revision*)
(28)	IS/IEC 61439-6 : 2012	Low-Voltage switchgear and controlgear assemblies Part 6 Busbar trunking systems (Busways)
(29)	IS 13010 : 2002	ac watthour meters, class 0.5, 1 and 2 — Specification (*first revision*)
	IS 13779 : 2020	a.c. static watthour meters, class 1 and 2 — Specification (*second revision*)
	IS 14697 : 2021	a.c. static transformer operated watthour meters (class 0.2 s and 0.5 s) and var-hour meters (class 0.2 s, 0.5 s and 1 s) — Specification (*first revision*)
	IS 15884 : 2024	Alternating current direct connected static prepayment meters for active energy (class 1 and class 2) — Specification (*first revision*)
	IS 16444 : 2015	a.c. static direct connected watthour smart meter class 1 and 2 — Specification

(30)	IS 15707 : 2006	Testing, evaluation, installation and maintenance of ac electricity meters — Code of practice
(31)	IS/IEC 60079-1 : 2014	Explosive atmospheres: Part 1 Equipment protection by flameproof enclosures “d” (*first revision*)
(32)	IS 5578 : 1984	Guide for marking of insulated conductors (*first revision*)
	IS 11353 : 2023/ IEC 60445 : 2021	Basic and safety principles for man-machine interface, marking and identification — Identification of equipment terminals, conductor terminations and conductors (*first revision*)
(33)	IS/IEC 60309-1 : 2021	Plugs, fixed or portable socket-outlets and appliance inlets for industrial purposes: Part 1 General requirements (*second revision*)
	IS/IEC 60309-2 : 2021	Plugs, fixed or portable socket-outlets and appliance inlets for industrial purposes: Part 2 Dimensional compatibility requirements for pin and contact-tube accessories (*second revision*)
(34)	IS/IEC 60079 (Part 1) : 2014	Explosive Atmospheres: Part 1 Equipment Protection by Flameproof Enclosures "d"
	IS 10322 (Part 5/Sec 5) : 2026/IEC 60598-2-5 : 2015	Luminaires: Part 5 Particular requirements, Section 5 Flood lights (*second revision*)
(35)	IS 12640 (Part 1) : 2024/ IEC 61008-1 : 2013	Residual current operated circuit-breakers without integral overcurrent protection for household and similar uses (RCCBs): Part 1 General rules (*third revision*)
	IS 12640 (Part 2) : 2016/ IEC 61009-1 : 2012	Residual current operated circuit-breakers with integral overcurrent protection for household and similar uses (RCBOs): Part 2 General rules (*second revision*)
	IS 14614 : 2023/ IEC 61543 : 2022	Residual current-operated protective devices (RCDs) for household and similar use — Electromagnetic compatibility (*first revision*)
	IS/IEC 60898-1 : 2015	Electrical accessories – Circuit-breakers for overcurrent protection for household and similar installations: Part 1 Circuit-breakers for a.c. operation (*first revision*)
	IS/IEC 60947-1 : 2020	Low-voltage switchgear and controlgear: Part 1 General rules (*second revision*)
	IS/IEC 60947-2 : 20xx	Low-voltage switchgear and controlgear: Part 2 Circuit-breakers (*under publication*)
	IS/IEC 60947-3 : 2020	Low-voltage switchgear and controlgear: Part 3 Switches, disconnectors, switch-disconnectors and fuse combination units (*second revision*)
	IS/IEC 60947-4-1 : 2023	Low-voltage switchgear and controlgear: Part 4 Contractors and motor-starters, Section 1 Electromechanical contactors and motors-starters (*third revision*)
	IS/IEC 60947-4-2 : 2020	Low-voltage switchgear and controlgear: Part 4 Contractors and motor-starters, Section 2 Semiconductor motor controllers starters and soft starters (*second revision*)

	IS/IEC 60947-4-3 : 2020	Low-voltage switchgear and controlgear: Part 4 Contractors and motor-starters, Section 3 Semiconductor controllers and semiconductor contactors for non-motor loads (*third revision*)
	IS/IEC 60947-5-1 : 2024	Low-voltage switchgear and controlgear: Part 5 Control circuit devices and switching elements, Section 1 Electromechanical control circuit devices (*third revision*)
	IS/IEC 60947-5-2 : 2019	Low-voltage switchgear and control gear: Part 5 Control circuit devices and switching elements, Section 2 Proximity switches (*first revision*)
(36)	IS/lEC 60529 : 2001	Degrees of protection provided by enclosures (IP code)
	IS 17050 : 2023 IEC 62262 : 2021 +AMD1 2021	Degrees of protection provided by enclosures for electrical equipment against external mechanical impacts (IK Code) (*first revision*)
(37)	IS 3961	Recommended current ratings for cables:
	(Part 2) : 2017	PVC insulated and PVC sheathed heavy duty cables (*first revision*)
	(Part 3) : 1968	Rubber insulated cables
	(Part 5) : 1968	PVC insulated light duty cables
	(Part 6) : 2016	Crosslinked polyethylene insulated PVC sheathed cables
(38)	SP 72 : 2025	National Lighting Code of India 2025 (*first revision*)
(39)	IS 4648 : 1968	Guide for electrical layout in residential buildings
(40)	IS 900 : 2019	Code of practice for storage, installation and maintenance of induction motors (*third revision*)
(41)	IS 9537	Specification for conduits for electrical installations:
	(Part 1) : 1980	General requirements
	(Part 2) : 1981	Rigid steel conduits
	(Part 3) : 1983	Rigid plain conduits of insulating materials
(42)	IS 16205	Conduit systems for cable management:
	(Part 1) : 2017	General requirements
	(Part 24) : 2017	Particular requirements — conduit systems buried underground
(43)	IS 14297 : 2024/ISO 9226 : 2012	Corrosion of metals and alloys — Corrosivity of atmospheres — Determination of corrosion rate of standard specimens for the evaluation of corrosivity (*first revision*)
(44)	IS/IEC 61537 : 2006	Cable management — Cable tray systems and cable ladder systems
(45)	IS 9537	Specification for conduits for electrical installations:

	(Part 1) : 1980	General requirements
	(Part 3) : 1983	Rigid plain conduits of insulating materials
(46)	IS 9537	Specification for conduits for electrical installations:
	(Part 1) : 1980	General requirements
	(Part 2) : 1981	Rigid steel conduits
(47)	IS 3837 : 1976	Specification for accessories for rigid steel conduits for electrical wiring (*first revision*)
	IS 14768	Conduit fittings for electrical installations — Specification:
	(Part 1) : 2000	General requirements
	(Part 2) : 2003	Metal conduit fittings
	IS 14772 : 2020	Boxes and enclosures for electrical accessories for household and similar fixed electrical installations — General requirements (*first revision*)
(48)	IS 3419 : 1988	Specification for fittings for rigid non-metallic conduits (*second revision*)
	IS 14772 : 2020	Boxes and enclosures for electrical accessories for household and similar fixed electrical installations — General requirements (*first revision*)
(49)	IS 18925 (Part 7) : 2025/ IEC 62561-7 : 2024	Lightning protection system components (LPSC): Part 7 Requirements for earthing enhancing compounds
(50)	IS 18925 (Part 5) : 2025/ IEC 62561-5 : 2023	Lightning protection system components (LPSC): Part 5 Requirements for earth electrode inspection housings and earth electrode seals
(51)	IS 18925 (Part 1) : 2025/ IEC 62561-1 : 2023	Lightning protection system components (LPSC): Part 1 Requirements for connection components
(52)	IS/IEC 62305-1 : 2010	Protection against lightning: Part 1 General principles
	IS/IEC 62305-2 : 2010	Protection against lightning: Part 2 Risk management
	IS/IEC 62305-3 : 2010	Protection against lightning: Part 3 Physical damage to structures and life hazard
	IS/IEC 62305-4 : 2010	Protection against lightning: Part 4 Electrical and electronic systems within structures
(53)	IS 16242	Uninterruptible power systems (UPS):
	(Part 1) : 2025/ IEC 62040-1 : 2017 + AMD1 : 2021 + AMD2 : 2022 CSV	Safety requirements (*first revision*)

	(Part 2) : 2020/ IEC 62040-2 : 2016	Electromagnetic compatibility EMC requirements (*first revision*)
	(Part 3) : 2025/ IEC 62040-3 : 2021	Method of specifying the performance and test requirements *(first revision*)
	(Part 5/Sec 3) : 2025/ IEC 62040-5-3 : 2016	d.c. output UPS, Section 3 Performance and test requirements
(54)	IS 17017 — All parts/sections	Specification for electric vehicle conductive charging system — All parts/sections
(55)	IS 17896 (Part 1) : 2022/ IEC TS 62840-1 : 2016	Electric vehicle battery swap system: Part 1 General and guidance
	IS 17896 (Part 2) : 2022/ IEC 62840-2 : 2016	Electric vehicle battery swap system: Part 2 Safety requirements
(56)	IS 17017 (Part 23) : 2021	Electric vehicle conductive charging systems: Part 23 d.c. electric vehicle supply equipment
(57)	IS 17017 (Part 24) : 2021	Electric vehicle conductive charging system: Part 24 Digital communication between a DC electric vehicle supply equipment and an electric vehicle for control of DC charging
(58)	IS/ISO 15118 — All parts/sections	Road vehicles — Vehicle to grid communication interface — All parts/sections
(59)	IS 17017 (Part 2/Sec 3) : 2020	Electric vehicle conductive charging system: Part 2 Plugs, socket — outlets, vehicle connectors and vehicle inlets, Section 3 Dimensional compatibility and interchangeability requirements for d.c. and a.c./d.c. pin and contact-tube vehicle couplers
(60)	IS 14286 : 2023 IEC 61215 : 2021 — All parts/sections	Terrestrial photovoltaic (PV) modules — Design qualification and type approval — All parts/sections
	IS 16228 : 2024/ IEC 62108 : 2022	Concentrator photovoltaic (CPV) modules and assemblies — Design qualification and type approval (*second revision*)
	IS 17210 (Part 1) : 2019/ IEC TS 62804-1 : 2015	Photovoltaic (PV) modules — Test methods for the detection of potential-induced degradation: Part 1 Crystalline silicon
	IS 16664 : 2018/ IEC 62716 : 2013	Photovoltaic (PV) modules — Ammonia corrosion testing
	IS/IEC 61730 — All parts	Photovoltaic (PV) module safety qualification — All parts
	IS/IEC 61701 : 2011	Salt mist corrosion testing of photovoltaic (PV) modules
(61)	IS 14286 : 2023 IEC 61215 : 2021 — All parts/sections	Terrestrial photovoltaic PV modules design qualification and type approval — All parts/sections
	IS 16170 (Part 1) : 2014/ IEC 61853-1 : 2011	Photovoltaic (PV) module performance testing and energy rating: Part 1 Irradiance and temperature performance measurements and power rating

	IS/IEC 61730 — All parts/sections	Photovoltaic (PV) module safety qualification — All parts/sections
	IS 17210 (Part 1) : 2019/ IEC TS 62804-1 : 2015	Photovoltaic (PV) modules — Test methods for the detection of potential-induced degradation: Part 1 Crystalline silicon
(62)	IS 2062 : 2011	Hot rolled medium and high tensile structural steel — Specification (*seventh revision*)
	IS 4759 : 1996	Hot-dip zinc coatings on structural steel and other allied products — Specification (*third revision*)
(63)	IS 2062 : 2011	Hot rolled medium and high tensile structural steel — Specification (*seventh revision*)
	IS 1079 : 2017	Hot rolled carbon steel sheet, plate and strip — Specification (*seventh revision*)
	IS 1161 : 2014	Steel tubes for structural purposes — Specification (*fifth revision*)
	IS 1239 (Part 1) : 2004	Steel tubes, tubulars and other wrought steel fittings — Specification: Part 1 Steel tubes (*sixth revision*)
(64)	IS/IEC 61683 : 1999	Photovoltaic systems — Power conditioners — Procedure for measuring efficiency
	IS/IEC 60068-2-1 : 2007	Environmental testing: Part 2 Tests, Section 1 Test A: Cold
	IS 16169 : 2019/ IEC 62116 : 2014	Utility-interconnected photovoltaic inverters — Test procedure of islanding prevention measures (*first revision*)
	IS/IEC 60068-2-2 : 2007	Environmental testing: Part 2 Tests, Section 2 Test B dry heat
	IS/IEC 60068-2-14 : 2023	Environmental testing: Part 2 Tests, Section 14 Test N: Change of temperature (*first revision*)
	IS/IEC 60068-2-30 : 2005	Environmental testing: Part 2 Tests, Section 30 Test Db: Damp heat cyclic (12 h + 12 h cycle)
	IS 14700 — All parts	Electromagnetic compatibility (EMC) — All parts
	IS 16221 (Part 2) : 2015/ IEC 62109-2 : 2011	Safety of power converters for use in photovoltaic power systems: Part 2 Particular requirements for inverters
(65)	IS 16221 (Part 2) : 2015/ IEC 62109-2 : 2011	Safety of power converters for use in photovoltaic power systems: Part 2 particular requirements for inverters
(66)	IS 17293 : 2020	Electric cables for photovoltaic systems for rated voltage 1 500 V d.c.
(67)	IS 14286 (Part 1/Sec 1) : 2023/ IEC 61215-1-1 : 2021	Terrestrial photovoltaic (PV) modules — Design qualification and type approval: Part 1-1 Special requirements for testing of crystalline silicon photovoltaic (PV) modules (*third revision*)

	IS/IEC 61730-1 : 2023	Photovoltaic (PV) module — Safety qualification: Part 1 Requirements for construction (*second revision*)
(68)	IS 12933	Solar flat plate collector — Specification:
	(Part 1) : 2025	Requirements (*third revision*)
	(Part 2) : 2025	Components (*third revision*)
	IS 16544 : 2016	All glass evacuated tubes solar water heating system
	IS 16542 : 2016	Direct insertion type storage water tank for all glass evacuated tubes solar collector — Specification
(69)	IS 12933	Solar flat plate collector — Specification:
	(Part 1) : 2025	Requirements (*third revision*)
	(Part 2) : 2025	Components (*third revision*)
(70)	IS 16544 : 2016	All glass evacuated tubes solar water heating system
(71)	IS 16542 : 2016	Direct insertion type storage water tank for all glass evacuated tubes solar collector — Specification
(72)	IS 302 (Part 2/Sec 76) : 1999	Safety of household and similar electrical appliances: Part 2 Particular requirements, Section 76 Electric fence energizers
(73)	IS/IEC 62305-3 : 2010	Protection against lightning: Part 3 Physical damage to structures and life hazard
(74)	IS/IEC 62305-4 : 2010	Protection against lightning: Part 4 Electrical and electronic systems within structures
(75)	IS/IEC 62305-1 : 2010	Protection against lightning: Part 1 General principles
(76)	IS/IEC 62305-2 : 2010	Protection against lightning: Part 2 Risk management
(77)	IS 16172 : 2023	Reinforcement couplers for mechanical splices of steel bars in concrete — Specification (*first revision*)
(78)	IS 18925 — All parts/sections	Lightning protection system components (LPSC) — All parts/sections
(79)	IS 12360 : 2026	Voltage bands for electrical installations including preferred voltage and frequency (*first revision*)
(80)	IS 15382 (Part 1) : 2022/ IEC 60664-1 : 2020	Insulation coordination for equipment within low-voltage systems: Part 1 Principles, requirements and tests (*second revision*)
(81)	IS 16463 (Part 11) : 2016/ IEC 61643-11 : 2011	Low-voltage surge protective devices: Part 11 Surge protective devices connected to low-voltage power systems — Requirements and test methods
(82)	IS/IEC 60479-1 : 2018	Effects of current on human beings and livestock: Part 1 General aspects

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART D BUILDING SERVICES

SECTION 3 AIR CONDITIONING, HEATING AND MECHANICAL VENTILATION

BUREAU OF INDIAN STANDARDS

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FOREWORD

This NBCS (Part D/Section 3) deals with the planning, selection, design considerations, and installation of air conditioning, heating and mechanical ventilation system for different types of building application and in towns and cities under all the climatic zones of India. It covers all aspects including the goals and objectives, basis of design, input parameters for design, guidelines for design of system, performance parameters, available system options, pre-planning considerations, range of equipment and system components, building management system, installation of the system, testing, commissioning and handing over and also operation and maintenance of the air conditioning, heating and mechanical ventilation system.

Indian construction industry is poised to add an-order-of-magnitude built foot-print in the coming years. With the advent of information technology and computers becoming part of our life-style, the requirement of air conditioning of built environment is being increasingly felt and met with. The challenge faced for this unprecedented development is the lack of material resources and natural resources like energy, water and clean air. Therefore, the selection of air conditioning and mechanical ventilation system, optimally suited for the specific type of building application and its climatic zone, becomes critical. It is necessary for the owner, designer, builder and developer to understand the provisions of this Section, and consult an air conditioning engineer at the planning stage.

Sustainable buildings movement in the country has gained tremendous momentum. The relevant 'Handbook on Sustainability in Buildings', deals with all aspects of sustainable buildings, from selection of site, building design, energy and water efficient systems, use of recycled material resources, construction, third party commissioning, operation and maintenance of sustainable buildings. By following the provisions of this Section in conjunction with those given in relevant 'Handbook on Sustainability in Buildings', India can successfully adopt sustainable buildings as the way of life, as has been the practice for centuries, prior to the onslaught of industrial revolution in India.

Computerized weather data is now available and has been included for around 145 locations across the country, covering all the five climatic zones. This data is based on the latest values obtained from India Metrological Department, Government of India.

This Section was first formulated in 1970 and was subsequently revised in 1983, 2005 and 2016 as a part of National Building Code of India. The major modifications made in 2005 version of this code included addition of several new terms and their definitions; incorporation of a new clause on design criteria; inclusion of 'indoor air quality' as one of the factors that needed to be controlled in the conditioned space; incorporation of recommendation for independent air handling unit rooms for each floor of large and multi storeyed buildings; inclusion of inside design conditions for various applications replacing earlier Table 2 and Table 3; revision of provisions on minimum outside fresh air in the light of the then accepted international norms thus covering a wider variety and a larger number of applications; addition of new details on temperature, humidity, vibration and noise; updation of provisions on application considerations, covering a wide variety of commercial applications, such as, offices, hotels, restaurants and computer rooms; inclusion of a new clause on statutory regulation/safety considerations; description of various system options available, under the clause on design considerations; updation of provisions on the characteristics and application of options available in piping, water distribution systems and piping layout; revision of provisions on air filters; revision of the clause on energy conservation and energy management to include concepts like energy targets, demand targets and consumption targets, the factors to be considered in system design that influence energy aspects, the need for analysis of operation of systems during various seasons of the year, and the need to incorporate energy recovery strategies. Apart from above, 'Automatic Controls' included in the 1983 version was replaced by building management system, which addressed not only the control function, but also had a telling impact on operation and maintenance as well, most importantly on the opportunities afforded to implement various energy conservation strategies; provisions on packaged air conditioners and room air conditioners were elaborated; provisions on heating were revised; provisions on symbols, units, colour code and identification of services, pipe work services, duct work services, valve labels and charts, and also on inspection, commissioning and testing were updated; and list of various parameters to be checked for performance of air handling unit, hydronic system balancing, and finally, the hand-over procedure were included.

The 2016 revision of this part introduced several important updates to align HVAC systems with modern needs and sustainable practices. It added new definitions to reflect emerging concepts and technologies and updated refrigerant guidelines to include eco-friendly options like zero-ozone-depleting and low-global-warming-potential refrigerants. Planning considerations were expanded to incorporate advanced systems such as VRF, district cooling, and hybrid central plants, supported by tools like energy modelling and solar shade analysis to optimize energy efficiency. The outdoor and indoor design conditions were updated using adaptive comfort standards and comprehensive weather data from across India. Key advancements in HVAC equipment included provisions for chilled beams, radiant floors, and geothermal systems were made. Specialized applications were addressed in greater detail, covering data centers, metro stations, and cold storage facilities critical for food security. Ventilation received a significant focus, emphasizing sustainability, demand control, and advanced fan designs. Installation practices were refined for ease of maintenance and better integration with building automation systems. The revision also standardized symbols and colour coding, introduced web-based monitoring for building management systems, and enhanced testing and commissioning protocols to ensure state-of-the-art performance.

In this revision, this publication has been renamed as National Building Construction Standards (NBCS).

This revision of this Part D/ Section 3 of this NBCS focuses on improving air conditioning, heating, and ventilation systems for better efficiency and sustainability. New features include advanced refrigerants, geothermal systems, and tools for energy-saving designs. It also addresses specialized needs like data centres and metro stations. These changes help ensure better performance, lower energy use, and reduced environmental impact.

The significant changes incorporated in this revision include the following:

a) Additional details on systems like variable refrigerant flow (VRF) and inverter-based cooling for better efficiency, in **4.1.4**.

b) Added new eco-friendly refrigerants with no harm to the ozone layer and very low impact on global warming, in **5.3**.

c) Addition of modern low-energy heating and cooling solutions, including evaporative cooling, radiant cooling, and solar-assisted systems. Additionally, it provides improved guidelines for system selection, installation, and applications across residential, commercial, and industrial sectors, in **6**.

d) Inclusion of new methods for cooling and heating using the earth's natural temperature are included, in **6.4**.

e) Addition of efficient heating solutions like solar-powered systems and ground heat pumps for cold regions, in **6.5**.

f) Addition of guidelines for selecting air-conditioning and ventilation systems across various building typologies, including residential, commercial, and transport hubs, in **12**.

g) New guidelines for cold storage facilities to improve food preservation and reduce waste, in **13.2**.

h) Inclusion of enhanced guidelines for using automation systems to monitor and control building performance, in **15.2**.

j) Introduction of uniform standards for hydronic and refrigerant piping in HVAC systems to enhance performance covering material selection, sizing, installation, testing, and maintenance for efficient fluid transport, in **16**.

k) Inclusion of new procedures for testing and setting up HVAC systems to ensure they work efficiently, in **17**.

m) Introduction of comprehensive smoke mitigation guidelines for substructures, superstructures, and exit pathways, in **19.**

n) Terminology clause has been updated with new terms and definitions.

The information contained in this section is based largely on the following Indian Standards:

IS 1391	Room air conditioners specification
(Part 1) : 2023	Unitary air conditioners (*fourth revision*)
(Part 2) : 2023	Split air conditioners (*fourth revision*)
IS 2379 : 2024	Colour code for pipeline identification — Code of practice (*second revision*)
IS 3315 : 2024	Direct evaporative air cooler — Specification (*fourth revision*)
IS 8148 : 2018	Ducted and package air-conditioners – Specification (*second revision*)
IS 7896 : 2023	Air conditioning outdoor design conditions data for Indian cities (*second revision*)

Assistance has also been derived from the following publications in the preparation of this Section:

Handbooks of Indian Society of Heating, Refrigerating and Air Conditioning Engineers (ISHRAE)

India Model for Adaptive Comfort, CEPT University, Ahmedabad

ISO 16484-1: 2024 Building automation and control systems (BACS) — Part 1: Project specification and implementation

The provisions on natural ventilation are given in Part D 'Building Services, Section 1 Lighting and Ventilation' of this NBCS.

The provisions of this Section are without prejudice to the various Acts, Rules and Regulations including *The Factories Act*, 1948 and the rules and regulations framed thereunder.

All standards, whether given herein above or cross-referred to in the main text of this Section, are subject to revision. The parties using this Section are encouraged to investigate the possibility of applying the most recent edition of the standards.

As the regulation of land development and buildings is a state subject and is dealt by the States and local bodies such as urban local bodies within their jurisdiction through building regulatory documents like building regulations, building byelaws, and fire regulations, this document is voluntary in nature and is non-binding. The implementation depends on adoption by concerned parties or stipulations in a contract or by appropriate adoption by the concerned authorities.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 'Rules for rounding off numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this Section.

Important Explanatory Note for Users of this NBCS

In any Part/Section of this NBCS, where reference is made to **'good practice'** in relation to design, constructional procedures or other related information, and where reference is made to **"accepted standard"** in relation to material specification, testing, or other related information, the Indian Standards listed at the end of the Part/Section shall be used as a guide to the interpretation.

At the time of publication, the editions indicated in the standards were valid. All standards are subject to revision and parties to agreements based on any Part/Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

In the list of standards given at the end of a Part/Section, the number appearing within parentheses in the first column indicates the number of the reference of the standard in the Part/Section. For example:

a) Good practice [D-3(1)] refers to the Indian Standard given at serial number (1) of the list of standards given at the end of this Section, that is, IS 3615 : 2020 'Glossary of terms used in refrigeration and air conditioning (*second revision*)'.

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART D BUILDING SERVICES

SECTION 3 AIR CONDITIONING, HEATING AND MECHANICAL VENTILATION

1 SCOPE

This NBCS (Part D/Section 3) covers the planning, design considerations, installation, testing, commissioning and handing over also operation and maintenance of air conditioning, heating and mechanical ventilation systems for buildings. It also covers refrigeration for cold storages.

The provisions of this Section aim to ensure an air conditioning, heating and mechanical ventilation system which shall provide comfort by managing air temperature, humidity, indoor air quality and distribution of conditioned air for the specific use and occupancy of built space while giving due consideration to minimizing energy consumption and other resources.

The provisions on natural ventilation are covered in Part D 'Building Services, Section 1 Lighting and Ventilation' of this NBCS.

The provisions in respect of air conditioning, heating and mechanical ventilation system in sustainable buildings are covered in relevant ‘Handbook on Sustainability in Buildings'.

2 TERMINOLOGY

For the purpose of this Section the following definitions shall apply in addition to those given in the accepted standard [D-3(1)] and the following shall apply.

2.1 Air Conditioning — The process of treating air so as to control simultaneously its temperature, humidity, purity, distribution and movement and pressure to meet the requirements of the conditioned space.

2.2 Air System Balancing — Adjusting air flow rates through air distribution system devices, such as fans and diffusers, by manually adjusting the position of dampers, splitter vanes, extractors, etc, or by using automatic control devices, such as constant-air-volume or variable-air-volume (VAV) boxes.

NOTE — Air system should be balanced in order to minimize throttling losses. For fans, its speed should be adjusted to meet design flow conditions. By creating correct air flow at fans and outlet, system performance shall be increased.

2.3 Atmospheric Pressure — The force per unit area exerted against a surface by the weight of the air above that surface. It is the pressure indicated by a barometer. Standard atmospheric pressure or standard atmosphere or barometric pressure is the pressure of 760 mm of mercury column having a density of 13 600 kg/m^3 under standard gravity of 9.8 m/sec^2 (10.332 mm of water column/101.325 kPa).

NOTE — Generally atmospheric pressure is used as a datum for indicating the system pressures in air conditioning and accordingly, pressures are mentioned above the atmospheric pressure or below the atmospheric pressure considering the atmospheric pressure to be zero. A ‘U’ tube manometer will indicate zero pressure when pressure measured is equal to atmospheric pressure.

2.4 Building Management System (BMS) — An energy management system relating to the overall operation of the building in which it is installed. It often has additional capabilities, such as equipment monitoring, protection of equipment against power failure, and building security. It may also be a direct digital control (DDC) system where the mode of control uses digital outputs to control processes or elements directly.

NOTE — Mechanical and electrical equipment installed in the building, such as, air conditioning, ventilation, lighting, lifts, power, pumping stations, firefighting systems, security systems are controlled and managed through BMS.

2.5 Building Energy Simulation — Use of computer models for design and optimization of building's energy performance, to compare the cost-effectiveness of energy conservation measures in the design stage as well as assessing various performance optimization measures during the operational stage.

2.6 Building Integrated Renewable Energy — Integration of renewable energy application in parts of the building envelope such as the roof, skylights, or facades.

2.7 Buildings Related Illnesses (BRI) — The diagnosable illness attributed directly to the specific air-borne building contaminants, like legionnaire’s disease, occupational asthma, etc.

NOTE — Indicators of BRI include complaints of cough, chest tightness, chills, fever and muscle aches. Occupants may need prolonged recovery times after leaving the building.

2.8 Coefficient of Performance, Compressor, Heat Pump — Ratio of the compressor heating effect (heat pump) to the rate of energy input to the shaft of the compressor, in consistent units, in a complete heat pump, under designated operating conditions.

2.9 Coefficient of Performance, Compressor, Refrigerating — Ratio of the compressor refrigerating effect to the rate of energy input to the shaft of the compressor, in consistent units, in a complete refrigerating plant, under designated operating conditions.

2.10 Coefficient of Performance (Heat Pump) — Ratio of the rate of heat delivered to the rate of energy input, in consistent units, for a complete operating heat pump plant or some specific portion of that plant, under designated operating conditions.

2.11 Coefficient of Performance (Refrigerating) — Ratio of the rate of heat removal to the rate of energy input, in consistent units, for a complete refrigerating plant or some specific portion of that plant, under designated operating conditions.

2.12 Cooling Load — Amount of cooling per unit time required by the conditioned space or product; or heat that a cooling system shall remove from a controlled system over time.

2.13 Cooling Tower — An enclosed device, often tower like, for evaporatively cooling water by contact with air.

2.14 Dedicated Outdoor Air System (DOAS) — A unit that is used to separately condition outdoor air brought into the building for ventilation or to replace air that is being exhausted.

2.15 Demand Based Ventilation — Intelligent airflow management that adjusts outside ventilation air based on the number of occupants and the ventilation demands that those occupants create.

2.16 Design Pressure Difference — The desired pressure difference between a given space and an adjacent space measured at the boundary of the given space under a specified set of conditions, such as, that required in various spaces of hospital, clean rooms, protected space in case of smoke control operation, etc.

2.17 Dew Point Temperature — The temperature at which condensation of moisture begins when the air is cooled at same pressure.

2.18 Dry-Bulb Temperature — The temperature of the air, read on a thermometer, taken in such a way as to avoid errors due to radiation.

2.19 Duct System — A continuous passageway for the transmission of air which, in addition to the ducts, may include duct fittings, dampers, plenums, grilles and diffusers.

2.20 Economizer, Air — It consist of duct, damper and control system that allow outside air to cool the building when outside air is cooler than inside.

2.21 Economizer, Water — In this system the supply air of a cooling system is cooled indirectly with water that is itself cooled by heat transfer or mass transfer to the environment without the use of mechanical cooling.

2.22 Effective Temperature — Combined effects of air temperature, humidity, air movement, mean radiant temperature, clothing and activity on the sensation of warmth or cold felt by the human body. Numerically equivalent to the temperature of still air producing similar thermal sensation as produced by combination of above six parameters of thermal comfort.

2.23 Energy Efficiency Ratio (EER) — Ratio of net cooling capacity in Btu/h to total rate of electric input in watts under designated operating conditions.

2.24 Energy Recovery Unit — A heat exchanger assembly for transferring energy between two isolated fluid sources. The recovery system may be of air-to-air design or a closed loop hydronic system design. The system will include all necessary equipment such as fans and pumps, associated ducts or piping and all controls (operating and safety), and other custom-designed features

2.25 Evaporative Cooling — The process of evaporating part of a liquid by supplying the necessary latent heat from the sensible heat of the main bulk of the liquid which is thus cooled.

2.26 Fire Damper — The damper, normally held open, installed in an air distribution system or in a wall or floor assembly and designed to close automatically in the event of a fire and maintain fire compartmentation.

2.27 Geothermal Heat Pump — A heating and/or cooling system utilizes the earth's crust, as heat source (in the winter) or a heat sink (in the summer) by using fluid to be pumped into the earth and circulated in order to exchange heat for the purpose of heating or cooling applications

2.28 Global Warming Potential (GWP) — The relative measure of how much a given mass of a refrigerant contributes to global warming over a given time period compared to the same mass of carbon dioxide over the same period.

NOTE — The GWP value of carbon dioxide is taken to be 1.0. The GWP value of a refrigerant is calculated over a time horizon. The time horizon shall greatly affect the numerical value of GWP. Usually the GWP values are reported over a 100 years' time horizon.

2.29 Heating Load — Heating rate required to replace heat loss from the space being controlled.

2.30 Heat Pump — A thermodynamic heating/refrigerating system to transfer heat. The condenser and evaporator may change roles to transfer heat in either direction. By receiving the flow of air or other fluid, a heat pump is used to cool or heat. Heat pumps may be the air source with heat transfer between the indoor air stream to outdoor air or water source with heat transfer between the indoor air stream and a hydronic source (ground loop, evaporative cooler, cooling tower, or domestic water).

2.31 Heat Recovery — Use of heat that would otherwise be wasted from a system or process, for example, heat-recovery chiller which uses hot waste gases as a heat source.

2.32 Hybrid Building — A building which contains both active and passive systems of heating or cooling. It requires small amount of non-renewable energy to maintain required amount of coefficient of performance (COP).

2.33 Hydronic Systems — The water systems that transfer heat to or from a conditioned space or process with hot or chilled water. The water flows through piping that connects a chiller or the water heater to suitable terminal heat transfer units located at the space or process.

2.34 Hydronic System Balancing — Adjusting water flow rates through hydronic distribution system devices, such as pumps and coils, by manually adjusting the position valves or by using automatic control devices, such as automatic flow control valves.

2.35 Indirect-Direct Cooling — The cooling which involves two stages:

a) The first stage, in which the air is made to pass through heat exchanger for sensible cooling (no direct contact of air and water), whereby the leaving air dry-bulb temperature (DBT) as well as the wet-bulb temperature (WBT) are reduced; and

b) The second stage, in which the air after the first stage is made to pass through the evaporative air-cooling (adiabatic cooling) application where water and air are in direct contact and there is simultaneous removal of sensible heat and the addition of moisture to the air giving lower DBT.

The resultant of this two-stage cooling is that the leaving air DBT is lower than ambient WBT.

NOTE — The first stage cooling is through indirect cooling. In this method, air-dry bulb and wet-bulb temperature are reduced without direct contact of air with water and through heat exchange only.

2.36 Indoor Air Quality (IAQ) — Air quality that refers to the nature of unconditioned or conditioned air that circulates throughout the space/area where one works or lives, that is, the air one breathes when indoors.

2.37 Infiltration/Exfiltration — The phenomenon of air leaking into (infiltration) or leaking out (exfiltration) out of an air-conditioned space.

2.38 Latent Heat — Change of enthalpy during a change of state, usually expressed, in kcal/kg. With pure substances, latent heat is absorbed or rejected at constant temperature at any pressure.

2.39 Latent Heat Load — Cooling load required to remove latent heat.

2.40 Mean Radiant Temperature — The uniform temperature of an imaginary enclosure in which the radiant heat transfer from the human body is equal to the radiant heat transfer in the actual non-uniform enclosure.

2.41 Mixed Mode Building — A hybrid approach to space conditioning that uses a combination of natural ventilation and mechanical systems. These buildings utilize mechanical cooling only when and where it is necessary to supplement the natural ventilation.

2.42 Naturally Conditioned Building — A building in which the ventilation system rely on opening and closing of window of the space to maintain the thermal comfort of the space rather than mechanical systems.

2.43 Operative Temperature — A uniform temperature of a radiantly black enclosure in which an occupant would exchange the same amount of heat by radiation plus convection as in the actual non-uniform environment. It is the combined effects of the mean radiant temperature and air temperature calculated as average of the two. It is also known as dry resultant temperature or resultant temperature.

2.44 Ozone Depletion Potential (ODP)—A relative capability of a refrigerant or a gas to degrade ozone in the atmosphere as compared to trichlorofluoromethane [R-11 or Clorofluorocarbon-11(CFC-11)]. The ODP of CFC-11 is taken to be 1.0.

2.45 Passive Cooling — A building design approach that focuses on heat gain control and heat dissipation in a building in order to improve the indoor thermal comfort with low or zero energy consumption by using natural ventilation, air cooling and shades.

2.46 Passive Heating — Passive heating uses the energy of natural source such as the sun, to keep the occupants of the building comfortable by design approach of building without the use of mechanical or electrical heating systems.

2.47 Plenum — An air compartment connected to one or more distributing ducts.

2.48 Positive Ventilation — The supply of outside air by means of a mechanical device, such as a fan.

2.49 Psychrometric Chart — A chart graphically representing the thermodynamic properties of moist air.

2.50 Recirculated Air — The return air that has been passed through the conditioning apparatus before being re-supplied to the space.

2.51 Refrigerant — The fluid used for heat transfer in a refrigerating system, which absorbs heat at a low temperature and a low pressure of the fluid and rejects heat at a higher temperature and a higher pressure of the fluid, usually involving changes of state of the fluid.

2.52 Relative Humidity — Ratio of the partial pressure of actual water vapour in the air as compared to the partial pressure of maximum amount of water that may be contained at its dry-bulb temperature.

NOTE — When the air is saturated, dry-bulb, wet-bulb and dew point temperatures are all equal, and the relative humidity is 100 percent.

2.53 Return Air — Air returned from conditioned or refrigerated space.

2.54 Sensible Heat — Heat which is associated with a change in temperature; in contrast to a heat interchange in which a change of state (latent heat) occurs.

2.55 Sensible Cooling — The process of removing sensible heat (lowering the dry-bulb temperature) from the air passing through it under specified conditions of operation.

2.56 Shade Factor — The ratio of instantaneous heat gain through the fenestration with shading device to that through the fenestration.

2.57 Sick Building Syndrome (SBS) — A term used to describe the presence of acute non-specific symptoms in the majority of people, caused by working in buildings with an adverse indoor environment.

NOTE — SBS could be a cluster of complex irritative symptoms like irritation of the eyes, blocked nose and throat, headaches, dizziness, lethargy, fatigue irritation, wheezing, sinusitis, congestion, skin rash, sensory discomfort from odours, nausea, etc. These symptoms are usually short-lived and experienced immediately after exposure; and may disappear when one leaves the building.

2.58 Smoke Barrier — A continuous membrane, either vertical or horizontal, such as a wall, floor, or ceiling assembly, that is designed and constructed to restrict the movement of smoke in conjunction with a smoke control system.

2.59 Smoke Damper — A damper similar to fire damper, however, having provision to close automatically on sensing presence of smoke in air distribution system or in conditioned space.

2.60 Smoke Management — A smoke control method that utilizes natural or mechanical systems to maintain a tenable environment for the means of egress from a large-volume space or to control and reduce the migration of smoke between the area on fire and communicating spaces.

2.61 Stack Effect — The vertical airflow within buildings driven by air buoyancy due to temperature-induced density differences between the building interior and exterior or between two interior spaces.

2.62 Static Pressure — The normal force per unit area that would be exerted by a moving fluid on a small body immersed in it if the body were carried along with the fluid. Practically, it is the normal force per unit area at a small hole in a wall of the duct through which the fluid flows (piezometer) or on the surface of a stationary tube at a point where the disturbances, created by inserting the tube. It is supposed that the thermodynamic properties of a moving fluid depend on static pressure in exactly the same manner as those of the same fluid at test depend upon its uniform hydrostatic pressure.

2.63 Supply Air — The air that has been passed through the conditioning apparatus and taken through the duct system and distributed in the conditioned space.

2.64 Terminal Devices — Devices fixed in the air-conditioned space for distribution of conditioned supply air and return of air such as, supply and return air grilles and diffusers.

2.65 Thermal Adaptation — The gradual diminution of the people’s response to repeated environmental stimulation and subsumes all processes which building occupants undergo in order to improve the fit of the indoor climate.

2.66 Thermal Comfort – That condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation.

2.67 Thermal Insulation Material — A material used over the conducting material to retard the flow of heat energy in the form of heat loss or gain to facilitate the temperature control as the process and prevent permeability of moist vapour and reduces condensation on cold surfaces.

2.68 Thermal Energy Storage — Storage of thermal energy, sensible, latent or combination thereof for use in central system for air conditioning or refrigeration. It uses a primary source of refrigeration for cooling and stored thermal energy for reuse at peak demand or for backup as planned.

2.69 Velocity Pressure — The pressure exerted by movement of air which makes the air to travel to longer distance in ducts. This pressure is always in the direction of flow.

2.70 Variable Refrigerant Flow (VRF) System — A heating and/or cooling system in which the flow of the refrigerant shall be varied according to the load.

2.71 Water Hardness — The hardness in water represented by the sum of calcium and magnesium salts in water, which may also include aluminium, iron, manganese, zinc, etc.

2.72 Water Treatment — The treatment of water circulating in a hydronic system, so that it shall be used without creating undue corrosion or scaling to the piping systems and other deleterious effects.

2.73 Wet-Bulb Temperature — The temperature at which liquid or solid water, by evaporating into air, shall bring the air to saturation adiabatically at the same temperature. Wet-bulb temperature is the temperature indicated by a wet-bulb thermometer constructed and used according to specifications.

2.74 Definitions/Terminology Reference to Refrigerants — Refer to the accepted standard [D-3(2)] for all the definitions. In addition, below are some definitions.

2.74.1 *Glide* — The difference in the dew and bubble point of a zeotropic refrigerant at constant pressure.

2.74.2 *Occupational Exposure Limit* (*OEL*) — The threshold amount of time-weighted average (TWA) concentration a normal 8 hour shift and a 40 hour work week to which nearly all workers shall be repeatedly exposed without any adverse effects.

3 BASIS OF DESIGN

3.1 Planning and Design Considerations

In any building, clear definition of design considerations holds the key for a good HVAC system. This includes, appropriate system selection, system sizing, layout and location planning, planning for operation, maintenance and controls as explained in following pages.

3.2 Fundamental Planning Requirements

The objective of installing air conditioning, heating and mechanical ventilation in buildings shall be to provide comfortable conditions without compromising on health and safety of occupants. Air conditioning, heating and mechanical ventilation installation shall aim at controlling the following factors in the building:

a) thermal comfort;

b) air quality, air quantity and air movement;

c) sound and vibration;

d) through meeting the minimum energy efficiency levels;

e) ensuring electrical; and

f) fire safety requirements.

3.2.1 All plans, design, drawings, specifications and data for air conditioning, heating and mechanical ventilation systems of all buildings and serving all occupancies within the scope of this NBCS, shall be supplied to the Authority, where called for.

3.2.2 The plans, design and drawings for air conditioning, heating and mechanical ventilation (HVAC) systems shall include all details and data necessary for detailed load calculation through computer simulation such as:

a) building name, type and location, address;

b) owners' name;

c) HVAC designers' name;

d) use of building;

e) building orientation: north direction on plans and design drawings;

f) general plans, dimensions and height of all rooms in SI unit;

g) intended use of internal spaces;

h) detail or description of wall construction, including insulation and finish;

j) detail or description of roof, ceiling and floor construction, including insulation and finish;

k) detail or description of windows and outside doors, including sizes, thermal properties, weather stripping, chajjas or projections;

m) internal load, such as people, equipment, computer/server load and lighting load;

n) layout showing the location, size and components of the HVAC equipment being installed;

p) information regarding air distribution system;

q) information on air and water systems and their flow rates and pressure drops;

r) information regarding location, size and accessibility of shafts;

s) information regarding type and location of dampers (both volume control and fire/smoke dampers) used in air conditioning system, such as, whether motorized or manually operated and rating;

t) location and grade of the required fire separations;

u) water treatment and softening arrangement;

v) information on presence of any chemical fumes or gases; and

w) HVAC automation design, description and piping and instrumentation (generally referred to as P&I drawing) drawing.

3.3 Fundamental Design Requirements

The following guidelines address critical factors such as load calculations, system adjustments for off-peak hours, and specialized needs for various applications, ensuring optimal performance and energy conservation across diverse scenarios.

3.3.1 Heat load calculation shall take into account the following factors:

a) recommended indoor temperature, relative humidity, air velocity, mean radiant temperature, clothing, activity and IAQ parameters;

b) outside and indoor design conditions as specified;

c) details of building construction and orientation of exposures of building components;

d) fenestration area, thermal properties and shading factors;

e) occupancy: number of people and their schedule of activities;

f) ventilation: requirement for fresh air;

g) infiltration, air leakage;

h) internal load: Equipment, computer/server and lighting;

j) effective volume; and

k) occupancy, lighting and equipment schedule.

3.3.2 The design of air conditioning, heating and mechanical ventilation system and its associated controls shall also consider the following:

a) application;

b) permissible control limits;

c) fire safety;

d) opportunities for heat recovery, condensate drain recovery;

e) energy efficiency;

f) filtration standard;

g) hours of use;

h) suitable diversity factor based on usage; and

j) outdoor and indoor air quality.

3.3.3 Due consideration shall be given to air conditioning load encountered during off-peak hours including night, weekend, holidays. The system shall be designed for the maximum operational efficiency to achieve lowest annual energy consumption. Consideration shall be given to the anticipated future changes (permanent or temporary) in building load. The system shall be designed for maximum operational efficiency is achieved throughout.

3.3.4 The air conditioning system for special applications like hospitals, operating theatres, computer rooms, data centres and telecommunication rooms, clean rooms, laboratories, libraries, museums, art galleries, sound recording studios, etc shall be designed as per specific requirement.

3.3.5 Computer based hourly load calculation and energy simulation tools should be used for HVAC equipment sizing and to identify effect of various energy conservation measures on energy consumption.

3.3.6 An uncertainty analysis should be carried out based on the input parameter accuracy level. The system design should be determined by the uncertainty analysis considering the parameters like variation in climatic conditions, material properties, usage pattern, internal loads over design or under design of the should be avoided.

3.3.7 The system sizing shall be based upon outdoor and indoor design conditions, considering a safety factor, together with capacity deration due to local conditions as well as aging of equipment. Performance maps of major equipment at different climatic conditions and loads should be considered for accessing their suitability, sufficiency and energy efficiency.

3.4 System Layout and Space Planning

Each type of HVAC system has peculiar space and layout requirement. Major requirements for planning an efficient and serviceable layout are explained below.

3.4.1 *Equipment Room for Central Air Conditioning Plant*

These guidelines address the provisions of equipment room for central air conditioning plant.

3.4.1.1 This room shall be located preferably within the building being air conditioned and closer to external wall for facilitating ventilation and equipment movement. The equipment may also be installed in a separate service block which should also be located as close as possible to the load/building being conditioned. The clear headroom below soffit of beam should be minimum 4.5 m for larger capacity chillers (500 TR and above) and minimum 3.6 m for smaller plants.

3.4.1.2 The floors of the equipment rooms should be compacted and finished. For floor loading, the air conditioning engineer should be consulted (*see* Part C ‘Structural Design, Section 1 Loads and Load Effects’ of this NBCS).

3.4.1.3 Supporting of pipe within plant room spaces should be normally from the floor. However, outside plant room areas, structural provisions shall be made for supporting the water pipes from the floor/ceiling slabs. All floor and ceiling supports shall be isolated from the structure to prevent vibration transmission.

3.4.1.4 Equipment rooms, wherever necessary, shall have provision for mechanical ventilation. In hot and dry climate, evaporative air cooling shall be considered to maintain plant room temperature.

3.4.1.5 Plant machinery in the plant room shall be placed on levelled plain/reinforced cement concrete foundation block and provided with anti-vibratory supports or alternatively on inertia bases. Supports for appliances shall be designed and constructed to sustain vertical and horizontal loads within the stress limitations specified in the Part C 'Structural Design' of this NBCS. All foundations should be protected from damage by providing epoxy coated angle nosing. Seismic restraints requirement should also be considered (*see* **17.4.3**).

3.4.1.6 Appropriate sound insulation and noise control measures shall be taken in plant room space as per Part D 'Building Services, Section 4 Acoustics, Sound Insulation and Noise Control' of this NBCS. Acoustic treatment as may be required shall be provided in plant room space to prevent noise transmission to adjacent occupied areas.

3.4.1.7 In case air conditioning plant room is located in basement, equipment movement route shall be planned to facilitate future replacement and maintenance. Service ramps or hatch in ground floor slab should be provided in such cases. Fire egress and emergency battery backup lighting shall be provided for the plant room operator.

3.4.1.8 Floor drain channels or dedicated drain pipes in slope shall be provided within plant room space for effective disposal of waste water, if necessary, by automatic level-controlled sump pumps. Fresh water connection may also be provided in the air conditioning plant room.

3.4.1.9 Thermal Energy Storage should be used for limiting maximum demand, by controlling peak electricity load through reduction of chiller capacity, and by taking advantage of high system efficiency during low ambient conditions. Thermal storage will also help in reducing operating cost by using differential time-of-the day power tariff, where applicable. In case of central plant designed with thermal energy storage, its location shall be decided in consultation with the air conditioning engineer. For roof top installations, structural provision shall take into account load coming on the building/structure due to the same. For open area surface installation, horizontal or vertical system options shall be considered and approach ladders for manholes provided. Buried installation shall take into account loads due to movement of vehicles above the area. Provision for adequate expansion tank and its connection to thermal storage tanks shall be made.

3.4.2 *Equipment Room for Air Handling Units and Package Units*

These guidelines ensure optimal placement, safety, and functionality of equipment rooms for air handling and package units within the building's HVAC system**.**

3.4.2.1 This shall be located as centrally as possible to the conditioned area and contiguous to the corridors or other service areas for carrying air ducts in ceiling spaces.

3.4.2.2 In case of special and high-rise buildings, air handling units shall be provided in accordance with fire and life safety considerations, given in Part F 'Fire and Life Safety' of this NBCS. Air handling unit rooms should preferably be located vertically one above the other.

3.4.2.3 Provision shall be made for the entry of outdoor ventilation air into air handling unit room. For energy conservation, it is desirable to install mechanism for modulating the outdoor air quantity based on demand.

3.4.2.4 Exterior openings for outdoor air intake and also exhaust outlets shall have louvers with rain protection profile, volume control damper, pre-filter and bird screen.

3.4.2.5 In all cases, outdoor air intakes shall be located to avoid contamination from exhaust outlets and pollution sources in concentration higher than normal in the building locality. The separation distance between fresh air intake and any exhaust outlets shall be 8 m preferably.

3.4.2.6 Exhaust air from any dwelling unit shall not be circulated/ingress directly or indirectly to any other dwelling unit, to public corridor or into public stairway.

3.4.2.7 All air handling rooms should have floor drains. The trap in floor drain shall provide a water seal between the air-conditioned space and the drain line.

3.4.2.8 Supply/return air duct serving other areas shall not be taken through fire exits.

3.4.2.9 Waterproofing of air handling unit rooms shall be carried out to prevent damage to floor below.

3.4.2.10 The floors should be finished smooth. For floor loading, the air conditioning engineer should be consulted (*see* Part C 'Structural Design, Section 1 Loads and Load Effects' of this NBCS).

3.4.2.11 Structural design should avoid beam obstruction to the passage of supply and return air ducts. Adequate ceiling space should be made available outside the air handling unit room to permit installation of supply and return air ducts and fire/smoke dampers at compartment wall crossings.

3.4.2.12 Appropriate sound insulation and noise control measures shall be taken in air handling unit rooms, if located in close proximity to occupied areas, as per Part D 'Building Services, Section 4 Acoustics, Sound Insulation and Noise Control' of this NBCS. The air handling unit rooms shall be acoustically treated in accordance with the noise control requirements if located in close proximity to occupied areas.

3.4.2.13 Access door to air handling unit room shall be single/double leaf type, air tight, opening outwards and should have a sill to prevent flooding of adjacent occupied areas. It is desired that access panels in air-conditioned spaces should be provided with tight sealing, gaskets and self-closing devices for air conditioning to be effective.

3.4.2.14 It should be possible to isolate the air handling unit room in case of fire. The door should be fire resistant (*see* Part F 'Fire and Life Safety' of this NBCS) and fire/smoke dampers shall be provided in supply/return air duct at air handling unit room wall crossings. Annular space between the duct and the wall should be fire sealed using appropriate fire resistance rated material.

3.4.2.15 Fire isolation shall be provided for vertical fresh air duct, connecting several floors.

3.4.2.16 It is desirable that individual air handling unit should be installed for each fire compartment, alternately, fire barrier should be provided at each fire separation for air handling units serving more than one compartment.

3.4.3 *Pipe Shafts*

These guidelines address the placement, safety, and accessibility requirements for pipe shafts to ensure effective distribution and maintenance of building services.

3.4.3.1 The shafts carrying chilled water pipes should be located adjacent to air handling unit room or within the room.

3.4.3.2 Shaft carrying condensing water pipes to cooling towers located on terrace should be vertically aligned.

3.4.3.3 All shafts shall be provided with fire barrier at floor crossings following the fire safety requirements.

3.4.3.4 Access to shaft shall be provided at every level, if there is any serviceable component in the shaft. In case of tall buildings, care shall be taken for expansion/contraction of pipes while planning the supports.

3.4.4 *Supply Air Ducts and Return Air Ducts*

These guidelines ensure efficient and safe design of supply and return air ducts, focusing on airflow distribution, energy conservation, and compliance with safety standards.

3.4.4.1 The duct supports shall be designed to handle the load and also to take into account seismic considerations. The support material should be galvanized/coated steel or aluminium and facilitate ease of installation at site using alternatives such as fully threaded rod/angle, chromium plated steel threaded rods or channel section/wire support systems using stud anchors provided in the ceiling slab from drilled holes or anchors suitable for threaded rods, wires without damaging the slab or structural member. Wire Rope when used shall be rated to take seismic loads. Steel sections shall be analysed for both tensile and compressive loads for strength and serviceability for the maximum length of element being used for bracing and other supports. Appropriate loads and its combinations, as per relevant clauses in Indian standards should be considered in design. Each straight run of the service shall be braced with a minimum of one transverse braces and one longitudinal-transverse brace with distance not greater than 12 m between them.

3.4.4.2 If false ceiling is provided, the supports for the duct and the false ceiling, shall be independent. Collars for grilles and diffusers shall be taken out only after false ceiling/boxing framework is done and frames for fixing grilles and diffusers have been installed. Flexible ducts may be used for making the final connections.

3.4.4.3 Where a duct penetrates the masonry wall, it shall either be suitably covered on the outside to isolate it from masonry, or an air gap shall be left around it to prevent vibration transmission. Further, where a duct passes through a fire resisting compartment/barrier, the annular space shall be sealed with fire sealant to prevent smoke and fire transmission as per relevant clauses of this NBCS.

3.4.5 *Cooling Tower*

These guidelines focus on the efficient design, placement, and maintenance of cooling towers to optimize cooling performance, minimize energy use, and ensure safe operation.

3.4.5.1 Cooling towers are used to dissipate heat from water cooled refrigeration, air conditioning and industrial process systems to the atmosphere. Cooling is achieved by evaporating a small proportion of recirculating water into outdoor air stream. Cooling towers shall be installed at a place where free flow of ambient air is available.

3.4.5.2 Range of a cooling tower is defined as temperature difference between the entering and leaving water. Approach of the cooling tower is the difference between leaving water temperature and the ambient air wet-bulb temperature.

3.4.5.3 *Selection of cooling tower*:

Following factors shall be considered for selection of cooling tower:

a) design wet-bulb temperature and approach of cooling tower. The designer shall endeavour for reducing the approach for maximizing the energy conservation potential;

b) height limitation and aesthetic requirement;

c) location of cooling tower considering possibility of easy drain back from the system;

d) placement with regard to adjacent walls, windows and other buildings, and effects on these from any water carried over by the air stream;

e) vibration and noise levels, particularly during silent hours;

f) material of construction for the tower;

g) direction and flow of prevailing wind;

h) quality of water used for make-up;

j) maintenance and service space availability; and

k) ambient air quality.

3.4.5.4 The recommended floor area requirement for various types of cooling tower is as given below:

a) Natural draft: 0.15 to 0.20 m^2/3.516 kW cooling tower; and

b) Mechanical draft: 0.07 to 0.10 m^2/3.516 kW cooling tower.

3.4.5.5 Structural provision for the cooling tower shall be taken into account while designing the building. Vibration isolation shall be an important consideration in structural design.

3.4.5.6 Special care should be taken in design where noise transmitted to the adjoining building shall be of serious concern. Special vibration control and sound attenuation devices may be required in that case. Appropriate sound insulation and noise control measures shall be taken in such cases in accordance with relevant requirements of this NBCS. System may be designed to have sound absorption ≥ 0.8 and sound insulation of ≥ 50 dB.

3.4.5.7 Certain amount of water is lost from circulating water in the cooling tower, as given below:

a) *Evaporation loss* — It is usually about 1 percent of the rate of water circulation.

b) *Drift loss* — The drift loss shall be below 0.1 percent of rate of water circulation.

c) *Blow-down/bleed-off* — The amount of blowdown shall be below 0.8 percent of the total water circulation. If simple blow-down is inadequate to control scale formation, chemicals may be added to inhibit corrosion and limit microbiological growth. Provision shall be made to make-up for the loss of circulating water.

3.4.5.8 Provision for make-up water tank to the cooling tower shall be made. Make-up water tank to the cooling tower shall be separate from the tank serving drinking water. Makeup water should be sourced from treated water from sewage treatment, waste water treatment plant, or from rain water harvesting. Make-up water having contaminants or hardness, which shall adversely affect the refrigeration plant life, shall be treated. Treated water where hardness as ppm of $CaCO_3$ is reduced to 50 ppm or below is recommended for air conditioning applications. Water with *p*H value less than 5 shall also need to be treated.

3.4.5.9 Cooling tower should be so located as to eliminate nuisance from drift to adjoining structures.

3.4.6 *Building Envelope*

The envelope of the building including wall, roof and fenestration may be planned as per relevant guidelines/best practices ('Handbook on Sustainability in Buildings').

3.4.7 *Fire Safety*

For fire safety in case of special and high-rise buildings, provisions of Part F 'Fire and Life Safety' of this NBCS should be applicable.

3.4.8 *Sound Insulation and Noise Control*

Sound insulation and noise control measures for HVAC system shall be in accordance with Part D 'Building Services, Section 4 Acoustics, Sound Insulation and Noise Control' of this NBCS.

3.4.8.1 *Designing for background noise control and vibration*

The background noise and vibration created by air distribution through the HVAC system, combined with noise from equipment and outdoor sources of noise and vibration may causes significant disturbance to building users. Adoption of measures for adhering to indoor noise limits and vibration control should be ensured in the design of equipment, their foundation, supports and air distribution system. Threshold values for indoor sound levels, are given in Table 1 and Table 2 below. The buildings/indoor spaces will be classified as Class A, B and C where Class A refers to aspirational, Class B refers to acceptable and Class C refers to minimum acceptable.

3.4.9 *Energy Conservation*

Designers shall aim for energy efficiency in buildings with the right blend of passive and active design strategies in accordance with relevant guidelines/best practices ('Handbook on Sustainability in Buildings'), so as to minimise the energy use while ensuring comfort.

3.5 Outside design conditions

The outdoor design conditions shall be considered in accordance with accepted standard [D-3(3)]. Table 3 presents design conditions taken from this standard as ready reference. For cities not included in this table, it is recommended that extrapolation may be done, from the data of the nearby listed city, but keeping into consideration the specific topographical and climatic conditions of the concerned location. Values of ambient dry-bulb temperatures and wet-bulb temperatures, against the various annual percentiles, represent the value that is exceeded on average by the indicated percentage of the total number of hours. The 0.4 percent, 1.0 percent, 2.0 percent values are exceeded on average 35 h, 88 h and 175 h respectively in a year. The 99.0 percent and 99.6 percent values are defined in the same way but are usually reckoned as the values for which the corresponding weather elements are less than the design conditions of 88 h and 35 h respectively.

Mean coincidental values are the average of the indicated weather element occurring concurrently with the corresponding design value. After the calculation of design dry-bulb temperatures, the program locates the values of corresponding wet-bulb temperatures from the database for that particular station, the average of these values is computed, which are then called mean of coincidental wet-bulb temperature. In the same way, design wet-bulb temperatures and coincidental dry-bulb temperatures are evaluated.

The design values of 0.4 percent, 1.0 percent and 2.0 percent annual cumulative frequency of occurrence may be selected depending upon application of air conditioning system. For normal comfort conditions, values under 1.0 percent column should be used for cooling loads and 99 percent column for heating loads. For critical applications, values under 0.4 percent column should be used for cooling loads and 99.6 percent column for heating loads.

Table 1 Requirements of Acoustic Comfort

(*Clause* 3.4.8.1)

SI No.	**Types of Buildings**	**Noise Criterion**			**Reverberation Time**			**Speech Transmission Index**		
		A	B	C	A	B	C	A	B	C
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
i)	**Residences, apartments, condominiums**	30	35	40	< 0.8 s	NA	NA	*0.6	*0.5	*NA
								Applicable for atriums and corridors		
ii)	**Hospitality**									
a)	Individual rooms or suites	30	35	40	< 0.8 s	< 0.6 s	< 1.0	0.6	0.5	NA
b)	Meeting/banquet rooms	30	35	40	< 0.5 s			0.7	0.6	0.5
c)	Corridors, lobbies	40	45	45	NA			NA	NA	NA
d)	Service/Support areas	40	45	50	NA			0.5	NA	NA
e)	All day dining and restaurants	45	50	50	<1.2s	<1.5s	<1.75s	0.6	0.5	NA
iii)	**Office buildings**									
a)	Executive and private offices	30	35	40	< 0.6 s	< 0.7 s	< 0.8 s	0.6	0.5	NA
b)	Conference rooms	30	35	35	< 0.6 s			0.7	0.6	0.5
c)	Teleconference rooms	25 (max)			< 0.6 s			0.7	0.6	0.5
d)	Open – plan offices	35	40	40	< 0.8 s			0.6	0.5	NA

Table 1 (*Concluded*)

SI No.	Types of Buildings	Noise Criterion			Reverberation Time			Speech Transmission Index		
		A	B	C	A	B	C	A	B	C
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
e)	Corridors and lobbies	40	45	45	NA			NA	NA	NA
f)	Collaborative space				< 0.8 s			0.5	NA	NA
g)	Cafeteria/Town hall	40	45	45	< 1.0 s	< 1.2 s	< 1.2 s	0.6	0.5	NA
iv)	**Education**									
a)	Class rooms up to 70 m^2	40 (*Max*)			< 0.6 s	< 0.8 s	< 1.0 s	0.6	0.5	NA
b)	Class rooms over 70 m^2	35 (*Max*)						0.6	0.5	NA
c)	Large lecture rooms, without speech amplification	35 (*Max*)						0.6	0.55	0.5
v)	**Libraries**	35	40	40	< 1.0 s	< 1.2 s	< 1.2 s	0.6	0.5	NA
vi)	**Health care***									
a)	Open Ward	35	35	45	< 1.0s	< 0.8 s	< 1.0 s	0.7	0.6	0.5
b)	Individual rooms or suites	30	35	40	< 0.8s			0.7	0.6	0.5
c)	Meeting rooms /Conference room	25	30	35	< 0.6s			0.5	NA	NA
d)	Teleconferencing rooms	25	NA	NA	< 0.6s			0.7	0.6	0.5
e)	Operating rooms	35	40	45	< 0.8s			0.6	0.5	NA
f)	Corridors, lobbies	35	45	45	< 1.0s			NA	NA	NA
g)	Testing/research lab, minimal speech	45	50	55	< 0.8s			0.5	NA	NA
h)	Research lab, extensive speech	40	45	50	< 0.8s			0.7	0.6	0.5
j)	Auditoria, large lecture rooms	25	30	NA	< 0.8s			0.6	0.5	NA

NOTES

1 In this table are given the performance requirements in terms of recommended dBA noise level (ideal), the not to exceed noise level (max), and the maximum acceptable reverberation time (T60) for many spaces including offices.

2 For the Class A and Class B, a building should score 90 percent and 80 percent respectively on the occupant satisfaction survey. There is no such requirement to achieve Class C.

3 Any other type of space not mentioned in the Table above shall meet requirements of the nearest representative category of that space.

4 For more details on Reverberation Time, refer graph with respect to volume and application in annexure.

5 * values measured in unoccupied condition.

Table 2 Threshold Noise Isolation Criteria Level Depending Upon Type of Space

(*Clause* 3.4.8.1)

SI No.	Building	Type of space	D_w/NIC		
			Class A	Class B	Class C
(1)	(2)	(3)	(4)	(5)	(6)
i)	Office	Between two offices	45	40	40
		Where privacy is important			
		Cellular offices			
		Between enclosed office and circulation area	40	35	30
		Between two meeting or conference rooms	50	45	45
		Between meeting or conference room and circulation area	40	35	30
		Between two training rooms	50	45	45
		Between training room and circulation area	40	35	30
ii)	Residential	Partitions separating a water closet (WC) from a noise sensitive room	45	40	35
iii)	Hospitality	Partitions and floors between rooms and corridors			
		Walls and floor between two guestrooms/suites	55	50	45
		Between guestrooms/suites and circulation area	40	40	40
		Walls and floor between banquet halls and guestrooms/suites	55	50	50
		Between banquet hall and circulation area or pre functions	45	40	40
iv)	Entertainment	Walls of cinemas, auditoriums, studios, pubs	60	55	50
v)	Education	Between classrooms, labs, lecture halls	50	50	45
vi)	Hospital or Health care*	Between two patient rooms and circulation area	40	40	35
		Between patient room and circulation area (with entrance)	35	30	25
		Between Patient Room and Service Area	50	45	45
		Between Consultation Room and Public Space/Patient Rooms	40	40	40
		Between Consultation Room and Circulation Area (with entrance)	35	30	25

NOTE — Weighted level difference (D_w) a single integer number found by comparing the measured spectrum with the 'standard' curves for airborne and impact insulation. The D_w value is where the curve meets the 500 Hz curve and the unfavourable deviation is 32 dB. D_w will be identical to $D_{Nt,w}$ when T = 0.5 seconds. Noise Isolation Class NIC a single number rating of the degree of speech privacy achieved through the use of an acoustical ceiling and sound absorbing screens in an open office..

Table 3 Summary for Outdoor Design Conditions

(*Clause* 3.5)

Sl No.	City	Heating DB		Cooling DB/MCWB						Evaporation WB/MCDB					
		99.6 percent	99 percent	0.40 percent		1 percent		2 percent		0.40 percent		1 percent		2 percent	
(1)	(2)	(3)	(4)	(5)		(6)		(7)		(8)		(9)		(10)	
1)	Agartala	10.8	11.6	35.2	25	34.5	25	33.8	27	28.5	33	28.1	32	27.8	32
2)	Agra	4.6	6.1	42.1	21	40.8	22	39.8	22	28.7	31	28.3	30	28	31
3)	Ahmedabad	12.3	13.2	42.7	25	41.7	22	41	22	30.2	35	29.3	34	28.4	33
4)	Aizawl	10.5	11.3	30.5	20	29.5	21	28.9	21	24.8	27	24.5	26	24.1	27
5)	Ajmer	4.8	5.6	41.5	22	40.7	21	39.4	21	25.2	34	24.9	34	24.7	33
6)	Akola	12.4	13.9	43.1	23	42.2	21	41.4	22	26.9	33	26.5	32	26.2	31
7)	Aligarh	3.9	5.3	42.9	23	41.8	23	40.4	24	28.3	33	27.9	34	27.6	33
8)	Allahabad	9.8	10.6	43.1	23	41.7	23	40.3	23	28.7	32	28.3	33	28	32
9)	Amaravati	19.2	19.8	42	27	39.7	27	38.1	26	28.4	33	28.2	32	27.8	33
10)	Amritsar	3	4.5	42	23	41	23	39	23	29.2	32	28.6	32	28.2	31
11)	Anantapur	16.9	18.1	40	24	39.5	24	38.7	23	26.3	35	25.8	33	25.5	34
12)	Aurangabad	11.8	12.9	40.1	23	39.3	22	38.3	22	26.8	34	26	32	25.5	31
13)	Balasore	12.9	13.9	36.8	26	35.5	26	34.6	27	28.8	33	28.4	33	28.1	33
14)	Bareilly	6.4	7.2	39.6	23	38.7	26	37.7	25	29.2	34	28.8	33	28.4	33
15)	Barmer	10.6	11.5	43.2	23	42	22	40.4	24	28.3	36	27.9	35	27.5	34

Table 3 (*Continued*)

Sl No.	City	Heating DB		Cooling DB/MCWB						Evaporation WB/MCDB					
		99.6 percent	99 percent	0.40 percent		1 percent		2 percent		0.40 percent		1 percent		2 percent	
(1)	(2)	(3)	(4)	(5)		(6)		(7)		(8)		(9)		(10)	
16)	Belgaum	13.5	14.6	36.7	19	35.5	18	34.2	19	24.1	29	23.7	29	23.4	28
17)	Bengaluru	15.6	16.2	34.1	21	33.4	20	32.7	19	23.5	29	23.1	29	22.8	28
18)	Bhagalpur	13.1	13.8	38.3	22	36.8	25	35	27	29.3	34	28.9	33	28.7	32
19)	Bhavnagar	12	12.8	42.4	25	41.3	27	39.8	25	28.4	30	28.1	32	27.8	32
20)	Bhilai	12.7	14	42.6	23	41.7	24	40.4	23	26.8	31	26.5	32	26.2	31
21)	Bhopal	9	10.2	42	21	40.7	25	39.5	21	26	30	25.7	30	25.3	29
22)	Bhubaneswar	14.1	15.1	38.9	27	37.8	27	36.7	26	30.1	35	29.5	33	29.1	33
23)	Bhuj	12.4	13.3	40.5	23	39.5	24	38.3	23	28.1	36	27.6	33	27.3	33
24)	Biharsharif	7.8	8.7	40.1	24	38.7	24	37.6	24	28.4	31	28	32	27.7	31
25)	Bikaner	7.6	9.1	44.8	22	43.3	23	41.9	23	27.6	34	27.2	32	26.8	33
26)	Bilaspur	11.8	13	43.2	22	42.3	23	41.3	23	26.9	31	26.6	31	26.4	31
27)	Chandigarh	2.8	4	43	22	40.8	20	39.2	18	27.2	33	26.8	32	26.5	32
28)	Chennai	20.5	21	39	26	38	26	37	26	28.5	34	28.1	34	27.8	35
29)	Chitradurga	16.2	16.9	37.4	21	36.5	21	35.6	20	23.8	27	23.5	26	23.2	26
30)	Coimbatore	18.6	19.5	36.5	23	35.8	24	34.9	24	25.4	33	25.1	31	24.9	29

Table 3 (*Continued*)

Sl No.	**City**	**Heating DB**		**Cooling DB/MCWB**						**Evaporation WB/MCDB**					
		99.6 percent	99 percent	0.40 percent		1 percent		2 percent		0.40 percent		1 percent		2 percent	
(1)	(2)	(3)	(4)	(5)		(6)		(7)		(8)		(9)		(10)	
31)	Cuddalore	20.1	20.8	37.9	26	37.1	26	36.1	27	29	33	28.7	33	28.3	34
32)	Dahod	8.6	9.8	41.1	20	40.4	23	39.3	21	27	30	26.5	32	25.7	33
33)	Daltonganj	8.8	9.9	43.3	24	42	25	41	24	28.1	32	27.7	31	27.5	32
34)	Davanagere	16.9	17.7	37.4	21	36.5	21	35.7	21	24.2	29	23.8	29	23.5	29
35)	Dehradun	5.8	6.6	37.7	22	36.2	23	34.5	22	27	30	26.5	30	26.2	30
36)	Dhanbad	8	9.3	41.5	23	40.5	22	39.7	22	27.4	32	27	32	26.7	31
37)	Dharmsala	3.7	4.7	32.1	20	31.1	21	30.2	18	23.7	28	23.4	26	22.9	25
38)	Dibrugarh	10.2	11	35	28	34	27	33.2	27	29.2	34	28.6	33	28.1	32
39)	Diu	10.5	11.4	35.9	24	34.6	23	33.6	22	25.1	30	24.8	29	24.6	29
40)	Erode	18.3	18.9	40.3	23	39.3	23	38.3	24	26.5	31	25.8	30	25.4	31
41)	Etawah	3.8	5.3	44.2	24	43.1	25	42	25	28.9	36	28.2	37	27.6	34
42)	Ganganagar	4.6	6.1	44.2	22	42.7	26	40.8	25	29.1	35	28.7	34	28.4	35
43)	Gangtok	1.4	2.3	23.1	19	22.7	18	22.3	19	19.8	22	19.6	22	19.4	22
44)	Gaya	7	9	43.3	20	41.8	23	40.2	21	28.5	33	28	33	27.7	32
45)	Gorakhpur	8.5	9.6	40.7	23	38.9	23	37.7	22	28.1	32	27.8	33	27.5	33

Table 3 (*Continued*)

Sl No.	**City**	**Heating DB**		**Cooling DB/MCWB**						**Evaporation WB/MCDB**					
		99.6 percent	99 percent	0.40 percent		1 percent		2 percent		0.40 percent		1 percent		2 percent	
(1)	(2)	(3)	(4)	(5)		(6)		(7)		(8)		(9)		(10)	
46)	Gulbarga	19.4	20.4	41.5	24	40.6	25	39.8	25	27.4	36	27	34	26.6	35
47)	Guna	8.5	10	42.8	22	41.9	22	40.9	22	27	33	26.7	31	26.4	32
48)	Guntur	16.6	17.7	41.1	25	39.6	25	38.5	25	28.6	31	28.3	31	28.1	31
49)	Guwahati	11.2	12.1	35.4	27	34.5	29	33.9	27	29.2	34	28.9	33	28.6	33
50)	Gwalior	4.9	5.7	43.2	24	42.2	24	40.9	23	28.5	34	28.2	35	27.8	33
51)	Hissar	4.1	5.1	43.8	25	42.6	24	41.2	23	29	37	28.7	34	28.3	33
52)	Honavar	18.8	19.8	34.3	24	33.6	24	33.1	25	27.8	32	27.4	32	27.2	31
53)	Hubballi	12.5	13.2	41.8	24	40.7	23	39.4	24	26	26	25.5	29	25.2	30
54)	Hyderabad	15.3	16.3	41	22	39.6	22	38.4	24	25.4	34	25	31	24.7	31
55)	Imphal	4.9	5.9	32	21	31.3	23	30.7	23	25.7	31	25.2	30	24.8	29
56)	Indore	10.4	11.3	39.9	19	38.9	21	37.9	21	25.6	31	25.1	29	24.8	29
57)	Itanagar	8.8	9.7	35.2	29	34.3	29	33.4	29	29.8	34	29.5	34	29.1	32
58)	Jabalpur	8.4	9.8	41.6	20	40.7	20	39.5	20	26.3	30	25.9	31	25.6	30
59)	Jagdalpur	9.6	11.1	39.2	20	38.1	23	37	23	26.6	36	25.9	32	25.5	31
60)	Jaipur	8.4	9.3	42.4	20	41	21	40	21	27.6	33	27.2	31	26.9	32

Table 3 *(Continued)*

Sl No.	**City**	**Heating DB**		**Cooling DB/MCWB**						**Evaporation WB/MCDB**					
		99.6 percent	99 percent	0.40 percent		1 percent		2 percent		0.40 percent		1 percent		2 percent	
(1)	(2)	(3)	(4)	(5)		(6)		(7)		(8)		(9)		(10)	
61)	Jaisalmer	8.3	9.3	44.3	24	42.8	23	41.7	25	28.1	38	27.6	34	27.2	36
62)	Jalandhar	4.3	5.5	43.7	21	42.4	21	40.7	21	25.6	33	25	36	24.6	33
63)	Jammu	4.8	5.8	41.9	21	40.1	20	38.9	21	28.6	32	27.9	30	27.4	32
64)	Jamnagar	7.9	8.9	38.7	24	37.5	23	36.5	24	27.7	30	27.5	31	27.3	32
65)	Jamshedpur	9.8	10.7	41.4	23	39.8	23	38.2	24	27.6	33	27.3	33	27	32
66)	Jhansi	6.1	7	44.9	24	43.7	22	42.8	22	27.6	34	27.1	31	26.9	33
67)	Jharsuguda	11	12	42	24	40.8	24	39.5	23	27.8	31	27.4	32	27.1	31
68)	Jodhpur	9	10.4	42.1	22	40.7	23	39.8	23	27.9	33	27.4	34	27	32
69)	Jorhat	8.5	9.2	33.1	27	32.6	26	31.6	27	27.7	31	27.5	30	27.2	30
70)	Kakinada	18.1	19.4	42.2	26	39.4	25	37.3	28	29.2	35	28.8	33	28.4	34
71)	Kalingapatam	15.8	17.6	35.3	29	34.6	29	34	28	29.7	34	29.5	33	29.1	33
72)	Kannur	20.6	21.2	36.4	24	35.6	24	34.9	24	26.8	30	26.5	31	26.3	30
73)	Kanpur	6.4	7.2	43.4	23	42	23	40.9	23	28.5	34	28.2	34	28	33
74)	Karaikal	21.8	22.7	37	26	36.2	26	35.3	26	29.1	34	28.9	34	28.4	32
75)	Karimnagar	13.4	14.7	42.7	24	41.9	26	40.7	25	28.2	37	27.6	34	27.2	35

Table 3 (*Continued*)

Sl No.	**City**	**Heating DB**		**Cooling DB/MCWB**						**Evaporation WB/MCDB**					
		99.6 percent	99 percent	0.40 percent		1 percent		2 percent		0.40 percent		1 percent		2 percent	
(1)	(2)	(3)	(4)	(5)		(6)		(7)		(8)		(9)		(10)	
76)	Karnal	4.7	5.6	40.8	22	39.7	24	38.4	22	27.8	33	27.3	31	26.9	32
77)	Karwar	20.6	21.6	35.9	27	35.4	26	34.9	26	29.6	34	29.2	34	28.8	33
78)	Kavaratti	23.3	24	33.8	28	33.4	27	32.9	27	28.6	33	28.2	33	27.9	32
79)	Kochi	22.8	23.2	32.9	26	32.6	26	32.3	26	27.6	32	27.3	31	27.1	31
80)	Kodaikanal	7	7.7	24.4	15	23.4	14	22.6	14	15.8	22	15.4	22	15.1	21
81)	Kohima	5.9	6.8	27.1	20	26.3	21	25.6	20	21.6	23	21.3	24	21.1	24
82)	Kolhapur	19.4	20.3	35.6	20	35.1	20	34.5	20	27.4	28	26.6	27	25.5	29
83)	Kolkata	12	13	37	28	36.3	28	35.7	28	29.6	33	29.2	34	28.8	34
84)	Kollam	21.8	22.3	34.2	25	33	23	32.4	23	26.8	30	26.6	30	26.4	29
85)	Kota	10	11.2	43.5	21	42.3	21	41	22	27.1	32	26.8	31	26.5	31
86)	Kozhikode	22.6	23.1	34.8	29	34.3	28	33.9	27	29.2	34	28.9	33	28.6	33
87)	Kurnool	17.1	18	41.1	22	40.1	24	39.2	24	26.1	32	25.8	34	25.5	33
88)	Leh	-20.7	-19	26.6	10	25.8	11	24.8	11	14	23	13.5	21	12.9	20
89)	Lucknow	6.7	8	42	23	41	23	40	24	29.4	34	29	36	28.6	34
90)	Ludhiana	2.6	3.6	40.7	22	39.3	24	38.1	22	28.1	30	27.6	32	27.2	32

Table 3 (*Continued*)

Sl No.	**City**	**Heating DB**		**Cooling DB/MCWB**						**Evaporation WB/MCDB**					
		99.6 percent	99 percent	0.40 percent		1 percent		2 percent		0.40 percent		1 percent		2 percent	
(1)	(2)	(3)	(4)	(5)		(6)		(7)		(8)		(9)		(10)	
91)	Machilipatnam	20.4	20.9	40.3	28	38.7	27	37.1	27	29.7	36	29.3	36	28.8	34
92)	Madurai	18.1	18.8	40.9	24	39.6	25	38.8	25	28.1	32	27.4	32	27	32
93)	Mangaluru	21.3	22	34.2	24	33.7	25	33.3	25	27	33	26.7	31	26.5	30
94)	Minicoy	23.9	24.4	33.3	28	32.9	28	32.5	28	28.7	32	28.3	32	28.1	32
95)	Moradabad	5.2	6.6	42.1	23	40.7	24	39.4	25	28.8	35	28.3	33	27.8	33
96)	Mumbai	19	20.2	35	23	34.7	24	33.9	23	27.9	31	27.7	31	27.3	31
97)	Muzaffarpur	8.5	9.3	38.9	25	37.9	26	36.8	27	29.5	35	29.2	34	28.9	32
98)	Mysuru	14.6	15.1	36.7	21	35.5	22	34.4	22	24	25	23.6	29	23.2	27
99)	Nagappattinam	22.7	23.2	36.9	26	36.2	26	35.4	27	29.1	32	28.9	32	28.6	32
100)	Nagpur	12	13	44	22	43	22	42	22	27.5	31	27.1	29	26.7	31
101)	Nashik	9.5	10.1	37.3	19	36.5	20	35.6	19	26.3	28	25	27	24.3	27
102)	Nellore	21	21.6	41	28	39.6	27	38.4	28	28.8	36	28.5	38	28.2	35
103)	New-Delhi	5	6.5	43.6	21	42.6	22	41	23	28.2	36	27.8	35	27.5	30
104)	Nizamabad	15.4	16.6	43.3	24	41.9	24	40.3	23	26.2	30	25.9	30	25.6	31
105)	Ongole	21.5	21.8	41.9	27	39.2	26	37.7	27	28.7	36	28.3	36	27.8	34

Table 3 (*Continued*)

Sl No.	City	Heating DB		Cooling DB/MCWB						Evaporation WB/MCDB					
		99.6 percent	99 percent	0.40 percent		1 percent		2 percent		0.40 percent		1 percent		2 percent	
(1)	(2)	(3)	(4)	(5)		(6)		(7)		(8)		(9)		(10)	
106)	Panaji	19.8	20.5	34.1	26	33.8	27	33.3	26	28.2	33	27.9	32	27.6	32
107)	Pasighat	11	11.9	34.1	26	33.3	27	32.4	26	27.7	32	27.3	31	27	31
108)	Patiala	6.2	7	42.2	26	40.4	24	38.8	25	29.4	34	29	34	28.6	33
109)	Patna	7	8.2	41	24	39.6	26	37.7	23	28.6	33	28.3	33	28	32
110)	Pendra-road	9	10.2	39.7	21	38.7	21	37.6	23	26.2	31	25.7	30	25.3	29
111)	Port-Blair	22.1	22.9	33.1	27	32	27	31.3	26	27.5	32	27.2	31	26.9	30
112)	Pune	10.2	11.2	38.7	19	37.5	20	36.3	19	24.6	30	24	30	23.8	29
113)	Raipur	13.1	14.2	42.1	24	41.1	23	40	24	27.1	31	26.8	32	26.5	31
114)	Rajkot	12	13	41.3	21	39.9	23	38.9	24	27.4	29	27	30	26.7	31
115)	Ranchi	8.9	10	38.9	20	37.7	20	36.3	20	25.9	30	25.4	29	25.2	29
116)	Ratnagiri	17.9	18.6	34.1	22	33.7	24	33.1	23	27.1	31	26.9	30	26.7	30
117)	Raxaul	8.3	9.3	38.6	25	36.3	26	34.8	25	29	32	28.6	32	28.3	32
118)	Roorkee	4.4	5.3	40.4	24	39.1	23	37.9	23	27.9	32	27.4	31	27.2	32
119)	Sagar	8.1	9.5	41.9	24	41.1	23	40	21	26.5	37	25.9	33	25.5	30
120)	Saharanpur	4.2	4.9	43.2	22	42	23	40.7	24	28.5	33	28.2	33	27.9	34

Table 3 (*Continued*)

Sl No.	**City**	**Heating DB**		**Cooling DB/MCWB**						**Evaporation WB/MCDB**					
		99.6 percent	99 percent	0.40 percent		1 percent		2 percent		0.40 percent		1 percent		2 percent	
(1)	(2)	(3)	(4)	(5)		(6)		(7)		(8)		(9)		(10)	
121)	Salem	17.5	18.2	39.9	24	39.1	22	38.1	23	25.6	30	25.2	31	25	30
122)	Sangli	7.8	8.5	40.1	20	38.9	19	37.8	18	24.5	27	24.2	27	23.9	28
123)	Satna	7.6	8.6	43.4	23	42.2	22	40.5	23	27.5	33	27	31	26.7	30
124)	Shillong	3.3	4.3	26.1	21	25.5	21	24.9	20	21.5	24	21.1	24	20.9	24
125)	Shivamogga	13.7	14.7	39	21	38	20	36.9	20	24	29	23.8	29	23.6	28
126)	Siliguri	8.6	9.6	36.3	30	35	28	33.9	28	30.8	32	30	31	29.1	32
127)	Silvassa	9	10.6	36.8	22	35.4	18	34.6	20	25.7	29	25.4	29	25	28
128)	Solapur	15.2	16.4	40.7	21	39.9	22	39.1	21	26.1	34	25.5	34	25.1	34
129)	Srinagar	-3.7	-2.4	31	20	29.9	20	28.9	20	22.4	30	21.9	28	21.3	26
130)	Surat	13.3	14.7	37.5	22	36.1	23	35.1	24	28.4	31	28.1	31	27.8	30
131)	Tezpur	11.2	12.1	34.5	29	33.8	26	33.1	27	29	32	28.6	32	28.2	32
132)	Thanjavur	18.8	19.8	41.5	26	40.5	25	39.3	25	27.4	35	27.1	32	26.9	31
133)	Thiruvananthapuram	22.5	23	34.3	26	33.6	25	33.1	26	27.8	32	27.4	31	27.2	32
134)	Thoothukudi	20.2	21	39.2	25	38.4	25	37.6	26	27.8	32	27.5	31	27.2	31

Table 3 (*Concluded*)

Sl No.	City	Heating DB		Cooling DB/MCWB						Evaporation WB/MCDB					
		99.6 percent	99 percent	0.40 percent		1 percent		2 percent		0.40 percent		1 percent		2 percent	
(1)	(2)	(3)	(4)	(5)		(6)		(7)		(8)		(9)		(10)	
135)	Thrissur	19.3	20.3	37.8	26	36.1	27	34.8	25	28.8	31	28.6	32	28.2	31
136)	Tiruchrapalli	20	20.7	39	26	38.4	26	37.8	26	27.1	35	26.8	34	26.5	34
137)	Tirunelveli	20.3	21	41.8	24	40.3	25	39.1	24	26.5	30	26.2	30	26	31
138)	Tiruppur	16.4	17	31.9	20	30.8	20	29.9	18	21.9	25	21.6	24	21.4	24
139)	Tumakuru	14.7	15.5	37.8	19	36.4	20	35.2	18	22.3	30	21.9	30	21.5	28
140)	Udaipur	6.5	8.4	40.7	22	39.9	20	38.6	21	26.2	31	25.9	30	25.6	31
141)	Varanasi	8	9.9	43	24	42	24	41	24	28.7	35	28.4	33	27.9	33
142)	Vellore	15.9	16.7	42.1	23	40.3	23	38.8	22	25.6	29	25.3	31	25.1	30
143)	Veraval	15.5	16.5	35.2	22	34	26	33.2	28	28.8	33	28.5	32	28.3	32
144)	Vishakhapatnam	20	21.2	34	27	33.4	27	33	28	29.3	32	28.8	32	28.4	32
145)	Warangai	13.8	14.6	43.9	23	42.9	23	41.6	23	27.5	32	27.2	32	26.9	31

3.6 Inside Design and Operating Conditions

One of the primary objectives of designing indoor environment is to ensure thermal comfort and indoor air quality of all occupants. Air conditioning, heating and mechanical ventilation (HVAC) system is employed to achieve thermal comfort inside building, when means to achieve the same only through building design is limited.

According to the internationally accepted definition, thermal comfort is that state of mind which expresses satisfaction with the indoor environment. The above definition clearly highlights the importance of both the psychological (mental) and physiological (physical) factors in determining acceptable thermal comfort conditions. The following five environmental parameters are important for thermal comfort and indoor air quality while designing the HVAC system because these are directly controllable by an HVAC system**:**

a) air temperature (ºC);

b) radiant temperature (ºC);

c) air speed (m/s);

d) relative humidity (percent); and

e) indoor air quality.

In addition to the above five environmental parameters, there are two personal or behavioural parameters that also affect thermal comfort but are not controllable by the HVAC system and they are:

1) activity rate (W/m^2); and

2) clothing insulation ($m^2.K/W$).

There are number of secondary parameters also which are important to define thermal comfort conditions such as, radiative temperature asymmetry, temperature gradient, and draught rate.

Air conditioning systems for interior spaces intended for human occupancy shall be sized for not more than 26 °C for cooling and for not less than 18 °C for heating at occupied level.

HVAC systems should also be designed to control the humidity. Relative humidity in occupied spaces should not fall below 30 percent and should not exceed 70 percent. Adequate measures should be provided in system design itself for keeping it in the prescribed range including humidification and dehumidification as needed.

Air velocity control should be used to facilitate thermal adaptation as well as to save energy as described in **3.6.1**. However, air velocity should not exceed 1.5 m/s at the work plane to avoid discomfort due to draft and fluttering of papers etc.

While the system sizing needs to be done for design conditions mentioned above, the systems should be provided with features that facilitate thermal adaptation to be practiced by occupants. Buildings should provide users and facility managers to control air velocity in spaces and around individuals so that higher temperature set point shall be kept for saving energy. Buildings should provide spaces to control the set point individually as the temperature at which set point is to be kept varies as per the change in outdoor conditions over the time.

In conditioned buildings, the values for quality of thermal environment parameters for representative occupant of a space shall be as specified in Table 4 below.

Table 4 Conditions for Thermal Comfort

(*Clause* 3.6)

Sl No.	Air Velocity	Weather Condition	Level of Activity	Reference Table or Threshold Values
(1)	(2)	(3)	(4)	(5)
i)	Up to 0.2 m/s	Summer/winter	Met value ≤ 1.2	Table 5
ii)	Above 0.2 m/s	Summer/winter	Met value ≤ 1.2	Table 5 + Fig. 1 or Table 6
iii)	-	Summer	-	Relative humidity: 30 to 70 percent

Table 5 Acceptable Range of Operative Temperature with Air Velocity up to 0.2 m/s

(*Table* 4)

Sl No.	Level of Activity	Operative Temperature (°C)	
		Summer (Cooling Season) ~ 0.5 clo	Winter (Heating Season) ~ 1.0 clo
(1)	(2)	(3)	(4)
i)	Met > 1 and up to 1.2	23.0 ± 3.0	19.0 ± 4.0
ii)	Met ≤ 1.0	24.5 ± 2.5	22.0 ± 3.0

NOTE — At still air condition, operative temperature is the average of air temperature and mean radiant temperature. For details ISHRAE IEQ Standard 10001 can be referred.

High air velocity shall give opportunity of keeping higher air temperature without compromising thermal comfort. However, it is also suggested to keep under consideration noise and other effect of high indoor air velocity.

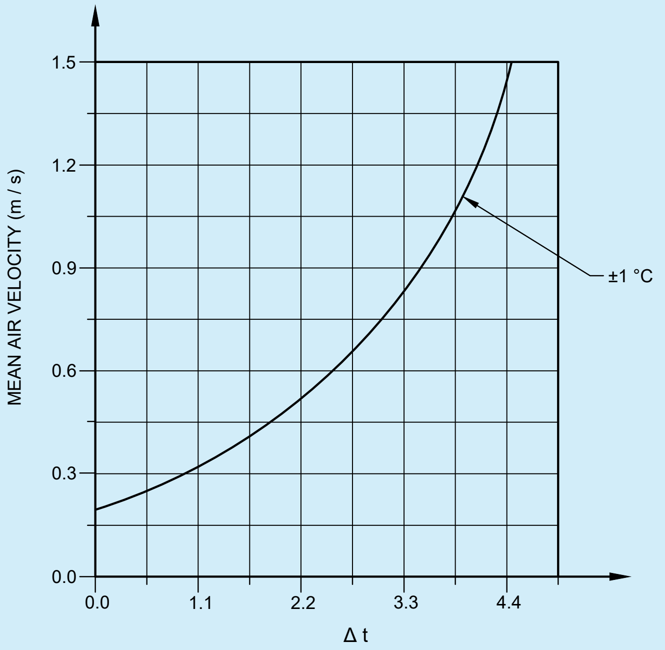


FIG. 1 REQUIRED AIR SPEED TO OFFSET INCREASED OPERATIVE TEMPERATURE (IN CELSIUS)

3.6.1 *Designing for Using Adaptive Thermal Comfort in Operation*

Design based on use of an adaptive thermal comfort model during operation of building plays a major role in reducing energy use whilst maintaining the comfort, productivity and well-being of occupants. This approach recognizes that people's thermal comfort needs depend on their past and present context and that these needs vary with the outdoor environmental conditions of their location. For more details, refer Part D 'Building Services, Section 1 Lighting and Natural Ventilation' of this NBCS.

3.6.1.1 *Path A*

The general requirements concerning predominantly dry bulb temperature (DBT) and mean radiant temperature (MRT) based adaptive thermal comfort model which differentiates the thermal response of occupants in air conditioned and mixed-mode buildings. For more details, refer Part D 'Building Services, Section 1 Lighting and Natural Ventilation' of this NBCS.

3.6.1.2 *Path B*

Since in many buildings, especially where microclimatic interventions or where occupants from wide range of ambient/indoor conditions (outside of the period of occupancy in the building in consideration) are likely to be present, it may be difficult to determine their running mean monthly outdoor temperature and they are likely to display different order of thermal adaptation. This alternate path for estimation of thermal comfort is through calculation of standard effective temperature (SET) using the look up Table 6 and Table 7, given below provided option for determining set of indoor conditions that are likely to provide thermal comfort.

The recommended range of SET for Indian conditions over all types of buildings is 23.5 ºC to 25.5 ºC, with 80 percent acceptability. The term SET includes combined effect of all five parameters that govern thermal comfort, including various adaptive actions such as air velocity, adjusting clothing, adjusting temperature set point, adjusting activity level, and humidity. Same method shall be used in unconditioned buildings as well for assessment of thermal comfort.

The desired value of SET shall be achieved at different values of air temperatures depending upon the values of other parameters. This Table 6 and Table 7 shall also be used in designing radiant cooling systems, personalised air conditioning system etc.

Table 6 Calculated Standard Effective Temperature for Adaptive Thermal Comfort

(*Clause* *3.6.1.2* *and* *Table 4*)

Standard Effective Temperature for Activity Level 1 Met (Office Work Type Activity) and Clothing 1.0 Clo (Winter Clothing)

AT (°C) ↓	MRT (°C) →	14				16				18				20				22				24				26				28				30				32			
	AV (m/s) → RH (percent) ↓	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4
14	20	16.1	13.9	12.8	12.1	17	14.6	13.5	12.7	18	15.4	14.1	13.4	19	16.2	14.8	14	19.9	16.9	15.5	14.6	20.9	17.7	16.2	15.3	21.9	18.5	16.9	15.9	23	19.3	17.7	16.6	24	20.2	18.4	17.3	24.9	21	19.1	17.9
	40	16.2	14	13	12.3	17.2	14.8	13.6	12.9	18.1	15.5	14.3	13.5	19.1	16.3	15	14.2	20.1	17.1	15.7	14.8	21.1	17.9	16.4	15.4	22.1	18.7	17.1	16.1	23.1	19.5	17.8	16.7	24.1	20.3	18.5	17.4	25	21.1	19.3	18.1
	60	16.4	14.2	13.1	12.4	17.3	14.9	13.8	13.1	18.3	15.7	14.5	13.7	19.2	16.5	15.2	14.3	20.2	17.2	15.8	15	21.2	18	16.5	15.6	22.2	18.8	17.3	16.2	23.2	19.6	18	16.9	24.3	20.5	18.7	17.6	25.2	21.3	19.4	18.2
	80	16.5	14.3	13.3	12.6	17.4	15.1	13.9	13.2	18.4	15.8	14.6	13.9	19.4	16.6	15.3	14.5	20.3	17.4	16	15.1	21.3	18.2	16.7	15.8	22.3	19	17.4	16.4	23.4	19.8	18.1	17.1	24.4	20.6	18.9	17.7	25.4	21.4	19.6	18.4
16	20	17	15.1	14.2	13.7	17.9	15.9	14.9	14.3	18.9	16.6	15.6	14.9	19.8	17.4	16.2	15.5	20.8	18.2	16.9	16.1	21.8	18.9	17.6	16.8	22.8	19.7	18.3	17.4	23.8	20.5	19	18.1	24.7	21.4	19.8	18.7	25.6	22.2	20.5	19.4
	40	17.2	15.3	14.4	13.9	18.1	16	15.1	14.5	19	16.8	15.7	15.1	20	17.6	16.4	15.7	21	18.3	17.1	16.3	22	19.1	17.8	17	23	19.9	18.5	17.6	24	20.7	19.2	18.3	24.9	21.5	19.9	18.9	25.8	22.4	20.7	19.6
	60	17.3	15.5	14.6	14	18.2	16.2	15.3	14.7	19.2	17	15.9	15.3	20.1	17.7	16.6	15.9	21.1	18.5	17.3	16.5	22.1	19.3	18	17.2	23.1	20.1	18.7	17.8	24.1	20.9	19.4	18.4	25.1	21.7	20.1	19.1	26.1	22.5	20.8	19.8
	80	17.5	15.6	14.8	14.2	18.4	16.4	15.4	14.8	19.3	17.1	16.1	15.5	20.3	17.9	16.8	16.1	21.3	18.7	17.5	16.7	22.3	19.5	18.2	17.3	23.3	20.3	18.9	18	24.3	21.1	19.6	18.6	25.4	21.9	20.3	19.3	26.4	22.7	21	19.9
18	20	17.9	16.4	15.7	15.2	18.8	17.1	16.3	15.8	19.8	17.8	17	16.4	20.7	18.6	17.6	17	21.7	19.4	18.3	17.7	22.7	20.2	19	18.3	23.7	20.9	19.7	18.9	24.6	21.8	20.4	19.6	25.4	22.6	21.1	20.2	26.3	23.4	21.8	20.9
	40	18.1	16.5	15.9	15.4	19	17.3	16.5	16	19.9	18	17.2	16.6	20.9	18.8	17.8	17.2	21.9	19.6	18.5	17.9	22.9	20.4	19.2	18.5	23.9	21.1	19.9	19.1	24.8	21.9	20.6	19.8	25.7	22.8	21.3	20.4	26.6	23.6	22	21.1
	60	18.2	16.7	16.1	15.6	19.2	17.5	16.7	16.2	20.1	18.2	17.4	16.8	21.1	19	18.1	17.4	22	19.8	18.7	18.1	23	20.5	19.4	18.7	24.1	21.3	20.1	19.3	25	22.1	20.8	20	26	23	21.5	20.6	26.9	23.8	22.2	21.3
	80	18.4	16.9	16.3	15.8	19.3	17.7	16.9	16.4	20.3	18.4	17.6	17	21.2	19.2	18.3	17.7	22.2	20	18.9	18.3	23.2	20.7	19.6	18.9	24.3	21.5	20.3	19.5	25.4	22.3	21	20.2	26.4	23.1	21.7	20.8	27.4	24	22.4	21.5
20	20	18.8	17.6	17.1	16.7	19.7	18.3	17.7	17.3	20.6	19.1	18.4	17.9	21.6	19.8	19	18.5	22.6	20.6	19.7	19.1	23.6	21.4	20.4	19.8	24.5	22.2	21.1	20.4	25.3	23	21.8	21	26.1	23.8	22.5	21.7	27	24.4	23.2	22.3
	40	19	17.8	17.3	17	19.9	18.6	17.9	17.6	20.8	19.3	18.6	18.2	21.8	20.1	19.3	18.8	22.8	20.8	19.9	19.4	23.8	21.6	20.6	20	24.7	22.4	21.3	20.6	25.6	23.2	22	21.3	26.5	23.9	22.7	21.9	27.3	24.6	23.4	22.5
	60	19.2	18	17.5	17.2	20.1	18.8	18.2	17.8	21	19.5	18.8	18.4	22	20.3	19.5	19	23	21	20.2	19.6	24	21.8	20.8	20.2	25	22.6	21.5	20.9	26	23.4	22.2	21.5	26.9	24.1	22.9	22.1	27.8	24.9	23.6	22.8
	80	19.4	18.3	17.8	17.5	20.3	19	18.4	18	21.2	19.7	19.1	18.6	22.2	20.5	19.7	19.2	23.2	21.3	20.4	19.8	24.3	22	21.1	20.5	25.4	22.8	21.8	21.1	26.4	23.6	22.4	21.7	27.4	24.4	23.1	22.3	28.4	25.2	23.8	23
22	20	19.7	18.8	18.5	18.3	20.6	19.6	19.1	18.8	21.5	20.3	19.8	19.4	22.5	21	20.4	20	23.5	21.8	21.1	20.6	24.3	22.6	21.8	21.2	25.2	23.4	22.4	21.9	26	24	23.1	22.5	26.8	24.7	23.8	23.1	27.6	25.3	24.3	23.7
	40	19.9	19.1	18.7	18.5	20.8	19.8	19.4	19.1	21.8	20.5	20	19.7	22.7	21.3	20.7	20.3	23.7	22.1	21.3	20.9	24.6	22.8	22	21.5	25.5	23.6	22.7	22.1	26.4	24.3	23.4	22.7	27.3	24.9	24	23.4	28.1	25.6	24.6	23.9
	60	20.1	19.3	19	18.8	21	20.1	19.6	19.4	22	20.8	20.3	20	22.9	21.5	20.9	20.5	24	22.3	21.6	21.1	25	23.1	22.3	21.8	26	23.8	22.9	22.4	26.9	24.6	23.6	23	27.9	25.3	24.3	23.6	28.8	26	24.9	24.2
	80	20.3	19.6	19.3	19.1	21.3	20.3	19.9	19.6	22.2	21	20.5	20.2	23.2	21.8	21.2	20.8	24.4	22.6	21.8	21.4	25.5	23.3	22.5	22	26.6	24.2	23.2	22.6	27.6	25	23.9	23.2	28.6	25.8	24.6	23.9	29.6	26.6	25.3	24.5
24	20	20.6	20.1	19.9	19.8	21.5	20.8	20.5	20.3	22.4	21.5	21.1	20.9	23.4	22.3	21.8	21.5	24.3	23	22.4	22.1	25.1	23.7	23.1	22.7	25.9	24.4	23.8	23.3	26.7	25	24.3	23.9	27.5	25.6	24.8	24.3	28.3	26.2	25.3	24.8

Table 6 (*Continued*)

Standard Effective Temperature for Activity Level 1 Met (Office Work Type Activity) and Clothing 1.0 Clo (Winter Clothing)

AT (°C) ↓	MRT (°C) →	14				16				18				20				22				24				26				28				30				32			
	AV (m/s) → RH (percent) ↓	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4
	40	20.8	20.3	20.2	20.1	21.7	21.1	20.8	20.6	22.7	21.8	21.4	21.2	23.6	22.5	22.1	21.8	24.6	23.3	22.7	22.4	25.5	24	23.4	23	26.4	24.7	24	23.6	27.3	25.3	24.6	24.1	28.1	26	25.1	24.6	28.9	26.6	25.7	25.1
	60	21.1	20.6	20.5	20.4	22	21.4	21.1	20.9	22.9	22.1	21.7	21.5	24	22.8	22.4	22.1	25	23.6	23	22.7	26	24.3	23.7	23.3	27	25.1	24.3	23.8	28	25.8	24.9	24.4	28.9	26.5	25.6	25	29.8	27.2	26.2	25.6
	80	21.3	20.9	20.7	20.6	22.3	21.6	21.4	21.2	23.3	22.4	22	21.8	24.5	23.1	22.7	22.4	25.7	24	23.3	23	26.8	24.9	24.1	23.6	27.9	25.7	24.8	24.3	28.9	26.5	25.5	24.9	29.9	27.3	26.2	25.6	30.8	28.1	26.9	26.2
26	20	21.5	21.3	21.3	21.3	22.4	22	21.9	21.8	23.3	22.7	22.5	22.4	24.2	23.5	23.2	23	25	24.1	23.7	23.5	25.8	24.7	24.2	24	26.6	25.3	24.8	24.5	27.4	25.9	25.3	24.9	28.2	26.5	25.8	25.4	29	27.1	26.3	25.9
	40	21.7	21.6	21.6	21.6	22.7	22.3	22.2	22.1	23.6	23.1	22.8	22.7	24.6	23.7	23.5	23.3	25.5	24.4	24	23.8	26.4	25.1	24.6	24.3	27.3	25.7	25.2	24.8	28.1	26.4	25.7	25.3	29	27	26.3	25.8	29.8	27.7	26.8	26.3
	60	22	21.9	21.9	21.9	23	22.6	22.5	22.5	24.1	23.4	23.2	23	25.1	24.2	23.8	23.6	26.2	24.9	24.5	24.2	27.2	25.7	25.1	24.8	28.1	26.4	25.7	25.3	29.1	27.1	26.4	25.9	29.9	27.8	27	26.5	30.8	28.5	27.6	27
	80	22.3	22.2	22.2	22.2	23.5	23	22.9	22.8	24.8	23.9	23.6	23.5	26	24.8	24.4	24.1	27.2	25.7	25.1	24.8	28.3	26.5	25.9	25.5	29.3	27.4	26.6	26.1	30.3	28.2	27.3	26.8	31.3	28.9	28	27.4	32.2	29.7	28.7	28
28	20	22.4	22.5	22.6	22.7	23.3	23.2	23.3	23.3	24.1	23.8	23.8	23.7	25	24.4	24.3	24.2	25.8	25	24.8	24.6	26.6	25.6	25.3	25.1	27.4	26.2	25.8	25.5	28.1	26.8	26.3	26	28.9	27.3	26.8	26.4	29.7	27.9	27.3	26.9
	40	22.7	22.9	23	23.1	23.7	23.6	23.6	23.6	24.6	24.2	24.1	24.1	25.5	24.9	24.7	24.6	26.4	25.6	25.3	25.1	27.3	26.2	25.8	25.6	28.2	26.8	26.4	26.1	29	27.5	26.9	26.6	29.8	28.1	27.5	27.1	30.6	28.7	28	27.6
	60	23.1	23.3	23.4	23.5	24.2	24.1	24.1	24.1	25.3	24.8	24.7	24.7	26.4	25.6	25.4	25.2	27.4	26.4	26	25.8	28.4	27.1	26.6	26.4	29.3	27.8	27.2	26.9	30.2	28.5	27.9	27.5	31.1	29.2	28.5	28	31.9	29.9	29.1	28.6
	80	23.8	24	24.1	24.2	25.2	25	24.9	24.9	26.5	25.9	25.7	25.6	27.8	26.8	26.5	26.3	28.9	27.6	27.2	27	30	28.5	27.9	27.6	31	29.3	28.6	28.2	32	30	29.3	28.9	32.9	30.8	30	29.5	33.7	31.5	30.6	30.1
30	20	23.3	23.6	23.8	24	24.1	24.2	24.3	24.4	24.9	24.8	24.8	24.8	25.8	25.4	25.3	25.3	26.6	26	25.8	25.7	27.3	26.5	26.3	26.2	28.1	27.1	26.8	26.6	28.9	27.7	27.3	27	29.6	28.2	27.7	27.5	30.3	28.8	28.2	27.9
	40	23.7	24.1	24.3	24.5	24.7	24.8	24.9	25	25.6	25.4	25.4	25.4	26.5	26.1	26	25.9	27.4	26.7	26.5	26.4	28.3	27.4	27.1	26.9	29.2	28	27.6	27.4	30	28.6	28.1	27.9	30.8	29.2	28.7	28.4	31.5	29.8	29.2	28.8
	60	24.5	24.9	25.1	25.3	25.6	25.7	25.8	25.9	26.7	26.4	26.4	26.4	27.8	27.2	27	27	28.8	27.9	27.7	27.5	29.8	28.6	28.3	28.1	30.7	29.3	28.9	28.6	31.5	30	29.5	29.2	32.4	30.7	30	29.7	33.2	31.3	30.6	30.2
	80	25.9	26.4	26.6	26.8	27.3	27.3	27.4	27.5	28.7	28.2	28.2	28.1	29.9	29.1	28.9	28.8	31	29.9	29.6	29.4	32	30.7	30.3	30	33	31.5	30.9	30.6	33.9	32.2	31.6	31.2	34.7	32.9	32.2	31.8	35.5	33.5	32.8	32.3
32	20	24.1	24.6	24.9	25.1	24.9	25.2	25.4	25.5	25.7	25.8	25.9	25.9	26.5	26.3	26.3	26.4	27.3	26.9	26.8	26.8	28.1	27.5	27.3	27.2	28.8	28	27.8	27.6	29.6	28.6	28.2	28.1	30.3	29.1	28.7	28.5	31	29.6	29.2	28.9
	40	24.8	25.4	25.7	25.9	25.8	26	26.2	26.4	26.7	26.7	26.8	26.9	27.6	27.3	27.3	27.3	28.5	28	27.8	27.8	29.3	28.6	28.4	28.3	30.2	29.2	28.9	28.7	31	29.8	29.4	29.2	31.7	30.4	29.9	29.7	32.5	30.9	30.4	30.1
	60	26.1	26.7	27	27.3	27.2	27.5	27.7	27.8	28.3	28.2	28.3	28.4	29.4	28.9	28.9	28.9	30.3	29.7	29.5	29.4	31.3	30.3	30.1	30	32.2	31	30.7	30.5	33	31.6	31.2	31	33.8	32.3	31.8	31.5	34.5	32.9	32.3	32
	80	28.7	29.3	29.7	29.9	30.1	30.2	30.4	30.5	31.4	31.1	31.1	31.2	32.5	31.9	31.8	31.8	33.5	32.6	32.4	32.3	34.5	33.4	33	32.9	35.3	34	33.6	33.4	35.6	34.7	34.2	33.9	36.1	35.3	34.7	34.4	36.7	35.3	34.7	34.9

Table 6 (*Continued*)

Standard Effective Temperature for Activity Level 1 Met (Office Work Type Activity) and Clothing 0.5 Clo (Summer Clothing)

AT (°C) ↓	MRT (°C) →	14				16				18				20				22				24				26				28				30				32			
	AV (m/s) → RH (percent) ↓	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4
14	20	11	7.2	5.3	4	12.1	8.2	6.2	4.9	13.3	9.1	7.1	5.7	14.4	10.1	8	6.5	15.6	11.1	8.9	7.4	16.8	12.2	9.8	8.3	18	13.2	10.7	9.1	19.2	14.2	11.7	10	20.4	15.2	12.6	10.9	21.6	16.3	13.6	11.8
	40	11.1	7.4	5.5	4.3	12.3	8.4	6.4	5.1	13.4	9.4	7.3	5.9	14.6	10.3	8.2	6.8	15.8	11.3	9.1	7.6	17	12.4	10	8.5	18.1	13.4	11	9.4	19.3	14.4	11.9	10.2	20.5	15.4	12.8	11.1	21.7	16.5	13.8	12
	60	11.3	7.6	5.8	4.5	12.4	8.6	6.6	5.4	13.6	9.6	7.5	6.2	14.8	10.6	8.4	7	15.9	11.6	9.3	7.9	17.1	12.6	10.3	8.7	18.3	13.6	11.2	9.6	19.5	14.6	12.1	10.5	20.7	15.6	13.1	11.3	21.9	16.7	14	12.2
	80	11.5	7.8	6	4.8	12.6	8.8	6.9	5.6	13.8	9.8	7.8	6.4	14.9	10.8	8.7	7.3	16.1	11.8	9.6	8.1	17.3	12.8	10.5	9	18.4	13.8	11.4	9.8	19.6	14.8	12.3	10.7	20.8	15.8	13.3	11.6	22	16.9	14.2	12.5
16	20	12.1	8.8	7.2	6.1	13.2	9.8	8.1	6.9	14.3	10.7	8.9	7.8	15.5	11.7	9.8	8.6	16.7	12.7	10.7	9.4	17.8	13.7	11.6	10.3	19	14.7	12.6	11.1	20.2	15.7	13.5	12	21.4	16.7	14.4	12.9	22.6	17.7	15.3	13.7
	40	12.2	9	7.5	6.4	13.4	10	8.3	7.2	14.5	11	9.2	8	15.7	11.9	10.1	8.9	16.8	12.9	11	9.7	18	13.9	11.9	10.5	19.2	14.9	12.8	11.4	20.4	15.9	13.7	12.2	21.5	17	14.7	13.1	22.7	18	15.6	14
	60	12.4	9.3	7.7	6.7	13.6	10.2	8.6	7.5	14.7	11.2	9.5	8.3	15.9	12.2	10.3	9.1	17	13.2	11.2	10	18.2	14.2	12.1	10.8	19.3	15.2	13.1	11.7	20.5	16.2	14	12.5	21.7	17.2	14.9	13.4	22.9	18.2	15.8	14.2
	80	12.6	9.5	8	7	13.7	10.5	8.8	7.8	14.9	11.4	9.7	8.6	16	12.4	10.6	9.4	17.2	13.4	11.5	10.2	18.3	14.4	12.4	11.1	19.5	15.4	13.3	11.9	20.7	16.4	14.2	12.8	21.9	17.4	15.1	13.6	23	18.4	16.1	14.5
18	20	13.1	10.4	9.1	8.2	14.3	11.3	9.9	9	15.4	12.3	10.8	9.8	16.5	13.3	11.7	10.6	17.7	14.3	12.6	11.4	18.8	15.2	13.4	12.3	20	16.2	14.3	13.1	21.2	17.2	15.2	13.9	22.3	18.2	16.2	14.8	23.5	19.2	17.1	15.6
	40	13.3	10.7	9.4	8.5	14.5	11.6	10.2	9.3	15.6	12.6	11.1	10.1	16.7	13.5	12	10.9	17.9	14.5	12.8	11.7	19	15.5	13.7	12.6	20.2	16.5	14.6	13.4	21.4	17.5	15.5	14.2	22.5	18.4	16.4	15.1	23.7	19.4	17.3	15.9
	60	13.6	10.9	9.7	8.8	14.7	11.9	10.5	9.6	15.8	12.8	11.4	10.4	16.9	13.8	12.2	11.2	18.1	14.8	13.1	12	19.2	15.7	14	12.9	20.4	16.7	14.9	13.7	21.6	17.7	15.8	14.5	22.7	18.7	16.7	15.4	23.9	19.7	17.6	16.2
	80	13.8	11.2	9.9	9.1	14.9	12.2	10.8	9.9	16	13.1	11.7	10.7	17.1	14.1	12.5	11.5	18.3	15	13.4	12.3	19.4	16	14.3	13.2	20.6	17	15.2	14	21.7	17.9	16.1	14.8	22.9	18.9	17	15.6	24	19.9	17.8	16.5
20	20	14.2	12	10.9	10.2	15.3	12.9	11.8	11	16.4	13.9	12.6	11.8	17.6	14.8	13.5	12.6	18.7	15.8	14.3	13.4	19.9	16.7	15.2	14.2	21	17.7	16.1	15	22.2	18.7	17	15.9	23.3	19.6	17.9	16.7	24.3	20.6	18.7	17.5
	40	14.4	12.3	11.3	10.6	15.6	13.2	12.1	11.4	16.7	14.2	12.9	12.2	17.8	15.1	13.8	12.9	18.9	16.1	14.7	13.7	20.1	17	15.5	14.6	21.2	18	16.4	15.4	22.4	18.9	17.3	16.2	23.5	19.9	18.1	17	24.5	20.8	19	17.8
	60	14.7	12.6	11.6	10.9	15.8	13.5	12.4	11.7	16.9	14.5	13.3	12.5	18	15.4	14.1	13.3	19.2	16.3	15	14.1	20.3	17.3	15.8	14.9	21.4	18.2	16.7	15.7	22.6	19.2	17.6	16.5	23.7	20.1	18.4	17.3	24.8	21.1	19.3	18.1
	80	14.9	12.9	11.9	11.3	16	13.8	12.7	12	17.1	14.8	13.6	12.8	18.3	15.7	14.4	13.6	19.4	16.6	15.3	14.4	20.5	17.6	16.1	15.2	21.6	18.5	17	16	22.8	19.5	17.9	16.8	23.9	20.4	18.7	17.6	25.1	21.3	19.6	18.4
22	20	15.3	13.6	12.8	12.3	16.4	14.5	13.6	13	17.5	15.4	14.4	13.8	18.6	16.3	15.3	14.6	19.7	17.3	16.1	15.4	20.9	18.2	17	16.1	22	19.2	17.8	16.9	23.1	20.1	18.7	17.7	24.2	21	19.5	18.5	25.1	22	20.3	19.3
	40	15.5	13.9	13.1	12.6	16.6	14.8	14	13.4	17.7	15.7	14.8	14.2	18.9	16.7	15.6	14.9	20	17.6	16.5	15.7	21.1	18.5	17.3	16.5	22.2	19.5	18.1	17.3	23.4	20.4	19	18.1	24.4	21.3	19.8	18.8	25.3	22.2	20.6	19.6
	60	15.8	14.2	13.5	13	16.9	15.1	14.3	13.8	18	16.1	15.1	14.5	19.1	17	16	15.3	20.2	17.9	16.8	16.1	21.3	18.8	17.6	16.9	22.5	19.7	18.5	17.6	23.6	20.7	19.3	18.4	24.7	21.6	20.1	19.2	25.7	22.5	20.9	19.9
	80	16.1	14.6	13.9	13.4	17.2	15.5	14.7	14.2	18.3	16.4	15.5	14.9	19.4	17.3	16.3	15.7	20.5	18.2	17.1	16.4	21.6	19.1	18	17.2	22.7	20	18.8	18	23.9	20.9	19.6	18.7	25	21.9	20.4	19.5	26.2	22.8	21.2	20.2
24	20	16.3	15.1	14.6	14.2	17.4	16	15.4	15	18.5	16.9	16.2	15.7	19.6	17.8	17	16.5	20.7	18.7	17.8	17.2	21.9	19.7	18.6	18	23	20.6	19.5	18.8	24	21.5	20.3	19.5	24.9	22.4	21.1	20.3	25.8	23.3	21.9	21

Table 6 (*Continued*)

Standard Effective Temperature for Activity Level 1 Met (Office Work Type Activity) and Clothing 0.5 Clo (Summer Clothing)

AT (°C) ↓	MRT (°C) →	14				16				18				20				22				24				26				28				30				32			
	AV (m/s) → RH (percent) ↓	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4	0.2	0.6	1	1.4
	40	16.6	15.5	15	14.7	17.7	16.4	15.8	15.4	18.8	17.3	16.6	16.1	19.9	18.2	17.4	16.9	21	19.1	18.2	17.6	22.1	20	19	18.4	23.2	20.9	19.8	19.1	24.2	21.8	20.6	19.9	25.2	22.7	21.4	20.6	26.2	23.6	22.2	21.3
	60	16.9	15.9	15.4	15.1	18	16.7	16.2	15.8	19.1	17.6	17	16.5	20.2	18.5	17.8	17.3	21.3	19.4	18.6	18	22.4	20.3	19.4	18.7	23.5	21.2	20.2	19.5	24.6	22.1	20.9	20.2	25.7	23	21.7	20.9	26.7	23.8	22.5	21.7
	80	17.2	16.2	15.8	15.5	18.3	17.1	16.6	16.2	19.4	18	17.3	16.9	20.5	18.9	18.1	17.7	21.6	19.7	18.9	18.4	22.7	20.6	19.7	19.1	23.8	21.5	20.5	19.8	25.1	22.4	21.3	20.6	26.3	23.3	22	21.3	27.4	24.1	22.8	22
26	20	17.4	16.6	16.4	16.2	18.5	17.5	17.1	16.9	19.6	18.4	17.9	17.6	20.6	19.3	18.7	18.3	21.7	20.2	19.5	19.1	22.8	21.1	20.3	19.8	23.9	21.9	21	20.5	24.8	22.8	21.8	21.2	25.6	23.7	22.6	21.9	26.5	24.3	23.4	22.6
	40	17.7	17.1	16.8	16.6	18.8	17.9	17.6	17.3	19.9	18.8	18.3	18	21	19.7	19.1	18.8	22	20.5	19.9	19.5	23.1	21.4	20.6	20.2	24.2	22.3	21.4	20.9	25.1	23.1	22.2	21.6	26.1	23.9	22.9	22.3	27.1	24.6	23.7	23
	60	18	17.4	17.2	17.1	19.1	18.3	18	17.8	20.2	19.2	18.7	18.5	21.3	20	19.5	19.2	22.3	20.9	20.3	19.9	23.4	21.8	21	20.6	24.6	22.6	21.8	21.3	25.7	23.4	22.5	21.9	26.7	24.2	23.3	22.6	27.8	25	23.9	23.3
	80	18.4	17.8	17.6	17.5	19.4	18.7	18.4	18.2	20.5	19.5	19.1	18.9	21.6	20.4	19.9	19.6	22.6	21.2	20.6	20.2	23.9	22.1	21.4	20.9	25.2	22.9	22.1	21.6	26.5	23.8	22.9	22.3	27.7	24.8	23.6	23	28.8	25.7	24.4	23.6
28	20	18.4	18.1	18.1	18	19.5	19	18.8	18.7	20.6	19.8	19.6	19.4	21.7	20.7	20.3	20.1	22.7	21.6	21.1	20.8	23.8	22.4	21.8	21.5	24.6	23.2	22.6	22.1	25.5	24	23.3	22.8	26.4	24.6	23.9	23.5	27.2	25.2	24.5	24
	40	18.8	18.6	18.5	18.5	19.9	19.4	19.3	19.2	20.9	20.3	20	19.9	22	21.1	20.7	20.5	23.1	21.9	21.5	21.2	24.1	22.8	22.2	21.9	25.1	23.6	22.9	22.5	26.1	24.3	23.6	23.2	27	25	24.2	23.8	27.9	25.7	24.8	24.3
	60	19.2	19	19	19	20.2	19.8	19.7	19.6	21.3	20.7	20.4	20.3	22.3	21.5	21.2	21	23.4	22.3	21.9	21.6	24.6	23.1	22.6	22.3	25.8	24	23.3	22.9	26.9	24.8	24	23.5	27.9	25.6	24.7	24.1	28.9	26.4	25.4	24.8
	80	19.5	19.4	19.4	19.4	20.6	20.2	20.1	20.1	21.6	21.1	20.8	20.7	22.7	21.9	21.6	21.4	24.1	22.7	22.3	22	25.5	23.6	23	22.6	26.8	24.6	23.8	23.3	28.1	25.6	24.6	24.1	29.3	26.5	25.4	24.8	30.4	27.4	26.2	25.5
30	20	19.5	19.6	19.7	19.8	20.5	20.4	20.4	20.5	21.6	21.3	21.2	21.1	22.6	22.1	21.9	21.8	23.7	22.9	22.6	22.4	24.5	23.6	23.3	23.1	25.4	24.3	23.9	23.6	26.3	24.9	24.4	24.1	27.1	25.5	24.9	24.6	28	26.1	25.5	25.1
	40	19.9	20.1	20.2	20.3	20.9	20.9	20.9	21	22	21.7	21.6	21.6	23	22.5	22.3	22.2	24	23.3	23	22.8	25.1	24	23.6	23.4	26.1	24.7	24.2	24	27	25.4	24.8	24.5	28	26.1	25.4	25	28.9	26.8	26	25.6
	60	20.3	20.5	20.7	20.8	21.3	21.3	21.4	21.4	22.3	22.1	22.1	22	23.5	22.9	22.7	22.6	24.7	23.7	23.4	23.2	25.9	24.6	24.1	23.9	27.1	25.4	24.8	24.5	28.2	26.2	25.5	25.1	29.2	27	26.2	25.8	30.2	27.8	26.9	26.4
	80	20.7	21	21.1	21.2	21.7	21.8	21.8	21.9	22.7	22.5	22.5	22.5	24.4	23.6	23.3	23.1	26	24.7	24.2	24	27.4	25.7	25.1	24.8	28.8	26.7	26	25.5	30	27.7	26.8	26.3	31.2	28.6	27.6	27	32.3	29.4	28.4	27.7
32	20	20.5	21	21.3	21.5	21.5	21.8	22	22.1	22.6	22.6	22.7	22.7	23.6	23.4	23.3	23.3	24.5	24	23.8	23.8	25.3	24.6	24.4	24.2	26.2	25.2	24.9	24.7	27.1	25.8	25.4	25.2	27.9	26.4	25.9	25.6	28.7	27	26.4	26.1
	40	21	21.5	21.8	22	22	22.3	22.5	22.6	23	23.1	23.1	23.2	24.1	23.8	23.7	23.7	25.1	24.5	24.3	24.2	26.1	25.2	24.9	24.8	27.1	25.9	25.5	25.3	28	26.6	26.1	25.8	29	27.3	26.7	26.3	29.9	27.9	27.3	26.9
	60	21.4	22	22.3	22.5	22.4	22.7	22.9	23.1	23.6	23.6	23.7	23.7	25	24.5	24.4	24.4	26.2	25.4	25.1	25	27.4	26.2	25.9	25.7	28.6	27	26.5	26.3	29.6	27.8	27.2	26.9	30.7	28.6	27.9	27.5	31.6	29.4	28.6	28.1
	80	21.8	22.4	22.9	23.3	23.1	23.7	24	24.2	25.1	25	25	25.1	26.9	26.2	26	25.9	28.5	27.3	26.9	26.7	29.9	28.3	27.8	27.5	31.2	29.3	28.6	28.2	32.4	30.2	29.4	29	33.5	31.1	30.2	29.7	34.5	31.9	30.9	30.3

NOTE — AT: Dry bulb temperature of indoor air, AV: Air velocity around occupant, MET: Metabolic rate, Clo: Thermal resistance due to clothing, MRT: Mean radiant temperature

Table 7 Minimum Ventilation Rates in Breathing Zone (*See* Notes 1 to 5)

(*Clause* 3.6.1.2)

(This table is not valid in isolation; it shall be used in conjunction with the accompanying notes)

Sl No.	**Occupancy Category**	**People Outdoor Air Rate, R_p**	**Area Outdoor Air Rate, R_a**	**Notes**	**Default Values**		**Air[1] Class**
					Occupant Density (*see* Note 4)	Combined Outdoor Air Rate (*see* Note 4)	
		l/s.person	l/s.m^2		Persons per 100 m^2	l/s.person	
(1)	(2)	(4)	(6)	(7)	(8)	(10)	(11)
i)	Correctional facilities:						
	a) Cell	2.5	0.6	–	25	4.9	2
	b) Dayroom	2.5	0.3	–	30	3.5	1
	c) Guard Stations	2.5	0.3	–	15	4.5	1
	d) Booking/waiting	3.8	0.3	–	50	4.4	2
ii)	Educational facilities:						
	a) Daycare (through age 4)	5	0.9	–	25	8.6	2
	b) Daycare sickroom	5	0.9	–	25	8.6	3
	c) Classrooms (ages 5-8)	5	0.6	–	25	7.4	1
	d) Classrooms (age 9 plus)	5	0.6	–	35	6.7	1
	e) Lecture classroom	3.8	0.3	–	65	4.3	1
	f) Lecture hall (fixed seats)	3.8	0.3	–	150	4.0	1
	g) Art classroom	5	0.9	–	20	9.5	2
	h) Science laboratories	5	0.9	–	25	8.6	2
	j) University/college laboratories	5	0.9	–	25	8.6	2

Table 7 (*Continued*)

Sl No.	**Occupancy Category**	**People Outdoor Air Rate, R_p**	**Area Outdoor Air Rate, R_a**	**Notes**	**Default Values**		**Air[1)] Class**
					Occupant Density (*see* Note 4)	Combined Outdoor Air Rate (*see* Note 4)	
		l/s.person	l/s.m^2		Persons per 100 m^2	l/s.person	
(1)	(2)	(4)	(6)	(7)	(8)	(10)	(11)
	k) Wood/metal shop	5	0.9	–	20	9.5	2
	m) Computer lab	5	0.6	–	25	7.4	1
	n) Media centre	5	0.6	*See* Note 6	25	7.4	1
	p) Music/theatre/dance	5	0.3	–	35	5.9	1
	q) Multi-use assembly	3.8	0.3	–	100	4.1	1
iii)	Food and beverage service:						
	a) Restaurant dining rooms	3.8	0.9	–	70	5.1	2
	b) Cafeteria/fast-food dining	3.8	0.9	–	100	4.7	2
	c) Bars, cocktail lounges	3.8	0.9	–	100	4.7	2
iv)	General:						
	a) Break rooms	2.5	0.3	–	25	5.1	1
	b) Coffee stations	2.5	0.3	–	20	5.5	1
	c) Conference/meeting	2.5	0.3	–	50	3.1	1
	d) Corridors	-	0.3	–	-	-	1
	e) Storage rooms	-	0.6	*See* Note 7	-	-	1

Table 7 (*Continued*)

Sl No.	**Occupancy Category**	**People Outdoor Air Rate, R_p**	**Area Outdoor Air Rate, R_a**	**Notes**	**Default Values**		**Air$^{1)}$ Class**
					Occupant Density (*see* Note 4)	Combined Outdoor Air Rate (*see* Note 4)	
		l/s.person	l/s.m^2		Persons per 100 m^2	l/s.person	
(1)	(2)	(4)	(6)	(7)	(8)	(10)	(11)
v)	Hotels, motels, resorts, dormitories:						
	a) Bedroom/living room	2.5	0.3	–	10	5.5	1
	b) Barracks sleeping areas	2.5	0.3	–	20	4.0	1
	c) Laundry rooms, central	2.5	0.6	–	10	8.5	2
	d) Laundry rooms within dwelling units	2.5	0.6	–	10	8.5	1
	e) Lobbies/pre-function	3.8	0.3	–	30	4.8	1
	f) Multipurpose assembly	2.5	0.3	–	120	2.8	1
vi)	Office buildings:						
	a) Office space	2.5	0.3	–	5	8.5	1
	b) Reception Areas	2.5	0.3	–	30	3.5	1
	c) Telephone/data entry	2.5	0.3	–	60	3.0	1
	d) Main entry lobbies	2.5	0.3	–	10	5.5	1
vii)	Miscellaneous spaces:						
	a) Bank vaults/safe deposit	2.5	0.3	–	5	8.5	2
	b) Computer (not printing)	2.5	0.3	–	4	10.0	1

Table 7 (*Continued*)

Sl No.	**Occupancy Category**	**People Outdoor Air Rate, R_p**	**Area Outdoor Air Rate, R_a**	**Notes**	**Default Values**		**Air[1] Class**
					Occupant Density (*see* Note 4)	Combined Outdoor Air Rate (*see* Note 4)	
		l/s.person	l/s.m^2		Persons per 100 m^2	l/s.person	
(1)	(2)	(4)	(6)	(7)	(8)	(10)	(11)
	c) Electrical equipment rooms	–	0.3	*See* Note 7	–	–	1
	d) Elevator machine rooms	–	0.6	*See* Note 7	–	–	1
	e) Pharmacy (preparation area)	2.5	0.9	–	10	11.5	2
	f) Photo studios	2.5	0.6	–	10	8.5	1
	g) Shipping/receiving	–	0.6	*See* Note 7	–	–	1
	h) Telephone closets	–	0.0	–	–	–	1
	j) Transportation waiting	3.8	0.3	–	100	4.1	1
	k) Warehouses	–	0.3	*See* Note 7	–	–	2
viii)	Public assembly spaces:						
	a) Auditorium seating area	2.5	0.3	–	150	2.7	1
	b) Places of religious worship	2.5	0.3	–	120	2.8	1
	c) Courtrooms	2.5	0.3	–	70	2.9	1
	d) Legislative chambers	2.5	0.3	–	50	3.1	1
	e) Libraries	2.5	0.6	–	10	8.5	1

Table 7 (*Continued*)

Sl No.	Occupancy Category	People Outdoor Air Rate, R_p	Area Outdoor Air Rate, R_a	Notes	Default Values		Air$^{1)}$ Class
					Occupant Density (*see* Note 4)	Combined Outdoor Air Rate (*see* Note 4)	
		l/s.person	l/s.m^2		Persons per 100 m^2	l/s.person	
(1)	(2)	(4)	(6)	(7)	(8)	(10)	(11)
	f) Lobbies	2.5	0.3	–	150	2.7	1
	g) Museums (children's)	3.8	0.6	–	40	5.3	1
	h) Museums/galleries	3.8	0.3	–	40	4.6	1
ix)	Residential:						
	a) Dwelling unit	2.5	0.3	*See* Notes 8 and 9	*See* Note 8	–	1
	b) Common corridors	–	0.3	–	–	–	1
x)	Retail:						
	a) Sales (except as below)	3.8	0.6	–	15	7.8	2
	b) Mall common areas	3.8	0.3	–	40	4.6	1
	c) Barbershop	3.8	0.3	–	25	5.0	2
	d) Beauty and nail salons	10	0.6	–	25	12.4	2
	e) Pet shops (animal areas)	3.8	0.9	–	10	12.8	2
	f) Supermarket	3.8	0.3	–	8	7.6	1
	g) Coin-operated laundries	3.8	0.3	–	20	5.3	2
xi)	Sports and entertainment:						
	a) Sports arena (play area)	–	1.5	*See* Note 10	–	–	1

Table 7 (*Continued*)

Sl No.	**Occupancy Category**	**People Outdoor Air Rate, R_p**	**Area Outdoor Air Rate, R_a**	**Notes**	**Default Values**		**Air[1] Class**
					Occupant Density (*see* Note 4)	Combined Outdoor Air Rate (*see* Note 4)	
		l/s.person	l/s.m^2		Persons per 100 m^2	l/s.person	
(1)	(2)	(4)	(6)	(7)	(8)	(10)	(11)
	b) Gym, stadium (play area)	–	1.5	–	30	–	2
	c) Spectator areas	3.8	0.3	–	150	4.0	1
	d) Swimming (pool and deck)	–	2.4	*See* Note 11	–	–	2
	e) Disco/dance floors	10	0.3	–	100	10.3	1
	f) Health club/aerobics room	10	0.3	–	40	10.8	2
	g) Health club/weight rooms	10	0.3	–	10	13.0	2
	h) Bowling alley (seating)	5	0.6	–	40	6.5	1
	j) Gambling casinos	3.8	0.9	–	120	4.6	1
	k) Game arcades	3.8	0.9	–	20	8.3	1
	m) Stages, studios	5	0.3	*See* Note 12	70	5.4	1

[1] Air Class Characteristic

1 Air with low contaminant concentration, low sensory-irritation intensity, and inoffensive odour.

2 Air with moderate contaminant concentration, mild sensory-irritation intensity, or mildly offensive odours. Class 2 air also includes air that is not necessarily harmful or objectionable but that is inappropriate for transfer or recirculation to spaces used for different purposes.

3 Air with significant contaminant concentration, significant sensory-irritation intensity, or offensive odour.

4 Air with highly objectionable fumes or gases or with potentially dangerous particles, bio aerosols, or gases, at concentrations high enough to be considered harmful.

Table 7 (*Concluded*)

Sl No.	**Occupancy Category**	**People Outdoor Air Rate, R_p**	**Area Outdoor Air Rate, R_a**	**Notes**	**Default Values**		**Air1) Class**
					Occupant Density (*see* Note 4)	Combined Outdoor Air Rate (*see* Note 4)	
		l/s.person	l/s.m^2		Persons per 100 m^2	l/s.person	
(1)	(2)	(4)	(6)	(7)	(8)	(10)	(11)

NOTES

1 The rates in this table are based on all other applicable requirements being met.

2 This table applies to no-smoking areas only. Rates for smoking-permitted spaces shall be determined using other methods.

3 Volumetric airflow rates are based on an air density of 1.2 kg of dry air/m^3, which corresponds to dry air at a barometric pressure of 1 atm (101.3 kPa) and an air temperature of 21°C. Rates may be adjusted for actual density but such adjustment is not required for compliance with this standard.

4 Actual occupant density should be considered, the default occupant density shall be used only when actual occupant density is not known. Default combined outdoor air (per person) rate is based on the default occupant density.

5 If the occupancy category for a proposed space or zone is not listed, the requirements for the listed occupancy category that is most similar in terms of occupant density, activities and building construction shall be used.

6 For high school and college libraries, use values shown for public assembly spaces- libraries.

7 The prescribed value may not be sufficient when stored materials include those having potentially harmful emissions.

8 Default occupancy for dwelling units shall be two persons for studio and one-bedroom units, with one additional person for each additional bedroom.

9 Air from one residential dwelling shall not be recirculated or transferred to any other space outside of that dwelling.

10 When combustion equipment is intended to be used on the playing surface, additional dilution ventilation and/or source control shall be provided.

11 The prescribed value does not allow for humidity control. Additional ventilation or dehumidification may be required to remove moisture.

12 The prescribed value does not include special exhaust for stage effects, for example, dry ice vapours, smoke.

3.6.2 *Designing for Air Quality*

The HVAC system shall be designed with adequate filtration for achieving following levels of indoor pollutants:

The threshold values for IAQ pollutants will be as mentioned in as per the Table 8 provided below. The buildings/indoor spaces will be classified as Class A, B and C where Class A refers to aspirational, Class B refers to acceptable and Class C refers to minimum acceptable.

Table 8 Threshold Values for IAQ Pollutants

(*Clause* 3.6.2)

Sl No.	**Pollutants**	**Units**	**Classification**		
			A	B	C
(1)	(2)	(3)	(4)	(5)	(6)
i)	CO_2	ppm	ambient + 350	ambient + 500	ambient + 700
ii)	$PM_{2.5}$	ug/m^3	< 15	< 25	< 25
iii)	PM_{10}	ug/m^3	< 50	< 100	< 100
iv)	O_3	ug/m^3	< 50	< 100	-
v)	TVOC (equivalent to isobutylene)	ug/m^3	< 200	< 400	< 500
vi)	CH_2O	ug/m^3	< 30	< 100	-
vii)	SO_2	ug/m^3	< 40	< 80	-
viii)	NO_2	ug/m^3	< 40	< 80	-
ix)	CO	ppm	< 2	< 9	< 9

NOTE — PM1.0 (sub-micron particles less than 1.0 µm in size) poses various health risks. PM1 particles may penetrate deep into the lungs and bloodstream, and prolonged exposure is associated with serious illnesses. Many bacteria and viruses are also within the PM1 size range, facilitating their spread indoors. The designers may consider filtration and air purification strategies that are effective in removing PM1 particles, thereby improving occupant well-being, productivity, and overall indoor air quality.

3.6.3 *Designing for Background Noise Control and Vibration*

The background noise and vibration created by air distribution through the HVAC system, combined with noise from equipment and outdoor sources of noise and vibration may causes significant disturbance to building users. Adoption of measures for adhering to indoor noise limits and vibration control should be ensured in the design of equipment, their foundation, supports and air distribution system.

4 HVAC SYSTEM TYPES

HVAC system requirements for the design, construction, installation, operation, replacement, repair, alteration, maintenance and end of life of mechanical cooling systems. It encourages the adoption of products designed with recyclability, reusability, and remanufacturing in mind, aiming to minimize waste, reduce environmental impacts, and promote resource efficiency throughout the entire lifecycle of the systems.

Following points to be considered for selection of cooling systems:

a) safeguard people from illness, injury or loss (including loss of amenity) due to the failure of air-conditioning installation;

b) it may be ensured that air-conditioning installation is suitable to meet the sizing requirement as per **3**;

c) conserve water and energy;

d) safeguard the environment;

e) safeguard public and private infrastructure; and

f) ensure that air-conditioning installation is designed and is capable of being maintained so that throughout its serviceable life it will continue to satisfy objectives (a) to (e).

Mechanical services, plant and equipment that are used for cooling, heating and/or ventilation of a building shall be adequate for the purpose meeting the basis of design. A building's HVAC system installation and maintenance shall support energy efficient outcomes and minimise any adverse impact on building occupants or occupants of adjoining places, the network utility operator's infrastructure, property and the environment.

Compliance with the requirement shall be verified either:

1) by satisfying the required criteria when tested in accordance with a specified test method endorsed by a recognised certification body; or

2) by calculation and certification by persons or organisations with recognised credentials in the testing of ventilation and air conditioning systems.

4.1 General

Systems for air conditioning may be broadly grouped as air-to-air, air-to-water, and liquid-to-liquid type. Suitability of system type shall not be generalized; hence it shall need to be building specific decision, considering initial cost, efficiency, maintenance, effect on building aesthetics, sound level, service life and other factors. Lower operating cost, central maintenance and control shall be of primary considerations.

It may be noted that central systems often require a higher initial cost than distributed systems but often result in annual energy savings. They also have a potential of reducing the total installed capacity by using load diversity. Over the life cycle, the centralized cooling systems usually prove to be more cost-effective when the total building load exceeds 350 kW (approximately 100 TR), depending on climate and patterns of occupancy use.

When low initial cost and simplicity are primary concerns, designers may select zone-by-zone distributed systems, incorporating either cooling or both heating and cooling facility. This approach shall normally be used for smaller buildings, however, larger buildings with multiple tenancy may also consider this as an option.

NOTES

1 Distributed systems, also known as unitary systems, individually consists of fan, cooling coil, compressor and outdoor condenser. Examples of distributed systems include unitary air conditioners, packaged rooftop air conditioners, variable refrigerant flows (VRFs), heat pumps, as well as refrigerant-based split-system fan-coil units (single or multi-unit).

2 Water-source heat pumps (WSHPs) are also considered as distributed systems in which the compressor is located close to the occupied space, but they are collectively served by a centralized water system with auxiliary heat rejection devices.

Comparative advantages, disadvantages and constraints of each option should be carefully evaluated before zeroing down to final HVAC system selection. Table 9 lists out various system characteristics of different HVAC systems; it may be used as a guiding tool for system selection.

Table 9 HVAC System Analysis and Selection Matrix

(*Clause* 4.1)

Sl No.	System Characteristics	Fixed Speed Unitary Systems (Window ACs/Split ACs/ Package ACs)	Variable Speed/Flow/ Frequency/capacity Unitary Systems (Split ACs/ Package ACs)	Variable Speed Multi or Modular Systems (VRF)	Central Systems
(1)	(2)	(3)	(4)	(5)	(6)
i)	Temperature	No uniform and effective control	Minimal uniform and effective control possible	Reasonably uniform and effective control possible	Uniform and effective control possible
ii)	Humidity	Effective control not possible	Effective control not possible	Effective control not possible	Effective control possible
iii)	Space pressure	Effective control not possible	Effective control not possible	Effective control not possible	Effective control possible
iv)	Capacity requirements	Capacity to suit zone peak, No diversity	Capacity to suit zone peak, No diversity	Capacity to suit zone peak, Limited diversity shall be considered	Allows the design engineer to consider HVAC diversity factors that reduce installed equipment capacity
v)	Redundancy	Does not have the benefit of back-up or standby equipment	Does not have the benefit of back-up or standby equipment	It has the benefit of partial back-up or standby equipment	Back-up or standby equipment shall easily be accommodated
vi)	Facility management	Allows minimal provision to maximize performance using good facility management techniques in operation	Allows minimal provision to maximize performance using good facility management techniques in operation	Limited possibilities to maximize performance using good facility management techniques in operation	Allows maximize performance using good facility management techniques in operation

Table 9 (*Continued*)

Sl No.	System Characteristics	Fixed Speed Unitary Systems (Window ACs/Split ACs/ Package ACs)	Variable Speed/Flow/ Frequency/capacity Unitary Systems (Split ACs/ Package ACs)	Variable Speed Multi or Modular Systems (VRF)	Central Systems
(1)	(2)	(3)	(4)	(5)	(6)
vii)	Spatial requirements	No plant/ equipment room required. Compromises building elevation	No plant/ equipment room required. Compromises building elevation	No plant/equipment room required. Outside units shall be located on roof or on adjacent ground. Very small depth but larger linear length (based on number of modular outdoor units) for shaft is required for refrigerant piping.	Equipment rooms/ spaces and accessible shaft required for chilled water piping
viii)	Electric supply	Distributed electric supply required	Distributed electric supply required	Zone wise distributed electric supply required	Minimal distribution cost by centralised supply near the substation
ix)	First cost	Minimum first cost	First cost marginally higher than fixed speed system	Moderate first cost but marginally higher than variable speed unitary product	Even with HVAC diversity, a central system may be of a bit higher or similar cost as a decentralized HVAC system
x)	Operating cost	Higher operating cost Strategic scheduling of multiple pieces of equipment shall save marginal operating cost. But equipment less efficient	Strategic scheduling of multiple pieces of equipment shall save reasonable operating cost. Higher peak energy requirement	Strategic scheduling of equipment shall save operating cost better than unitary product. Higher peak energy requirement	More energy-efficient primary equipment and multiple pieces of HVAC equipment allow staging of operation to match building loads while maximizing operational efficiency
xi)	Maintenance cost	Comparatively less maintenance cost	Maintenance cost marginally higher than fixed speed	Maintenance cost higher than both fixed and variable speed unitary system but less than central system	Comparatively higher since centralised equipment room requires operator with no access to occupant workspace, but with

Table 9 (*Concluded*)

Sl No.	System Characteristics	Fixed Speed Unitary Systems (Window ACs/Split ACs/ Package ACs)	Variable Speed/Flow/ Frequency/capacity Unitary Systems (Split ACs/ Package ACs)	Variable Speed Multi or Modular Systems (VRF)	Central Systems
(1)	(2)	(3)	(4)	(5)	(6)
					fewer pieces of HVAC equipment to service
xii)	Reliability	Reliable equipment but low service life	Reliable equipment but low service life	Reliable equipment but moderate service life	Reliable equipment with much longer service life
xiii)	Flexibility	Has to be placed at fixed locations	Has to be placed at fixed locations	Can be placed at distributed locations	Flexibility available in terms of alternative locations
xiv)	Level of control	Limited control level available	Limited control level available	Moderate control level available	Close control level available
xv)	Noise and vibration	Noise and vibration within/adjacent to occupied spaces for unitary window type air conditioners which is substantially reduced in case of split system	It is generally available in split system only for which noise and vibration is substantially reduced in occupied and adjacent spaces as compared to a window type air conditioner	Noise and vibration on roof terrace or ground away from occupied spaces, however the same shall be reduced with good installation practices	Noise and vibration away from occupied spaces
xvi)	Constructability	Multiple and similar-in-size equipment makes standardization a construction feature	Multiple and similar-in-size equipment makes standardization a construction feature	Multiple and similar equipment makes standardization a construction feature	Require more coordinated installation with added benefit of consolidated primary equipment in a central location.

4.1.1 *Window Air Conditioners*

Window Air Conditioners, as the name itself suggests, are usually fitted in a window or a recess created in a wall of a building. These are unitary direct expansion (DX) systems, having all the components packaged in a single box. The front side is designed to deliver the conditioned air to the connected space, and rear side shall be exposed to ambient for easy discharge of heat without any direct adverse effect on anyone else.

4.1.1.1 *Suitability*

Window air conditioners are suitable for residences, office cabin, general office area, and similar applications, where rigid comfort conditions are not required to be maintained.

4.1.1.2 *Limitations*

a) *Sound level* — Noise level of window air conditioner inside the conditioned room presents a serious problem due to close proximity of compressor to the occupied space;

   The noise level of window air conditioner shall be in accordance with the levels specified in Table 5 of accepted standard [D-3(4)];

b) *Fresh air for ventilation* — Most window air conditioners have a very small opening for entry of outdoor air for ventilation. As a result, the conditioned space, especially if occupied by more than 2-3 persons, may have higher levels of CO_2, as compared to centralised system; and

c) *Location* — Window air conditioner shall be mounted preferably at the window sill level on an external wall, where hot air from air-cooled condenser shall be discharged to the outdoor space without causing inconvenience to others. There should not be any obstruction for the inlet air to, nor for discharge air from, the condenser.

While deciding location of the window air conditioner, care shall be taken to ensure that the condensate drain water is piped to the ground level and does not drip in open space, causing nuisance.

Window air conditioner shall not be used for special applications like sterile rooms for hospitals and clean room applications where high filtration efficiency is desired, nor in applications where high amount of fresh air is desired for ventilation. It shall also not be used for areas that require close control of both the indoor temperature and relative humidity.

For detailed information regarding constructional and performance requirements and methods for establishing ratings of unitary (window) air conditioners, reference shall be made to the accepted standard [D-3(4)] and [D-3(5)].

4.1.1.3 For detailed information regarding constructional and performance requirements and methods for establishing rating of window type room air conditioners, reference shall be made to the accepted Indian standards.

4.1.2 *Split Air Conditioner*

Split air conditioners comprise of an indoor unit and an outdoor unit. Depending on its type, the Indoor unit may be mounted on either on floor, on wall, or at the roof. The outdoor unit consisting of compressor, heat exchanger, fan and motor; is installed in a separate independent cabinet. The indoor unit is an air handling system, designed primarily to provide conditioned air to an enclosed space, room or zone (conditioned space). It includes a prime source of refrigeration for cooling and dehumidification/heating and means for the circulation and filtering of air.

Various types of split air conditioners may be categorized based on type of compressor for outdoor unit and air-distribution for indoor unit, as below:

a) *Outdoor unit with variable speed compressor* — Also called an inverter AC or variable speed AC, works on part load depending on the demand for the conditioned space. This often uses a variable-frequency drive to control the frequency and thereby the speed of the compressor motor.

b) Outdoor unit with fixed speed compressor.

c) *Free-blow indoor unit* — It could be high wall mounted, ceiling suspended cassette (exposed type), or floor-mounted.

d) *Indoor unit* (*ceiling suspended*) — It is mounted in the ceiling void and provided with a duct collar and grille. This is commonly used in the vestibule of a hotel room.

e) *Ducted indoor unit* — It is generally mounted in ceiling void and requires duct work for air distribution.

4.1.2.1 *Suitability*

Split air conditioners are suitable for wide range of applications including residence, small office, club, restaurant, showroom, departmental store and others except for locations having high occupancy and requirement of high ventilation rates.

4.1.2.2 *Operating parameters*

In general, nominal capacity of the split air conditioner is rated as per accepted standard [D-3(6)] for an ambient temperature of 35 °C. Split ACs gets de-rated at higher ambient temperature (above 35 °C) in summer months, in most Indian cities, and locations where for significant duration ambient temperature is likely to be above 35 °C, information related to capacity deration and reduction in energy efficiency shall be the basis of system sizing.

At locations having high voltage fluctuation and inferior power quality, a voltage stabilizer shall be required to get stabilized rated voltage as per specifications defined by manufacturer. For 3 phase unit, it is recommended to use phase reversal protection device in power supply to the outdoor unit.

4.1.2.3 *Location*

Split air conditioner indoor units are to be mounted within the air-conditioned space or above the false ceiling from where the air distribution ducts are to be taken to the conditioned space for distribution of the conditioned supply air. When the indoor unit is mounted in the false ceiling, inspection panel shall be kept in the false ceiling to attend to the indoor unit, and periodic cleaning requirement of air filter. Outdoor unit shall be mounted at the nearest open area where unobstructed flow of outside air is available for the air-cooled condenser.

4.1.2.4 *Installation*

Wall mounted unit and similar exposed indoor unit are to be provided with installation plate for ease in installation. Care shall be taken to ensure clearance space as specified by the manufacturer is provided. The intake of return air shall not have any restrictions.

Ceiling suspended indoor unit shall be provided with vibration absorbers and isolators to minimize vibration transmission to the ceiling.

Outdoor unit shall be mounted on metal frame with anticorrosive coating or made of corrosion resistant material in an open area so that the condenser outlet air is thrown out with no obstruction and possible return of the air to condenser inlet side. Precaution shall also be taken that hot air from any one outdoor unit does not mix with the outdoor air intake of any other air-cooled condenser. This is generally referred as short cycling of the air and shall be avoided. The spacing around the condenser unit shall be ensured as per the manufacturer's installation guideline and recommendation. In case of multiple outdoor units in the same premise, the installations of all the condensing units shall be such that the outlet air from condensers shall not mix with the air inlet of any of the condensing units.

Service valves shall be provided on the outdoor unit for pressure testing of the system for leakages, for evacuation of moisture and air from the system, and to carry out predetermined gas quantity charge into the system. In case of maintenance of any part, it shall be provided with service valves to isolate and store the entire refrigerant charge within the outdoor unit by pumping down, thus saving the entire charge of refrigerant.

4.1.2.5 *Limitations*

Split air conditioners are not recommended for:

a) where distance between indoor and outdoor – Horizontal, vertical and total exceeds the limits as specified by manufacturers. Generally, the maximum of 30 m or higher as per recommendation of manufacturer from the outdoor unit for units up to 10 500 W (3 TR approximately), the horizontal distance between the indoor unit and outdoor unit should not exceed 10 m;

b) area requiring close and higher accuracy control of both the indoor temperature and relative humidity which is also referred as precision air conditioning;

c) special applications like sterile rooms for hospitals and clean room applications where high filtration efficiency is desired; and

d) spaces with large occupancy or high fresh air requirements.

4.1.2.6 For detailed information regarding constructional and performance requirements and methods for establishing rating of split type room air conditioners, reference shall be made to the accepted Indian standards.

4.1.3 *Ducted Split Air Conditioner*

Ducted split air conditioner (packages DX) units are ducted and packaged systems including rooftop and indoor packaged units in commercial air conditioning segment. Also known as unitary and light commercial systems, these typically should be used for small-to-medium commercial buildings to avoid the complexities associated with chilled water air conditioning systems. Packaged air conditioner shall be a self-contained unit suitable for floor mounting, or ceiling suspended ducted indoor units, designed to provide conditioned air through ducting in to the moderate sized conditioned spaces. It shall include a prime source of refrigeration for cooling and dehumidification, distinct facility for drawing of fresh air and mixing with return air, means for cleaning of mixed return and fresh air, and provision for external ducting for uniform air distribution in the conditioned spaces. If required, it shall also include winter heating and humidification package for winter operation. The machine shall be equipped with compressor, evaporator, expansion device and remote air-cooled condenser or water-cooled condenser with interconnected copper refrigerant piping.

Water cooled condenser packaged unit gives higher cooling capacity with lower power consumption as compared to an air-cooled condenser packaged unit which gets considerably de-rated in capacity for high (beyond 35 °C) ambient temperature in summer months for most of the cities in India. Air cooled package unit consequently also consumes more power in peak summer months. On the other hand, water-cooled condenser unit requires cooling tower with necessary piping and pump sets for circulating condenser-cooling water but is far more energy efficient at locations where ambient wet bulb temperatures are low in dry-summer months.

Water cooled systems shall be used where water for cooling is available. Treated wastewater, with proper TDS control shall be used in water cooled systems where available.

Packaged units with vertical air discharge should be used; however, if horizontal air discharge unit is procured then heat island effect would have to be avoided by providing clear unblocked space ahead of the condenser discharge.

4.1.3.1 *Suitability*

Packaged units are suitable for wide range of applications including office, club, restaurant, showroom, departmental store, banquet halls and others.

4.1.3.2 *Location*

Ducted split unit shall be mounted within the air-conditioned space with discharge air plenum or in a separate room from where the air distribution duct is taken to the conditioned space. While deciding location for the packaged unit, provision shall be kept for ease of servicing of the unit.

4.1.3.3 *Installation*

Ducted split unit shall be normally mounted on resilient pads which prevent vibration of the unit from being transmitted to the floor.

4.1.3.4 *Limitations*

Packaged air conditioners are not recommended for:

a) large multi-storey buildings, where multiplicity of compressors may entail subsequent maintenance problems;

b) where the length of air distribution ducting may exceed 30 m. However, duct length limitation depends upon permissible external static pressure specified by the manufacturer;

c) where the vertical distance of air-cooled condenser from the packaged unit exceeds about 20 m. The sum of horizontal and vertical distance should generally be kept within 25 m;

d) special applications like sterile rooms for hospitals and clean room applications where high filtration efficiency is desired. For these applications, special packaged units are available with high micron efficiency filters; and

e) operation theatres, where 100 percent fresh air is needed and fire hazard exists depending on the type of anaesthesia being used.

4.1.4 *Variable Refrigerant Flow System*

Variable refrigerant flow (VRF) systems are direct expansion (DX) multi-split system with compressors having ability to vary the refrigerant mass flow rate and, capable of delivering capacity according to variable load requirement. By delivering the variable refrigerant flow, VRF unit delivers required cooling/heating capacity allowing for substantial energy savings at partial-load conditions. VRF system has an outdoor unit connected with multiple number of indoor units via refrigerant piping, an attribute that distinguishes VRF system from other DX system. Other advantages of VRF system are its scalability, variable capacity, distributed temperature control, and the simultaneous cooling/heating mode application in different connected zones.

VRF system achieves temperature control on a zone-by-zone basis primarily by using refrigerant side control. As compared to the basic DX system, VRF Indoor unit has an additional electronic expansion device to control refrigerant flow passing through evaporator coil, to control indoor temperature, precisely based on the instantaneous load requirement. Similar to other air-cooled systems, air cooled VRF systems get derated at temperatures higher than rating temperature 35 °C. Therefore, sizing calculation shall be carried out based upon the information provided by the manufacturer about cooling/heating and energy performance at elevated temperatures.

VRF system is available with a dedicated air handling unit for supply of treated fresh air (TFA). In order to cater to fresh air needs, VRF system outdoor unit should be connected with TFA-AHU. A control box equipped with electronic expansion device and communication PCB is needed for TFA-AHU so that it shall communicate seamlessly with the VRF system outdoor unit.

VRF technology comes in two pipe or three pipe system. In a 2-pipe heat pump system, all of the zones shall either be in cooling mode or in heating mode. Application requiring simultaneous heating and cooling should have 3 pipe systems for enabling heat recovery.

4.1.4.1 *Configuration*

VRF system is available with air cooled or water-cooled condenser. Outdoor unit in VRF system could have multiple compressors, with one or more compressor provided with variable speed control. Generally, for air cooled VRF system, outdoor unit is available both with top discharge and with side discharge.

4.1.4.2 *Suitability*

VRF systems are suitable for a wide range of applications including residence, apartment, villa, small and big office, club, restaurant, showroom, departmental store, healthcare facility, hospitality, cultural facility, educational facility and industrial facility.

In VRF system, depending on application, same or different type of indoor units shall be connected to a single outdoor unit or to multiple outdoor units. VRF Indoor units and air handling units for fresh air or for special treatment of re-circulated air, shall be connected to the same refrigerant line, to facilitate more flexible system design, in mid and large size applications. However, usage of bigger AHU in VRF systems may have evident effect on the part load energy efficiency advantage of the system.

4.1.4.3 *Controls*

VRF systems shall have factory-packaged integral controls in each component; these communicate through their system specific protocol, to ensure that all system components operate collectively. VRF indoor and outdoor units include refrigerant and air side sensing and control devices which allow the system to optimize its output (compressor speed, discharge temperature, fan speed) based on inputs from controllers. Depending on the application and design, a VRF systems shall able to operate with at least one of the three different levels of controls: individual/group controller, centralized controller with remote monitoring and interface with building management system (BMS).

a) *Individual/group controller*

VRF indoor units shall be controlled individually with wired or wireless individual remote controller. Control options include ON/OFF temperature change, mode change, fan speed change and integration with the BMS system of the building. Applications such as a large common area in which multiple indoor units are running simultaneously, at the same condition, shall be controlled by a single remote controller by combining these indoor units as a group. All setting conditions remain same for all indoor units connected in the group. Each of the grouped indoor unit may operate according to the sensed return air temperature.

b) *Centralized controller with remote monitoring and control*

Centralized controller allows user to operate and monitor multiple indoor units centrally. Besides having all functions of individual remote controller, centralized controller has the additional facility of scheduling energy saving by operation restrictions, and web monitoring. In some applications, single outdoor unit is used by different tenants connected to different indoor units. In such cases, centralized controller offers facility of tenant billing through software application, depending on individual usage through proportional power distribution.

c) *Interface with building management system*

VRF system shall be integrated with building management system if available, with the use of different interface gateways that communicate with different protocols. With this interfacing, it is easy to operate and monitor air conditioning with user's building management system.

4.1.5 *Liquid Chilling System*

Liquid chilling system may be based on chilled water, brine, or other secondary coolant for air conditioning or refrigeration. The most frequent application of water chilling is for air conditioning. However, brine cooling systems for low temperature refrigeration requirement and chilling fluids for thermal storage processes, are also common.

The basic components of a vapour-compression, liquid-chilling system shall include a compressor, liquid cooler (evaporator), condenser – which could be air cooled or water cooled), compressor drive, liquid-refrigerant expansion or flow control device and control centre; it also normally includes a receiver, economizer, expansion turbine and/or sub cooler. In addition, auxiliary components may be used, such as a lubricant cooler, lubricant separator, lubricant-return device, purge unit, lubricant pump, refrigerant transfer unit, refrigerant vents, and/or additional control valves. Liquid chilling units are available with air cooled or water-cooled condensers. Wherever water is available for cooling, water cooled chillers shall be opted for.

4.1.5.1 *Vapour compression water chiller*

The unit shall be installed on to a solid foundation on appropriately designed resilient mountings as per the manufacturer recommendation. Pipe connections shall have flexible couplings; these should be considered in conjunction with the design of the pump mountings and the pipe supports.

Capacity control is required in all the chillers that shall be capable to maintain an approximately constant temperature of the chilled water leaving the evaporator. This may be adequate for one or two chiller packages, but a more elaborate central control and plant optimization system is desirable for a large number of chillers. The design of the refrigeration control system should be integrated, or be compatible, with the control system for the heat transfer medium circulated within the cooler.

Multiple chiller configuration, same or different size and types shall be used to achieve the highest energy efficiency and adequate system capacity availability at all conditions. System COP shall be the basis for design and selection of equipment.

Power consumption during operation should be reduced by taking advantage of a fall in the ambient dry bulb and wet bulb temperatures, which permit a corresponding increase in chilled water temperature and decrease in the condenser water temperature, and consequent considerable reduction in the compressor power consumption. It is important to optimize operating cost by optimum equipment selection and careful design of the automatic control system.

The water chilling packages are classified based on the type of compressor, as given below:

a) *Centrifugal compressor* — These compressors use impellers to impart pressure energy to the refrigerant. These may be modulated down to approximately 40 percent of full load capacity, with careful control of the condensing pressure. Part load operation of centrifugal compressor should be restricted to 40 percent or above in order to avoid surging of compressor that may damage it if continues to occur.

   In order to save energy, centrifugal compressors with variable speed drives (VFD's) should be preferred over fixed speed chillers. VFD's are used on chillers not only to enhance the part load performance but also to act as an alternate to auto-tap change starter for minimizing the starting current for the compressor.

   Modern variable-speed oil-free centrifugal chillers have the shaft with impeller levitated during rotation, using digitally controlled magnetic bearings. This unique feature reduces the friction and heat caused by conventional bearings, adding to the overall high efficiency. It also eliminates the need for lubricating oil and the ancillary components required to support the lubricating oil system, which further improves efficiency.

b) *Screw compressor* — Screw compressors are available in open and semi-hermetic form and are generally coupled directly to two-pole motors. The capacity of the compressor may be modulated down to about 20 percent of full load capacity.

   Similar to centrifugal compressors, screw compressors with VFD's may be used as an effective way to enhance the part load performance and also minimize the starting current for the compressor.

   These are generally specified and used for capacities up to 1 400 kW (approximately 400 TR).

   In systems using a direct expansion evaporator (DX chiller), oil is trapped in the evaporator and an oil recovery system is necessary. With some systems, oil cooler is required in the oil circulation system, to remove the heat gathered by oil during compression cycle.

c) *Scroll Compressor* — Scroll compressors are generally used in residential and small/light commercial air-conditioning. Scroll chillers may be used in smaller sizes up to 425 kW. They offer relatively higher efficiency over other types of compressors, however, scroll compressors are not suitable for higher capacity range.

d) *Reciprocating compressor* — Due to their relatively lower efficiency, reciprocating compressors are nearly phased out from the comfort air-conditioning application. However, for cold storage and other special purpose applications, these still have importance due to their capacity to offer high pressure ratio.

4.2 Vapour Absorption/Adsorption System

The absorption cycle uses a solution which, typically has two working fluids: an absorber and an absorbent. These fluids typically in liquid state, have significant change in solubility of the absorbent at different temperatures. Function of a vapor compressor is replaced by a liquid pump. The absorbent/refrigerant mixture is pumped to a higher pressure as a solution, where the refrigerant is boiled off by the application of heat and is subsequently condensed in the condenser.

Absorption machines are extensively used in liquid-chilling applications. These are most suitable for applications where waste heat is readily available. Solar energy assisted air-conditioning/cooling systems also use absorption system.

4.2.1 *Indirect Firing*

The lithium bromide/water absorption system shall be powered by medium or high temperature hot water and low or medium pressure steam. Water is the refrigerant and lithium bromide the absorbent. The four compartments enclosing the heat exchanger tube bundles for the condenser, evaporator, generator and absorber shall be in a single or multiple pressure vessel arrangement. The whole assembly has to be maintained under a high vacuum for the correct functioning of the unit. Water and absorbent solutions are circulated within the unit by electrically driven pumps.

Capacity control down to 10 percent of full load capacity is achieved by modulating the flow of the heating medium in relation to the cooling demand. There is some loss in performance at part load, which shall be compensated by refinements in the system design and control.

4.2.2 *Direct Firing*

Direct fired lithium bromide/water absorption systems have become common, by incorporating precise control of generator temperature necessary to avoid crystallization.

Ammonia/water systems are generally direct fired, but are rarely used for water chilling duties, except for small sized units, which are installed outside the building.

There are two reasons for this; firstly, capital costs are higher and secondly the danger to personnel in the event of leakage of the refrigerant.

Direct firing has the advantage that the losses in an indirect heating system are avoided, but in an air conditioning installation where a boiler system is installed to provide heating, the advantage is not of much concern.

Adsorption machines differ from absorption machines in the manner the two working media interact. Adsorption is a surface phenomenon, unlike absorption. More details about such systems are provided under **6**.

5 REFRIGERANTS

The refrigerant is a working fluid used in the refrigeration cycle of a refrigeration and air conditioning system. Due to its deteriorating impacts on climate (especially ozone depletion and global warming) overview of the requirements for the safe use of refrigerants, except for ammonia, in mechanical or vapor-compression refrigeration and air conditioning systems that are partly or completely installed inside buildings shall be provided. It is intended for the guidance of the engineers, contractors, installers, and service technicians on the safe use of these systems and summarizes the guidelines applicable for the safe design, construction, installation, and operation of systems thereby providing insight of environmental impact of refrigerant emission and its management to minimize the emission of environmentally damaging refrigerants.

The refrigerant is a working fluid that is used in the refrigerating cycle of a refrigeration and air conditioning system {*see* accepted standards [D-3(2)], [D-3(5)], [D-3(7)], [D-3(8)], [D-3(9)], [D-3(10)] and [D-3(11)]}. Refrigerant molecules shall be broadly classified into three categories: halocarbons, organic compounds, and inorganic compounds. The halocarbons shall be further subdivided into chlorofluorocarbon (CFC), hydrochlorofluorocarbon (HCFC), hydrofluorocarbon (HFC), hydrofluoroolefin (HFO) and hydrochlorofluoroolefin (HCFO). The organic compounds consist mostly of hydrocarbons (HC). Inorganic compounds include carbon dioxide and ammonia. Both zeotropic and azeotropic mixtures of two or more pure refrigerants are also used as refrigerants.

5.1 Numbering of Refrigerants

Refrigerants are numbered with an R-, followed by the identification number. The identifying numbers for hydrocarbons (for example, assigned identification of propane is R-290) and halocarbons (for example, assigned identification of difluoromethane is R-32) are explicitly related to their chemical formula. Isomers are identified by appending lowercase letters at the end of the identifying number (for example 1,1,2,2-Tetrafluoroethane and 1,1,1,2-Tetrafluoroethane are isomers, which have assigned identification of R-134 and R-134a, respectively). Alkenes are identified by adding “1” at the beginning of the number determined by the above method. The structural isomers are identified by appending lower case letters at the end. The suffixes "(Z)" and "(E)" are used to differentiate cis- and trans- isomers. For example, R-1234yf, R1234ze(E) and R1234ze(Z) are all isomers of tetrafluoropropene. An inorganic compound is identified by the digit 7 at the hundreds place of the identifying number followed by its molecular weight (for example, assigned identification of Ammonia is R-717). Refrigerant blends having the same pure components are assigned the same number, but different compositions are identified with an uppercase letter after the number. Series 400 (for example, R-410A is a blend of 50 percent by weight of R-32 and 50 percent by weight of R-125) and 500 refrigerant (for example, R-507A is a blend of 50 percent by weight of R-143a and 50 percent by weight of R-125) blends are zeotropic and azeotropic, respectively.

5.2 Safety Group Classification

The Table 10 provides the toxicity and flammability-based classifications for refrigerant safety.

Table 10 Refrigerant Classification Based on Toxicity and Flammability

(*Clause* 5.2)

Sl No. (1)	**Flammability** (2)	**Lower Toxicity Safety Group** (3)	**Higher Toxicity Safety Group** (4)
i)	Higher Flammability	A3	B3
ii)	Flammable	A2L	B2L
iii)	Lower Flammability	A2L	B2L
iv)	No Flame Propagation	A1	B1

The accepted standard [D-3(2)] has also established the maximum refrigerant concentration limit (RCL) in the air to avoid escape-impairing effects such as asphyxiation, acute toxicity, and flammability in normally occupied enclosed spaces. The RCL is established based on the most conservative limit between asphyxiation, acute toxicity, and flammability. This safety group classification is referred to in the installation and maintenance standards for HVAC equipment {*see* accepted standard [D-3(8)], [D-3(9)], [D-3(10)] and [D-3(11)]}.

Product safety standards for AC equipment, such as accepted standard [D-3(5)] and [D-3(7)] specify safety requirements for electrically operated refrigeration and air conditioning appliances that have an incorporated compressor. Accepted standard [D-3(5)] deals with the safety of electrical heat pumps, air-conditioners, and dehumidifiers, while accepted standard [D-3(7)] deals with the safety of commercial refrigerating appliances.

Refrigerants should preferably be non-flammable or have lower flammability. The flammable refrigerant system shall be built with necessary protection system. Similarly, refrigerants with lower toxicity are preferable. Suitable risk mitigation processes and instruments should be implemented to mitigate risk to the occupants and the property per the accepted standards. Accepted standards [D-3(8)], [D-3(9)], [D-3(10)] and [D-3(11)], set forth requirements for safeguarding people and property where refrigeration facilities are located and prescribes safety requirements.

5.3 Environmental Impact of Refrigerants

Refrigerants shall be released from the system during installation, minimizing refrigerant leaks, proper refrigerant recovery, and recycling during installation, operation, and disposal. Commercially used refrigerants shall be either ozone-depleting substances or greenhouse gases or shall be both. Releasing such refrigerants into the atmosphere shall be damaging to the environment. CFCs and HCFCs are ozone-depleting substances.

NOTE — India ratified the Montreal Protocol Agreement on Substances that Deplete the Ozone Layer in 1992 and CFCs in RAC units manufactured beyond 1 January 2003 have been phased out. The HCFCs are being phased out under the HCFC Phase-Out Management Plan (HPMP), and their use in RAC units manufactured beyond 1 January 2025 will be prohibited. The Kigali Amendment to the Montreal Protocol calls for the phase-down of HFCs due to their high GWP. India will complete its phase-down of HFCs in 4 steps from 2032 onwards with a cumulative reduction of 85 percent in 2047. The HFC phase-down schedule for India is scheduled to begin in 2032 and it will be completed in 2047. The baseline will be the average production and consumption of HFCs for the years 2024, 2025 and 2026. The quota will be frozen at the baseline level in 2028. The phase down will be achieved in four steps, with the cumulative reductions of production and consumption by 10 percent in 2032, 20 percent in 2037, 30 percent in 2042 and 85 percent reduction in 2047.

5.4 Classification of Commonly Used Refrigerants

The refrigerants shall be classified in accordance with accepted standard [D-3(2)] as listed in Table 11. This list is not exhaustive. The users must refer to tables from accepted standard [D-3(2)] for a complete list of refrigerants and accepted standards [D-3(8)], [D-3(9)], [D-3(10)] and [D-3(11)] for RCL values.

Table 11 Classification of Commonly Used Refrigerants

(*Clause* 5.4)

Sl No.	Refrigerant	Type	Refrigerant Safety Group Classification	Amount of Refrigerant in Occupied Space	
				RCL (g/m^3)	LFL (g/m^3)
(1)	(2)	(3)	(4)	(5)	(6)
i)	R11	CFC	A1	6.1	–
ii)	R12	CFC	A1	90	–
iii)	R22	HCFC	A1	210	–
iv)	R32	HFC	A2L	77	306
v)	R123	HCFC	B1	57	–
vi)	R134a	HFC	A1	210	–
vii)	R290	HC	A3	9.5	38
viii)	R404A	HFC	A1	500	–
ix)	R407C	HFC	A1	290	–
x)	R410A	HFC	A1	420	–
xi)	R448A	HFO	A1	390	–
xii)	R449A	HFO	A1	370	–
xiii)	R454A	HFO	A2L	52	293.9
xiv)	R454B	HFO	A2L	49	352.6
xv)	R454C	HFO	A2L	71	289.5
xvi)	R455A	HFO	A2L	79	432.1
xvii)	R513A	HFO	A1	320	–
xviii)	R514A	HFO	B1	14	–
xix)	R600a	HC	A3	9.5	38

Table 11 (*Continued*)

Sl No.	Refrigerant	Type	Refrigerant Safety Group Classification	Amount of Refrigerant in Occupied Space	
				RCL (g/m^3)	LFL (g/m^3)
(1)	(2)	(3)	(4)	(5)	(6)
xx)	R744	CO_2	A1	72	–
xxi)	R1234yf	HFO	A2L	75	289
xxii)	R1234ze(E)	HFO	A2L	76	303
xxiii)	R1233zd(E)	HFO	A1	85	–
xxiv)	R1336mzz(Z)	HFO	A1	84	–

NOTE — The RCL/LFL data is taken from accepted standard [D-3(8)], [D-3(9)], [D-3(10)] and [D-3(11)].

5.5 Occupancy Based Classification

Refrigerating systems shall have different locations based on how the space connected to them is occupied, which shall depend on how people in that space react to possible refrigerant exposure.

5.5.1 *Institutional Occupancy*

Portion of a building which occupants shall not readily leave without assistance. For example, prisons, hospitals etc.

5.5.2 *Public Places/Public Assembly Occupancy*

Where large number of people gather, and the occupants shall not quickly leave the space due to large gathering. For example, restaurants, movie theatres, auditoriums etc.

5.5.3 *Residential Occupancy*

Where people/occupants live either permanently or temporarily. For example, home/apartment/hotel/hostel etc.

5.5.4 *Commercial Occupancy*

Where people/occupants gather to do commercial transactions like small shops/offices etc.

5.5.5 *Large Mercantile Occupancy*

Where occupants/people gather in large quantities like 70+ people gather to a big grocery store like Big Bazaar.

5.5.6 *Industrial Occupancy*

Occupancy where general public is not allowed. Only controlled people are allowed which shall be used for manufacturing or as a warehouse

5.6 Classification as per Leakage Probability

These guidelines classify systems based on their likelihood of leakage, ensuring appropriate safety measures and maintenance practices are in place for each classification.

5.6.1 *Low Probability Systems* (*Indirect Systems*)

Any system where the design or placement of parts makes it unlikely that refrigerant will leak from a broken connection, seal, or component into the occupied space. Examples of low-probability systems include water-cooled chillers in machinery rooms.

5.6.2 *High Probability Systems* (*Direct Systems*)

Those systems where the components are designed or located in a way that makes it likely for refrigerant to leak into an occupied space from a broken connection, seal, or component. Examples of high-probability systems include direct expansion (DX) split systems, packaged DX rooftop units, and variable refrigerant flow (VRF) systems.

5.7 Classification as per System Locations

These guidelines categorize mechanical equipment by location to ensure safety and accessibility, from units within occupied spaces to those in dedicated machinery rooms or ventilated enclosures.

5.7.1 *Class* I – *Mechanical Equipment Located within the Occupied Space*

If the refrigerating system or any of its refrigerant-containing parts is located indoors in occupied space or non-occupied space that is not sealed from the occupied space or shall leak into the occupied space, then the system is considered to be of Class I unless the system complies with the requirements for other classes. Integral display units are typical examples of this category.

5.7.2 *Class* II – *Compressors and Pressure Vessels Outside the Occupied Space*

If all compressors and pressure vessels are outside the occupied space and refrigerant leaks from compressors or pressure vessels shall not flow into the occupied space then the requirements for a class II location shall apply to any refrigerant containing part located in the occupied space or that shall leak into the occupied space. Coil-type heat exchangers and pipework, including valves, may be located in an occupied space.

Refrigerant shall leak into the occupied space through heat transfer fluid if, for example:

a) the heat transfer fluid is ventilation air;

b) the heat transfer fluid is an open spray system;

c) leakage of the refrigerant into the occupied space is caused by leakage of the refrigerant into the heat transfer fluid; or

d) there is a heat transfer fluid relief valve or an automatic purge point vents into the space.

5.7.3 *Class* III – *Machinery Room or Open Air*

The requirements for a Class III location shall apply to any refrigerant containing part located in the open air or in a machinery room that is as per the requirements of accepted standard [D-3(10)]. Water or air-cooled chillers are typical examples of this type.

5.7.4 *Class* IV – *Ventilated Enclosures*

If, with the intent of preventing migration of leaked refrigerant to the surrounding area, refrigerant-containing parts are located in a ventilated enclosure that is as per the requirements of accepted standard **5.2.17** of [D-3(9)] and **4.6** of [D-3(10)] then the requirements for a Class IV location shall apply.

Heat pumps within a ventilated enclosure are typical examples.

5.8 Classification as per Access to Occupied Spaces, Machinery Rooms and Open Air

Access classification shall be determined according to Table 12.

The access category is defined according to Table 12 by consideration of the group of occupants who are least familiar with the safety precautions. For example, in a supermarket, department store or transport terminus an unregulated number of customers who are not familiar with the location or its safety precautions shall gather. In a general office the number of people in the building is more easily regulated and occasional visitors will be accompanied by a regular occupant who shall advise on the safety precautions in the event of an emergency. In a manufacturing facility all of the occupants will be familiar with the safety requirements and access to the workplace will be restricted.

A complex building shall contain several access categories, for example the public areas and the plant rooms in a hospital shall be classified as access Category A and access Category C respectively.

Table 12 Categories of Access

(*Clause* 5.8)

Sl No.	Categories	General Characteristics	Examples
(1)	(2)	(3)	(4)
i)	A	General access (least restrictive access to the space) Parts of buildings where a) Sleeping facilities are provided, b) People are restricted in their movement, c) An uncontrolled number of people are present, or d) To which any person has access without being personally acquainted with the necessary safety precautions.	Hospitals, courts or prisons, theatres, supermarkets, schools, lecture halls, public transport termini, hotels, dwellings, restaurants, car parks, footpaths, gardens
ii)	B	Supervised access Parts of buildings where only a limited number of people shall be assembled, some being necessarily acquainted with the general safety precautions of the establishment.	Business or professional offices, laboratories, places for general manufacturing, where people work, delivery zones and some non-public areas in supermarkets
iii)	C	Authorized access (most restrictive access to the space) Parts of buildings where only authorized persons have access, who are acquainted with general and special safety precautions of the establishment and where manufacturing, processing, or storage of material or products take place.	Manufacturing facilities, for example, for chemicals, food, cold stores, some non-public areas in supermarkets, fenced outdoor compounds or roofs with restricted access

Open air locations including roofs, car parks and outdoor equipment compounds are considered to be parts of the building. Machinery rooms shall not be considered as occupied space except as defined in **5.1** of accepted standard [D-3(10)].

Refrigerant quantity limits shall be as per accepted standard [D-3(8)] expect for:

a) *Institutional Occupancy* — Consider a safety factor of 0.5 (limiting the charge to 50 percent of the calculated charge) while calculating the charge limits;

b) *Residential Occupancy* — Listed self-contained systems limited to 3 kg charge limit;

c) *Commercial Occupancy* — Listed self-contained systems limited to 10 kg charge limit; and

d) Industrial occupancy and large mercantile occupancy spaces to follow requirements of charge limits in accepted standards [D-3(8)], [D-3(9)], [D-3(10)] and [D-3(11)].

5.9 Mixing of Refrigerants

Refrigerants with different refrigerant designations as per accepted standard [D-3(2)] shall not be mixed.

5.10 Purity

Refrigerants used in refrigeration systems shall be new, recovered or reclaimed refrigerants as per below.

5.10.1 *New Refrigerants*

Refrigerants shall be of purity level specified by the equipment or appliance manufacturer as per accepted standard [D-3(12)].

5.10.2 *Recovered Refrigerants*

Shall not be used in the refrigeration system as it may not meet the quality requirements of a system.

5.10.3 *Recycled Refrigerants*

Refrigerants that are recovered from refrigeration and air-conditioning systems shall not be used in other than the system from which they were recovered and in other systems of the same owner.

5.10.4 *Reclaimed Refrigerants*

Used refrigerants shall not be reused in a different owner's equipment or appliances unless tested and found to meet the purity requirements. Contaminated refrigerants shall not be reused unless reclaimed and found to meet the purity requirements. For additional information on purity requirements of refrigerants refer to accepted standard [D-3(12)].

5.10.5 High probability direct systems for human comfort applications shall only use A1 and A2L refrigerants. If the equipment is listed, it shall follow the requirements of accepted standard [D-3(5)] and [D-3(7)]. If the system is designed and installed at site, the requirements of accepted standards [D-3(8)], [D-3(9)], [D-3(10)] and [D-3(11)] will follow.

5.11 Machinery room/plant room systems shall follow accepted standards [D-3(8)], [D-3(9)], [D-3(10)] and [D-3(11)] requirements.

5.12 Lifecycle Management of Refrigerants

Lifecycle management of refrigerants shall encompass all phases from design, manufacturing, installation, operation, servicing, to decommissioning and end-of-life. In the design stage, appropriate selection of corrosion-resistant materials, robust packaging for transport and handling, protective coatings on brazed joints, and dimensioning of interconnecting tubes to prevent fractures shall be ensured. Manufacturing processes such as brazing shall be carried out under controlled conditions to minimize leakage risks. During installation and commissioning, only trained and certified technicians shall be permitted, using calibrated tools (for example, torque wrenches) and considering environmental conditions at site. In line with the *Kigali Amendment*, the phasedown of HCFCs and high-GWP HFCs shall be undertaken in accordance with national schedules, with preference given to adoption of lower-GWP alternatives such as olefins (HFOs).

At the operational and end-of-life stages, systems shall incorporate leak detection, regular monitoring, and timely repair. Recovery, recycling, reclamation, or safe destruction of refrigerants shall be carried out in accordance with the *E-Waste* (*Management*) *Rules*, the *Hazardous Waste Management Rules*, and relevant CPCB guidelines. Venting of refrigerants during maintenance, servicing, or decommissioning shall be strictly prohibited. All systems using flammable refrigerants shall be evacuated with vacuum pumps and purged with nitrogen as per manufacturer's specifications. Producers and manufacturers shall bear extended producer responsibility (EPR) for the collection and environmentally sound management of appliances containing refrigerants at end-of-life. Certified recovery and destruction facilities shall be used, with proper record-keeping and reporting to CPCB/state pollution control boards. Awareness among consumers, technicians, and service providers shall be promoted to ensure safe handling and environmentally responsible lifecycle management of refrigerants.

5.12.1 *Refrigerant Recovery*

When decommissioning an appliance that contains refrigerant, it should be properly recovered using certified equipment before servicing or disposing of the appliance.

5.12.2 *Certified Technicians*

Only individuals who are certified under Ozone Cell Regulations are allowed to handle and remove refrigerant from appliances.

5.12.3 *Responsible Disposal*

The final person or entity responsible for the disposal of the appliance (for example, scrap metal recyclers, landfills) should ensure that the refrigerant has been recovered beforehand.

5.12.4 *Documentation*

If the final disposer accepts an appliance that has had its refrigerant charge removed, they should maintain a signed statement from the person who removed the refrigerant. This statement should include details like the name and address of the person who performed the recovery and the date of recovery.

5.12.5 *Recovered Refrigerant Usage*

Recovered refrigerants should generally be reused only in the system from which they were recovered or in other systems owned by the same entity in line with **5.10.2** and **5.10.3**.

5.12.6 *Reclaiming Contaminated Refrigerant*

Contaminated refrigerants cannot be reused unless they are reclaimed to meet the purity requirements as per the accepted standard [D-3(12)] and in line with **5.10.4**.

5.12.7 *Filtering and Drying*

Recovered refrigerants should be filtered and dried before reuse.

Venting of refrigerants to the atmosphere should be avoided. During commissioning, any purging, if necessary, should be done outside or in a well-ventilated area to avoid formation of flammable or toxic atmosphere.

5.13 Total Equivalent Warming Impact (TEWI)/Life Cycle Climate Performance (LCCP)

There are 2 metrics used to calculate the greenhouse impact of a product/equipment over its lifetime. This is given in terms of its equivalent CO_2 emissions; in kg or Tonnes depending upon its absolute value.

The second metrics an extension of the first one in that it includes even the warming impact due to the manufacturing of the product as well as the indirect emission due to the atmospheric decomposition of the refrigerant including the energy consumed during the manufacture of the raw materials. For example, consider a Window unit. The coils are made of copper tubes and aluminium fins. Thus, if the copper tube manufacturing process and/or aluminium fin stock manufacturing process is highly energy inefficient then it will reflect badly in the LCCP of the Window unit. LCCP is more comprehensive as it has a “cradle to grave” approach and it has its merit in evaluating the overall impact.

The following equation gives the expression for calculating TEWI for a particular product (it shall not be generalized; it is application/product specific):

$$\text{TEWI} = \text{GWP} \times L \times n + \text{GWP} \times m \times (1-\alpha) + n \times E \times \beta$$

where

GWP = Refrigerant global warming potential (kg of CO_2/kg of refrigerant);
L = Annual leakage rate (kg/year);
n = System operating life time (years);
m = Refrigerant charge (kg);
α = Recycling factor (percent);
E = Annual energy consumption (kWh/year); and
β = CO_2 emissions on energy generation [kg CO_2/kWh].

The above equation is considering both the direct (due to refrigerant leakage/non recycling) and the indirect effect (due to energy consumption). TEWI is completely product/system/location dependent and shall not be generalized. However, it does give an idea as to how the indirect impact is much more than the direct impact. With the new low-GWP refrigerants being introduced, the value(s) of TEWI would be different than what they were with the old high-GWP refrigerants. Also, an important parameter is the β factor. This is based on the location/country where the system is operating. It is directly dependent on the fuel source/type of power generation plants being used to supply the electrical power. Naturally if the major source of power generation is fossil fuel. Coal-based thermal power generation then this factor will be high, and which turn will result in higher TEWI.

The following equation gives the expression for calculating LCCP for a particular product:

$$LCCP = Direct\ Emissions + Indirect\ Emissions$$

$$Direct\ Emissions = C \times (L \times ALR + EOL) \times (GWP + Adp.GWP)$$

$$Indirect\ Emissions = L \times AEC \times EM + \sum(M \times mm) + \sum(mr \times RM) \times +C(1 + L \times ALR) \times RFM + C \times (1 - EOL) \times RFD$$

where

C = Refrigerant charge (kg);
L = Average lifetime of equipment (year);
ALR = Annual leakage rate (percent of refrigerant charge);
EOL = End of life refrigerant leakage (percent of refrigerant charge);
GWP = Global warming potential (kg CO_{2e}/kg);
Adp. GWP = GWP of atmospheric degradation product of the refrigerant (kg CO_{2e}/kg);
AEC = Annual energy consumption (kWh);
EM = CO_2 Produced /kWh (kg CO_{2e}/kg);
M = Mass of unit (kg);
MM = CO_2 Produced/material (kg CO_{2e}/kg)
mr = Mass of recycled material (kg);
RM = CO_{2e} Produced/recycled material (kg CO_{2e}/kg);
RFM = Refrigerant manufacturing emissions (kg CO_{2e}/kg); and
RFD = Refrigerant disposal emissions (kg CO_{2e}/kg).

The above equation is as per the Guideline for LCCP recommended by International Institute for Refrigeration.

When it comes to selecting refrigerants and equipment, both choices are crucial due to their direct impact on a user's scope 1 and scope 2 emissions. Scope 1 emissions encompass direct greenhouse gas (GHG) emissions, which, in the case of refrigerants, primarily result from gas leakage at the premises. To mitigate these emissions, it is vital to adopt low global warming potential (GWP) refrigerants that minimize the environmental impact.

However, as we push for the rapid adoption of these low-GWP refrigerants, it is equally important to ensure that the efficiency and capacity of the equipment are not compromised. This balance is required because any reduction in equipment performance shall increase scope 2 emissions, which are indirect GHG emissions from the energy consumed by the equipment.

Leveraging digitally enabled and AI-driven solutions shall significantly enhance our approach to managing refrigerants. These advanced technologies provide predictive insights that help prevent gas leakages, reducing the need for technician visits and minimizing downtime for repairs. By integrating generative AI, we shall proactively address potential issues, further reducing scope 1 emissions by preventing leaks before they occur. Moreover, reducing technician visits not only lessens service providers' tailpipe emissions lowering the end user's scope 3 emissions, which are indirect emissions from third-party activities.

When selecting equipment and refrigerants, it’s crucial to consider the Total Equivalent Warming Impact (TEWI), which factors in both scope 1 and scope 2 emissions. This comprehensive approach ensures that the chosen solutions are sustainable over their entire lifecycle. Additionally, implementing digitization, advanced leak detection systems, and remote monitoring of refrigerants shall effectively map and manage the operational emissions associated with the equipment’s deployment at a user's premise. These technologies ensure that emissions are minimized, aligning with broader sustainability goals and regulatory requirements.

In summary, achieving a balanced and strategic selection of refrigerants and equipment, underpinned by AI and digital solutions, for reducing scope 1, scope 2, and scope 3 emissions. This integrated approach supports the fast-tracking of low-GWP refrigerants while maintaining operational efficiency and capacity, ultimately contributing to a more sustainable and compliant future in building operations.

6 LOW ENERGY COOLING

In addition to the popular air-conditioning options and traditional passive cooling options, various types of modern low energy heating/cooling solutions have also emerged which may be used to provide thermal comfort to occupants using alternative strategies. These include direct, indirect and hybrid evaporative cooling, radiant cooling/heating, structural cooling, solar assisted cooling/heating, and few others.

6.1 Evaporative Air Coolers

Evaporative coolers use the process of evaporation of water to lower air temperature. This method of comfort cooling not only conserves energy but also offers numerous benefits for environment. The principle for evaporative air cooling is straightforward: when water evaporates, it absorbs latent heat of evaporation from the surrounding air, thereby cooling the air. This is also termed as adiabatic cooling. This process is most effective in arid and semi-arid climates where the humidity is low, making evaporation more efficient.

An evaporative cooler typically consists of a fan, absorbent pads, a water reservoir and some kind of water distribution system including pump to distribute water on the pads, and often some set of louvers/deflectors to guide air to desired direction.

The process is:

a) the fan draws warm, dry air from the outside into the cooler;

b) the air passes through the water-saturated pads, where the water evaporates, and thereby absorbing heat from the air; and

c) the cooler but more humid air is then blown into the living space, lowering the temperature.

6.1.1 *Advantages of Evaporative Cooling*

These points highlight the key benefits and positive aspects of the specified system or approach, emphasizing efficiency, performance, and practicality.

a) *Energy efficiency* — Evaporative coolers consume significantly less energy compared to conventional air conditioners. They use only the power needed to run the fan and water pump, resulting in lower electricity bills and reduced carbon footprint;

b) *Environmental benefits* — Traditional air conditioners use refrigerants like CFCs and HFCs, which are harmful to the environment. Evaporative coolers, on the other hand, do not use these chemicals, making them an eco-friendly alternative;

c) *Cost-effective* — The initial purchase cost and maintenance expenses of evaporative coolers are significantly lower than those of air conditioning systems for a given cooling area. Evaporative air coolers have fewer mechanical parts, which means there are fewer components that shall break down;

d) *Improved air quality* — Evaporative coolers add moisture to the air, which shall be beneficial in dry climates where low humidity shall cause respiratory problems and dry skin. They also filter out dust and pollen as the air passes through the pads, improving indoor air quality;

   At times, several processes need humidity (for example, paper mill, garment industry, etc) and hence evaporative air cooling serves dual purpose of cooling and providing humidity; and

e) *Easy installation and maintenance* — These coolers are relatively simple to install, requiring only a water source and an electrical outlet. Maintenance is straightforward, typically involving the periodic cleaning or replacement of pads and ensuring the water reservoir is filled.

6.1.2 *Applications of Evaporative Cooling*

These points describe the various uses and suitable scenarios for implementing evaporative cooling, focusing on its effectiveness in specific environments and conditions. Following are some of different uses:

a) *Residential use* — They are ideal for cooling homes in dry climates. Portable models shall be moved from room to room, providing flexible cooling solutions. Even table top models are available for personal cooling purposes. Window or wall mounted units are available too;

b) *Commercial and industrial use* — Large evaporative coolers shall be used in showrooms, restaurants, institutes, warehouses, factories, and workshops where traditional air conditioning may be impractical or too expensive especially in semi-open spaces;

c) *Outdoor cooling* — Evaporative coolers are popular for outdoor events, patios, and agricultural applications. They shall create comfortable environments in open spaces where conventional cooling systems are ineffective; and

d) *Greenhouses* — These coolers are beneficial in horticulture for maintaining optimal temperature and humidity levels, promoting healthy plant growth. Other related uses are poultry farms, pig farms, etc.

6.1.3 *Sizing of Evaporative Cooling*

Air coolers are used either for spot cooling or space cooling:

a) *For spot cooling* — An important parameter to consider is the air throw the distance to which the air cooler will throw air with adequate velocity and air quantity;

b) *For space cooling* — Important parameter is air changeover. Generally, 20 to 40 air changeovers per hour (ACH) are required depending upon application and heat load; and

c) *The residential air coolers* — It shall be as per accepted standard [D-3(13)]. The large commercial air evaporative air-cooling system shall be as per the special publication.

   NOTES

   1 Further, ISHRAE simulation tool called EvapCal shall be used for sizing guidelines based upon city, heat load, required thermal comfort to correctly size the system.

   2 Special publication may be ISHRAE Standard 2005 : 2024.

6.1.4 *Limitations of Evaporative Cooling*

These points outline the challenges and constraints associated with evaporative cooling, highlighting factors that may affect its efficiency and suitability in certain conditions.

a) *Climate dependence* — The efficiency of evaporative coolers decreases significantly in humid climates. When the air is already saturated with moisture, it shall not absorb much more, making evaporation less effective and reducing the cooling capacity of the device;

b) *Limited to cooling only* — Evaporative coolers are designed to only cool the space and shall not condition it like air conditioner. Hence shall not be used for heating or dehumidification;

c) *Increased humidity* — While added humidity shall be beneficial in dry climates, it shall be problematic in areas that are already humid. High humidity levels shall create a sticky, uncomfortable indoor environment and potentially promote mould growth if not designed properly; and

d) *Water usage* — Evaporative coolers require a continuous supply of potable quality of water to operate, which shall be a concern in regions facing water scarcity or unavailability. However, their overall water consumption is relatively low compared to other water-intensive appliances.

6.1.5 *New Trends/Technologies in Evaporative Cooling*

Smart Controls, efficient cooling media and two stage, multi stage hybrid evaporative cooling system enhances the efficiency and comfort level. These technologies should be considered based on the climate conditions and application. Two stage are:

a) *Evaporative cooling systems* — Advanced version of direct evaporative cooling system, many times referred as dual stage evaporative cooling combines use of direct and indirect evaporative cooling system to provide supply air temperature which are much lower than wet bulb temperature and with lower specific humidity making the space temperature very comfortable in dry conditions; and

b) *Hybrid systems* — Some systems combine single or multiple stage evaporative cooling with traditional air conditioning, optimizing cooling performance while minimizing energy use. These hybrid systems switch between modes based on ambient conditions, providing efficient cooling in various climates. Indirect (air cooling by passing over a cool coil or heat exchanger) cooling is also often combined with a direct evaporative cooling process such devices are often termed as indirect direct evaporative coolers (IDEC). Cool coil may in turn use chilled water, evaporatively cooled water, pre-cooled air, or any such other cooling media.

6.2 Radiant Cooling and Heating

Radiant cooling system is a temperature-controlled system in which the temperature of the building surface facing indoor (ceiling, floor, wall etc) is reduced by the means of cool/chilled water which flows through a network of pipes embedded in the surfaces.

Any system shall only be called a radiant system if more than 50 percent of heat transfer takes place by radiative heat exchange by the temperature-controlled surface. Reduced surface temperature causes radiative heat exchange between human body and cold/hot surfaces and provide sensible cooling/heating inside the building. A separate air system shall be used for the ventilation requirements and handling the latent load.

The radiant cooling system design and installation shall ensure no condensation in the conditioned space.

6.2.1 *Advantages of Radiant Cooling System*

These points highlight the key benefits of radiant cooling, focusing on energy efficiency, comfort, and improved indoor air quality:

a) *Energy efficiency* — In radiant cooling system, cooling is provided through water which has a higher heat capacity than air which loses more energy in transportation. In radiant cooling system less fan energy is required than conventional all-air system due to very significant reduction in amount of air handled;

b) *Indoor air quality* — As a radiant cooling system is a hybrid system that also includes a separate air system to provide 100 percent outdoor air, the indoor air quality is enhanced;

c) *Thermal comfort* — Uniform temperature shall be maintained with radiant cooling system ensuring better thermal comfort;

d) *Integration with low grade energy/passive cooling sources* — In radiant cooling system a higher temperature 15 ºC to 20 ºC water temperature shall be used. The low-grade energy sources like cooling tower, geo-thermal and others shall be used; and

e) *Noise and reduced duct work* — This cooling system reduces noise, as they do not rely on fan and compressor for cooling, and this system use water pipes instead of the ducts, thereby having reduced duct work.

6.2.2 *Limitations of Radiant Cooling*

Radiant cooling is useful in the building where sensible load is higher and have humidity control. There are several areas like restaurant, lobby, and kitchen, etc where humidity control is very difficult, at such places, its application shall attract a problem of condensation. Similarly, if the latent load in a zone is significant then the use of radiant cooling system is limited. The radiant cooling system also has a limitation of cooling capacity in order to counter the condensation problem. Hence, the surfaces have to be maintained at a higher temperature as compared to the dew point temperature of indoor air.

6.2.3 *Types of Radiant Cooling Systems*

Following three types of Radiant systems are used:

a) *Radiant cooling panels system* (*RCP*) — The most extensively used system of radiant systems is the PANEL Systems. The insulation over the aluminium panel plays an important role in avoiding the heat transfer to the building structure. Poor connection shall lead to less heat transfer resulting in an inefficient system;

b) *Thermally activated building system* (*TABS*) — In thermally active building system (TABS) the conditioning plant operation is varied based on thermal loads. TABS has a high thermal inertia, which enables it to hold a large amount of heat within it during the day time and release this heat during night time to the hydronic system; and

c) *Embedded surface cooling systems* (ESC) — In embedded surface cooling system, an insulation cover on the pipes mounted on the side adjacent to the building structure minimizing thermal energy exchange of heat carrier with the building structure. Some floor systems are made by extruded plastic plates which forms capillary channels. In this case the heat exchange surfaces is very wide and at the same time the thickness of the system is very less which allows very low temperature differences.

6.2.4 *Requirement of Fresh Air Delivery*

Radiant cooling systems require a dedicated an outdoor air system responsible for supply of fresh/ventilation air into the radiant cooled space operating in parallel to the radiant cooling.

In case of high latent load and in case of oversized DOAS, energy savings from a radiant cooling system is reduced.

6.2.5 *Control Requirements*

Following controls are required to efficiently operate a radiant cooling system:

a) radiant surface temperature minimum two degree centigrade higher than indoor dew point temperature to avoid condensation on radiant surfaces. In case of occurrence;

b) water supply temperature or flow rate or both need to be controlled; and

c) modulate ventilation air supply as per the CO_2 monitoring.

6.3 Structural Cooling

Due to the high solar insolation during the daytime on built structures, heat gets embedded in the structure or the thermal mass of the buildings and is transmitted indoors. This heat raises the temperature of the indoor surfaces resulting in higher mean radiant temperatures experienced by occupants making them uncomfortable.

This heat has to be flushed out before it shall enter the living space.

This approach significantly reduces the cooling loads on the air conditioning system, in case the indoors are air conditioned.

Structural cooling generally employs the use of cooled water between 15 °C to nearly 30 °C, which is circulated in embedded piping network laid within the structure.

For air-conditioned areas, the minimum water temperature is 15 °C. Depending on the requirements this water temperature shall be higher up to 24 °C. This generally requires mechanical refrigeration similar to the chilled water supply in radiant cooling system.

Water between 20 °C and 30 °C can be generated employing natural cooling processes, which make use of the ambient conditions of air.

Naturally cooled water in ponds, rivers, or from geothermal sources should be considered. Properly designed and selected cooling towers make use of the lower wet bulb temperatures to achieve this cooling of water to slightly above prevailing wet bulb temperatures.

NOTES

1 In a conducive weather condition, cooled water shall be obtained by utilising the night sky cooling and storing the cooled water in an insulated and properly sized tank during the night. The same water shall be used to cool the structure during the harsh times of the day.

2 The water is circulated by employing a small pump, in the closed loop system. Principally, these systems are quite similar to thermally activated buildings covered under radiant cooling section.

6.3.1 *Advantages of Structural Cooling*

Structural cooling impedes solar heat from roof and floors by absorbing it before it causes thermal discomfort to occupants. Following are the advantages of structural cooling:

a) floor temperatures are maintained below body skin temperature, allowing the body to radiate the heat to the cooler surfaces;

b) reduces the cooling load on the building and lower size of ancillary cooling systems are required, leading to smaller pipes and ducting;

c) because of the large thermal mass of the structure, it shall act as a storage of cooling effect; and

d) as the Structure is cooled, it is maintained in a small band of temperature variations, thus eliminating the heat stress on the structure. The thermal expansion and contraction of the structure are very low, as compared to a building which is not structurally cooled.

6.3.2 *Applications*

Structural cooling is very versatile and shall be used to cool places like public utility areas, malls, hospitals, residential areas, office buildings, commercial spaces, educational institutes and many more applications to reduce air conditioner loads and provide comfort.

6.4 Geothermal for Heating and Cooling

Geothermal heating and cooling systems, also known as ground source heat pumps (GSHPs), uses the stable temperatures of the earth's subsurface to provide efficient climate control for buildings. By using the ground as a heat source in the winter and a heat sink in the summer, these systems shall achieve high efficiencies compared to conventional HVAC systems and needs to balance the earth as source.

NOTE — Geothermal systems shall be used in residential, commercial, and industrial buildings. They are particularly beneficial for new constructions but shall also be retrofitted into existing structures. Large-scale applications include district heating systems where multiple buildings are connected to a central geothermal system.

6.4.1 *Advantage of GSHP Systems*

GSHP systems offer significant energy efficiency, environmental benefits, and long-lasting performance. Following are the advantages of GSHP systems:

a) *Energy efficiency* — GSHPs achieves high efficiencies on the coldest winter nights, meaning they produce 3 units to 6 units of heat for every unit of electricity consumed;

b) *Cost savings* — GSHP systems provide substantial cost savings by delivering multiple units of heat for each unit of electricity, reducing energy bills over time;

c) *Environmental impact* — Reduce greenhouse gas emissions and reliance on fossil fuels; and

d) *Longevity* — Ground loops life of 50 years and above, and indoor components life of 20 years and above.

6.4.2 *Challenges with GSHP*

GSHP systems face certain challenges related to installation, maintenance, and initial investment:

a) *High initial cost* — Installation are expensive due to drilling and trenching requirements depending on terrain;

b) *Site-specific design* — Soil conditions, land availability, and local climate affect feasibility and design; and

c) *Maintenance* — While minimal, the system requires periodic maintenance, especially the indoor components. Geothermal heating and cooling systems represent a sustainable and efficient technology for managing building climate control. Despite the high initial investment, their long-term benefits in terms of energy savings, environmental impact, and system longevity make them an attractive option for a wide range of applications. As technology advances and installation costs decrease, geothermal systems are likely to become an increasingly common choice for sustainable building design.

6.5 Solar Cooling

There are different ways to utilise solar energy for producing cooling effect:

a) Solar thermal cooling systems

b) Solar photovoltaic cooling systems

Solar photovoltaic cooling systems is a vapour compression-based systems powered by electricity generated by solar photo voltaic system. Solar thermal based cooling systems use heat-based cooling systems that do not need electricity driven mechanical compressor.

6.5.1 *Solar Thermal Cooling Systems*

There are two different types of solar thermal cooling systems absorption type and desiccant type. All of these are driven by the heat from solar energy as explained below.

6.5.1.1 *Absorption cooling*

Vapour absorption machines (VAMs) are used for cooling using waste steam or hot water as a byproduct of process in various industries. VAMs use a salt-based solution (typically lithium bromide solution) to alternative evaporate water out and then condense it back into the solution. Types of VAMs depending on the temperature of the heat source:

a) *Single effect* — Uses hot water source between 80 °C to 90 °C to drive the cooling cycle.

b) *Double effect* — Uses 120 °C to 140 °C steam to drive the cooling cycle.

c) *Triple effect* — Uses 180 °C to 210 °C steam to drive the cooling cycle.

For most buildings, single effect VAM and double using solar hot water is the viable configuration. Double effect VAMs offer higher COP of 1.2 to 1.4, it is recommended to use single effect VAMs it is recommended to design the VAM around this temperature even though the COP of such system is only 0.7 to 0.8. Higher operating hours in a year make such a system more viable at lower COP.

Double and triple effect VAMs shall be used in buildings where waste heat or low-cost heat >120 °C is available in immediate vicinity. This would typically be in industrial settings.

6.5.1.2 *Adsorption cooling*

Adsorption cooling systems use solid desiccant material like silica gel to enable a heat driven cooling cycle. Water is used as a refrigerant in such systems. The cycle works by alternating ‘adsorption’ and ‘desorption’ of water from a solid desiccant. Heat between 60 °C to 80 °C is required for ‘desorption’ and heat from solar collectors shall be used.

The COP of adsorption chiller is between 0.35 to 0.55 depending on the chilled water temperature required, hot water source temperature and condenser water temperature. While lower COP increases the solar field size, adsorption chiller’s ability to operate even at 60 °C source temperature allows.

6.5.1.3 *Desiccant cooling*

This typically refers to liquid desiccant cooling where solar heat is used to regenerate the desiccant. Typical regeneration temperature is 60 °C that be consistently achieved using solar collectors.

6.5.2 *Advantages of Solar Thermal Cooling Systems*

Solar thermal cooling systems offer sustainable and energy-efficient solutions by harnessing solar energy for cooling purposes, reducing reliance on conventional energy sources. Following are the advantages of solar thermal cooling systems:

a) *Energy efficiency* — Overall cooling system electricity consumption shall be 0.4 kW/Ton to 0.6 kW/Ton compared to 1 kW/Ton to 1.4 kW/Ton for conventional air conditioning systems; and

b) *Lower carbon footprint* — Lower electricity consumption leads to lower carbon footprint of the system. This shall be useful for achieving decarbonization goals of the building or organization.

6.6 Personal Environmental Control Systems

Personal environmental control systems (PECS) includes low-energy, low-powered personalised HVAC systems as well as controls and sensors. The PECS largely shall be categorised into the following five categories and further detailed in Table 13:

a) Heating only PECS;

b) Cooling only PECS;

c) Ventilation only PECS;

d) Heating and ventilation PECS;

e) Cooling and ventilation PECS; and

f) Heating, cooling and ventilation PECS.

NOTE — Heating PECS and cooling PECS rely only on conduction and radiative heat transfer without convection (air movement). While all PECS with ventilation, rely on air as a heat transfer medium, hence air movement in ventilation PECS is inherent.

Table 13 Personal Environmental Control Systems

(*Clause* 6.6)

a) Heating only PECS Devices

Warmed Seat	**Device Description**	**Warmed Seat Heated Using Electrical Elements or Embedded Water Tubes**	The warmed seat is recommended to be used in combination with a foot heater.
	T_{room}	> 5 °C	
	$T_{PECS\text{-}surface}$	< 44 °C	
	V_{PECS}	N/A	
	Target body parts	Back, buttocks, thighs	
	PECS position	As the occupant's seat	
	Restriction of movement	Occupant shall remain in contact with the seat fabric	
	Manual control	Temperature	
	Background ventilation	Required	
Radiant Foot Heater		**Radiant Foot Heater heated using electrical elements**	The radiant foot heater should be operated in the range of T_{room}+10 °C to T_{room}+20 °C for optimum comfort.
	T_{room}	> 10 °C	
	$T_{PECS\text{-}surface}$	< 30 °C	
	V_{PECS}	N/A	
	Target body parts	Feet	
	PECS position	~20 cm from the feet	
	Restriction of movement	Feet shall remain adjacent to the heated surface	
	Manual control	Temperature	
	Background ventilation	Required	
Radiant Heating Panel		**Radiant Heating Panels placed as desktop partitions heated using electrical elements or embedded water tubes**	The exposed surface area of the radiant heating panel to the occupant should be optimized by placing more panels to the left and right sides of the occupant.
	T_{room}	> 19 °C	
	$T_{PECS\text{-}surface}$	< 23 °C	
	V_{PECS}	N/A	
	Target body parts	Face, chest, arms, legs	
	PECS position	~50 cm from the occupant, as the desk partition	

Table 13 (*Continued*)

	Restriction of movement	Occupant should remain in the field of view of the Radiant Panel	
	Manual control	Temperature	
	Background ventilation	Required	
Palm Warmer		**Desktop-based Palm Warmers heated using electrical elements**	The device shall be placed such that it acts as a resting spot for the hands while typing.
	T_{room}	> 18 °C	
	$T_{PECS\text{-}surface}$	< 35 °C	
	V_{PECS}	N/A	
	Target body parts	Palms	
	PECS position	On the desktop, between the computer keyboard and the occupant.	
	Restriction of movement	Palms shall be in direct contact with the device surface	
	Manual control	None	
	Background ventilation	Required	
b) Cooling only PECS Devices			
Cooled Seat	**Device Description**	**Seat cooling using embedded water pipes cooled using compressive cooling**	It is recommended to use a movable desktop fan in combination with the cooled seat.
	T_{room}	< 45 °C	
	$T_{PECS\text{-}air}$	> 18 °C	
	V_{PECS}	N/A	
	Target body parts	Back, buttocks, thighs	
	PECS position	As the occupant's seat	
	Restriction of movement	Occupant shall remain in contact with the seat fabric	
	Manual control	Temperature	
	Background ventilation	Required	
Cooled Garment		**Jacket-like garment using phase change materials or compressive cool air supply**	Typical cooled garments are battery-operated, with an average charge lasting for ~ 6 hours; they weigh around 3 kg to 5 kg; cooled garments with phase change materials typically perform better than those with embedded fans.
	T_{room}	< 34 °C	
	$T_{PECS\text{-}air}$	> 21 °C	
	V_{PECS}	N/A	
	Target body parts	Chest, back, shoulders	
	PECS position	As the occupant's vest	
	Restriction of movement	None	
	Manual control	Temperature	
	Background ventilation	Required	

Table 13 (*Continued*)

Radiant Cooling Panel		**Radiant Cooling Panels placed as desktop partitions cooled using embedded water pipes using compressive cooling**	The exposed surface area of the radiant cooling panel to the occupant should be optimized by placing more panels to the left and right sides of the occupant.
	T_{room}	< 32 °C	
	$T_{PECS\text{-}air}$	> 17 °C	
	V_{PECS}	N/A	
	Target body parts	Face, chest, arms, legs	
	PECS position	~ 50 cm from the occupant, as the desk partition	
	Restriction of movement	Occupant should remain in the field of view of the radiant panel	
	Manual control	Temperature	
	Background ventilation	Required	
c) Ventilation only PECS Devices			
Desktop-based Devices	**Device Description**	**Desk-mounted air-terminal device supplying (fresh or recirculated) air at room temperature**	The airflow shall not strike the desktop and the airflow pattern should preferably be kept as close to the natural wind pattern in terms of its turbulence and frequency of variability.
	T_{room}	< 30 °C	
	$T_{PECS\text{-}air}$	Same as T_{room}	
	V_{PECS}	< 1.5 m/s	
	Target body parts	Face, neck, chest, arms	
	PECS position	~50 cm from the occupant, on the desktop	
	Restriction of movement	Occupant shall move while manually changing the airflow direction of the fan/device	
	Manual control	Air velocity, direction	
	Background ventilation	Optional	
Movable Panel		**Desktop based movable air-terminal device supplying (fresh or recirculated) air at room temperature**	The air stream should enter the occupant's breathing zone parallel to the cheek, avoiding direct contact with the eyes.
	T_{room}	< 28 °C	
	$T_{PECS\text{-}air}$	Same as T_{room}	
	V_{PECS}	< 0.7 m/s	
	Target body parts	Face, neck, chest, arms	
	PECS position	~50 cm from the occupant, on the desktop	
	Restriction of movement	Occupant is free to move within the flow region while adjusting the direction of the panel	
	Manual control	Air velocity, direction	
	Background ventilation	Optional	
Headrest-embedded Device		**Seat headrest-based air-terminal device supplying recirculated air at room temperature**	Air terminal devices with a large opening area require low air

Table 13 (*Continued*)

	T_{room}	< 26 °C	velocity and vice versa.
	$T_{PECS\text{-}air}$	Same as T_{room}	
	V_{PECS}	< 0.6 m/s	
	Target body parts	Face	
	PECS position	As the seat headrest, next to the cheeks	
	Restriction of movement	Occupant shall keep the head on the headrest.	
	Manual control	Air velocity	
	Background ventilation	Required	
Pedestal Fan		**Pedestal fan supplying recirculated air at room temperature**	The fan direction should be kept such that it does not cause discomfort by displacement of light-weight objects on the desktop.
	T_{room}	< 30 °C	
	$T_{PECS\text{-}air}$	Same as T_{room}	
	V_{PECS}	< 2.5 m/s	
	Target body parts	Whole body	
	PECS position	~ 1.5 m from the occupant	
	Restriction of movement	Occupant is free to move within the flow region while adjusting the direction of the fan	
	Manual control	Air velocity, direction	
	Background ventilation	Optional	
Ceiling Fan		**Ceiling-mounted fan supplying recirculated air at room temperature**	To optimize the effect of the fan, it should be placed on the ceiling right above the desktop, with the rotating blades at an angle of 30° to 45° from the ceiling.
	T_{room}	< 30 °C	
	$T_{PECS\text{-}air}$	Same as T_{room}	
	V_{PECS}	< 1 m/s	
	Target body parts	Head, shoulders	
	PECS position	~ 1.5 m above the occupant, on the ceiling	
	Restriction of movement	Occupant shall remain in the flow direction	
	Manual control	Air velocity	
	Background ventilation	Optional	
Ventilated Seat		**Ventilated seat embedded with fans supplying recirculated air at room temperature**	The occupant's body should not block the complete airflow and it should reach the breathing zone.
	T_{room}	< 32 °C	
	$T_{PECS\text{-}air}$	Same as T_{room}	
	V_{PECS}	< 2 m/s	
	Target body parts	Buttocks, back, thighs	
	PECS position	As the occupant's seat	
	Restriction of movement	Occupant shall remain in contact with the seat fabric	
	Manual control	Air velocity	

Table 13 (*Continued*)			
	Background ventilation	Required	
Ventilated Garment		**Jacket-like garment embedded with low-wattage fans supplying recirculated air at room temperature**	A typical battery-operated ventilated garment operates up to 7 hours on 60 percent output power.
	T_{room}	< 34 °C	
	$T_{PECS\text{-}air}$	Same as T_{room}	
	V_{PECS}	Equivalent to a flow rate of < 22 L/s	
	Target body parts	Chest, Back	
	PECS position	As the occupant's vest	
	Restriction of movement	No restriction in movement	
	Manual control	Air velocity	
	Background ventilation	Required	
d) Heating and Ventilation PECS Devices			
Desk-mounted Device	**Desk-mounted air-terminal device supplying air warmed through compressive heating**		The device should be used in combination with a Foot-heating Panel; the airflow should not directly strike the eyes of the occupant as it might lead to dry-eye discomfort.
	T_{room}	> 19 °C	
	$T_{PECS\text{-}air}$	< 25 °C	
	V_{PECS}	< 1 m/s	
	Target body parts	Face, arms, chest, front thighs	
	PECS position	~ 50 cm from the occupant, on the desktop	
	Restriction of movement	Occupant shall remain in the flow direction	
	Manual control	Temperature, air velocity, direction	
	Background ventilation	Optional	
Ventilated and Warmed Seat	**Warmed seat with embedded fans – the seat is warmed using electrical elements or embedded water pipes**		The device should be used in combination with a foot-heating panel
	T_{room}	> 20 °C	
	$T_{PECS\text{-}air}$	< 45 °C	
	V_{PECS}	< 0.7 m/s	
	Target body parts	Neck, back, buttocks, back thighs	
	PECS position	As the occupant's seat	
	Restriction of movement	Occupant shall remain in contact with the seat	
	Manual control	Temperature, air velocity	
	Background ventilation	Required	
Nozzle	**Nozzle-based air terminal device supplying air warmed through compressive heating**		The air stream should enter the occupant’s breathing zone parallel to the cheek, avoiding direct contact with the eyes.
	T_{room}	> 19 °C	
	$T_{PECS\text{-}air}$	< 50 °C	
	V_{PECS}	< 1 m/s	

Table 13 (*Continued*)

	Target body parts	Head, neck	
	PECS position	~ 1 m from the occupant, directed towards the head	
	Restriction of movement	Occupant shall remain in the flow direction	
	Manual control	Temperature, air velocity	
	Background ventilation	Optional	
Movable Panel	**Desk-mounted movable air terminal device supplying air warmed through compressive heating**		The air stream should enter the occupant's breathing zone parallel to the cheek, avoiding direct contact with the eyes.
	T_{room}	> 20 °C	
	$T_{PECS\text{-}air}$	< 26 °C	
	V_{PECS}	< 1 m/s	
	Target body parts	Head, neck, chest, arms	
	PECS position	~ 50 cm from the occupant, directed towards the head	
	Restriction of movement	Occupant is free to move within the flow region while adjusting the direction of the panel	
	Manual control	Temperature, air velocity, direction	
	Background ventilation	Optional	
e) Cooling and Ventilation PECS Devices			
Desk-mounted Device	**Desk-mounted air-terminal device supplying air cooled through compressive cooling**		The air stream should enter the occupant's breathing zone parallel to the cheek, avoiding direct contact with the eyes.
	T_{room}	< 30 °C	
	$T_{PECS\text{-}air}$	> 15 °C	
	V_{PECS}	< 1.5 m/s	
	Target body parts	Face, neck, chest	
	PECS position	~50 cm from the occupant, on the desktop	
	Restriction of movement	Occupant shall remain in the flow direction	
	Manual control	Temperature, air velocity	
	Background ventilation	Optional	
Desk-edge based Device	**Desk-edge mounted horizontal air terminal slits supplying air cooled through compressive cooling**		The device should preferably provide a vertical airflow directly under the occupant's chin and should have adjustable vanes for manual adjustment of airflow direction.
	T_{room}	< 26 °C	
	$T_{PECS\text{-}air}$	> 20 °C	
	V_{PECS}	< 1 m/s	
	Target body parts	Face, neck	
	PECS position	~ 10 cm from the occupant, on the desk edge	

Table 13 (*Continued*)

	Restriction of movement	Occupant shall remain directly above the device outlet	
	Manual control	Temperature, air velocity, direction	
	Background ventilation	Optional	
Movable Panel	**Desk-mounted movable air terminal device supplying air cooled through compressive cooling**		The air stream should enter the occupant's breathing zone parallel to the cheek, avoiding direct contact with the eyes.
	T_{room}	< 30 °C	
	$T_{PECS\text{-}air}$	> 20 °C	
	V_{PECS}	< 1 m/s	
	Target body parts	Face, neck, chest, shoulders, arms	
	PECS position	~50 cm from the occupant, on the desktop	
	Restriction of movement	Occupant is free to move within the flow region while adjusting the direction of the panel	
	Manual control	Temperature, air velocity, direction	
	Background ventilation	Optional	
Armrest-embedded Device	**Seat armrest-mounted air terminal device supplying air cooled through compressive cooling**		The airflow should strike the occupant at a 45° angle from below.
	T_{room}	< 25 °C	
	$T_{PECS\text{-}air}$	> 20 °C	
	V_{PECS}	< 0.7 m/s	
	Target body parts	Face, neck, chest, arms	
	PECS position	As the armrest of the occupant's seat	
	Restriction of movement	Occupant shall remain seated and the armrests shall not be blocked	
	Manual control	Temperature, Air Velocity	
	Background ventilation	Required	
Floor-mounted Device	**Floor-mounted air terminal device supplying air cooled through compressive cooling, also known as underfloor air distribution**		The device should be used in combination with a desk-mounted or movable panel device for better control
	T_{room}	< 27 °C	
	$T_{PECS\text{-}air}$	> 16 °C	
	V_{PECS}	< 1 m/s	
	Target body parts	Feet, legs, thighs, buttocks	
	PECS position	~50 cm from the occupant's seat, on the floor	
	Restriction of movement	Occupant shall move radially around the device	
	Manual control	Temperature, air velocity	
	Background ventilation	Optional	
	Ceiling-mounted air terminal device supplying air cooled through compressive cooling		The airflow should have a low turbulence

Table 13 (*Concluded*)

Ceiling-mounted Device	T_{room}	< 29 °C	intensity and long range.
	$T_{PECS\text{-}air}$	> 21 °C	
	V_{PECS}	< 0.8 m/s	
	Target body parts	Head, neck, shoulders	
	PECS position	~1.5 m above the occupant's head, on the ceiling	
	Restriction of movement	Occupant shall move around the vertical flow	
	Manual control	Temperature, air velocity	
	Background ventilation	Optional	
Radiant Cooling Panel with Fan	**Radiant panels placed as desktop partitions with embedded water pipes cooled using compressive cooling - used in combination with low-power desktop fans**		The exposed surface area of the radiant panel to the occupant should be maximized; the airflow from the fan should not strike the desktop.
	T_{room}	< 28 °C	
	$T_{PECS\text{-}air}$	> 17 °C	
	V_{PECS}	< 1.5 m/s	
	Target body parts	Face, neck, chest, arms	
	PECS position	Radiant panels as the desk partition ~ 50 cm from the occupant; Fan on the desktop, ~ 40 cm from the occupant	
	Restriction of movement	Occupant shall remain exposed to the radiant surface and shall move fan as per comfort	
	Manual control	Temperature, air velocity, direction	
	Background ventilation	Optional	

7 DISTRICT COOLING SYSTEMS

District cooling systems (DCS) provides and distributes cooling energy from a central plant to a surrounding cluster of residences, commercial spaces, industries, or institutions occupied by tenants or clients.

In a district cooling system, a large central plant produces chilled water for supply to multiple buildings through an insulated closed-loop underground piping network. Traditional AC systems consume a majority of a building's peak electricity demand, usually at peak cost. With district cooling, peak demand on the grid, as well as operating energy consumption, decreases. It avoids the capital costs of installing multiple HVAC systems that is chillers and cooling towers and associated mechanical and electrical equipment at each building to a central location, freeing up valuable rooftop and building space. By aggregating the cooling needs of multiple buildings, district cooling generates economies of scale. Further, DCS also contributes to sustainability by ensuring reuse of STP water and reducing refrigerant requirement and leakages.

In India, DCS is ideal for mixed-use developments, large infrastructure projects such as aero cities, industrial clusters, residential clusters, educational campuses, IT parks, smart city infrastructure or retrofit of a DCS system for an existing cluster of individually cooled buildings or a redevelopment of existing buildings.

DCS provide several economic benefits to end-users, including reduced capital and operating costs, less frequent maintenance, space savings, and lower electricity usage than in more traditional AC systems (*see* Table 14).

Table 14 Benefits of DCS Systems

(*Clause* 7)

Environmental	Societal	Economic
(1)	(2)	(3)
		For DCS Service Providers/Investors:
a) Energy saving b) Peak energy demand reduction c) Carbon and GHG emission saving d) Enabling transition to low or zero GWP refrigerants e) Water conservation f) Improved micro-climatic conditions by reduced urban Heat Island Effect g) Improved air quality	a) Enhanced aesthetics b) Local business development c) Skill development and improved employability d) Security of supply for cooling e) Access to affordable cooling for achieving thermal comfort f) Improved quality of life g) Reduced noise from cooling equipment	a) New business venture with competitive advantage b) Long-term stable and profitable revenues c) Employment generation Avoided investments in summer electricity peak production, transmission, and distribution Higher energy and resource utilization
		For end-users of DCS:
		a) Avoided capital expenditure (CAPEX) and space requirement for cooling equipment like chillers and cooling towers and related costs b) Reduced O&M cost

7.1 Key Components of District Cooling System

District cooling systems (DCS) shall utilize recycled treated water from sewage effluent as cooling tower makeup water. Municipalities should provide this recycled water for in-house treatment, addressing water shortages and promoting water circularity initiatives in cities. Following are the requirements of DCS:

a) DCS benefit from technologies like thermal energy storage (TES) and free cooling. TES reduces peak electricity costs by shifting cooling production to off-peak hours, while free cooling leverages ambient conditions to lower overall electricity demand.

b) In some cases, district cooling systems may directly use seawater or fresh surface water for heat rejection, subject to local laws.

c) Large central plants should use waste heat or geothermal energy for absorption refrigeration in district cooling systems. This approach is more feasible at the district scale than for individual buildings.

7.1.1 *District Cooling Plant*

The district cooling plant (DCP) generates chilled water for cooling services. It includes chillers, cooling towers, pumps, and auxiliary systems. Thermal energy storage (TES) shall enhance chiller capacity. DCPs play a crucial role in efficient and sustainable cooling solutions for urban areas. All new plants with capacity equal to or greater than 10 000 TR shall include a TES system. All new plants with capacity equal to or greater than 10 000 TR shall carry out due feasibility analysis to include a TES system. Further, for all cluster development of multiple buildings with cumulative cooling demands above 5 000 TR, setting up of District Cooling System, if feasible, should be considered.

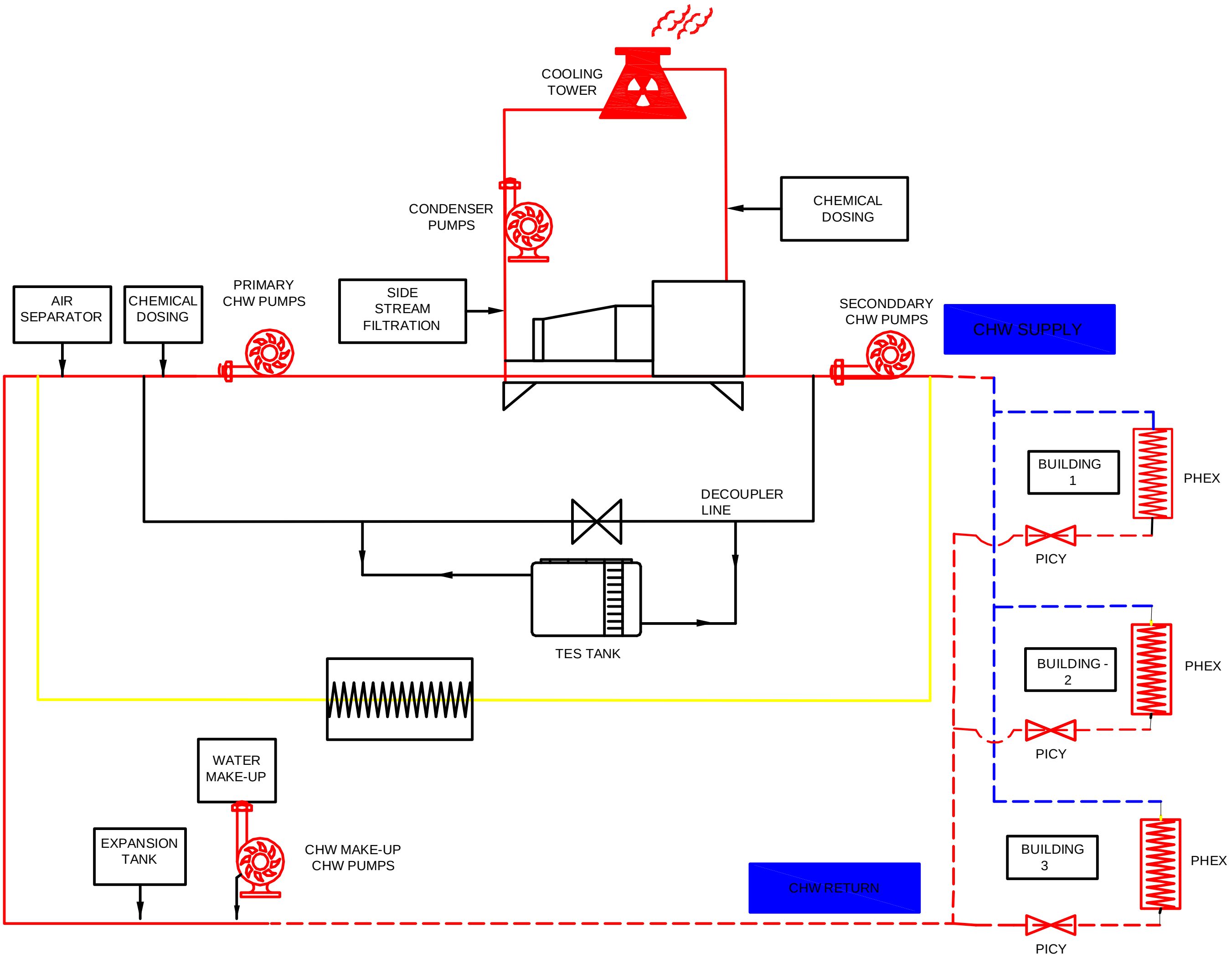

COOLING TOWER
CONDENSER PUMPS
CHEMICAL DOSING
AIR SEPARATOR
CHEMICAL DOSING
PRIMARY CHW PUMPS
SIDE STREAM FILTRATION
SECONDDARY CHW PUMPS
CHW SUPPLY
BUILDING 1
PHEX
DECOUPLER LINE
PICY
TES TANK
BUILDING - 2
PHEX
PICY
WATER MAKE-UP
EXPANSION TANK
CHW MAKE-UP CHW PUMPS
BUILDING 3
PHEX
CHW RETURN
PICY

FIG. 2 LAYOUT OF A DISTRICT COOLING SYSTEM

7.1.2 *Distribution Network*

Based upon ease of operation, geographical constraints, safety, and applications, there are two kinds of distribution networks underground pre-insulated and above-ground site insulated chilled water distribution systems. Carbon steel or mild steel pipes should be used for chilled water and condenser water distribution piping, with proper protective coating wrap for preventing thermal losses. In the Indian context, an indicative DC system design (including the distribution system) is presented in Fig. 2. However, the actual design specifications may vary depending on a multitude of factors. Distribution pipelines should be designed with a life expectancy of minimum 40 years. Following shall be the default design conditions for the distribution network, unless specified by the designer/user:

a) Ambient temperature (for design): based on where the DC system is located;

b) Chilled water supply temperature at DCP: 5 °C ± 1 °C;

c) Temperature rise in the chilled water supply distribution network: 0.5 °C to1 °C per unit length (0.5 °C up to 5 000 m);

d) Approach across Energy Transfer Station: </= 1.1 °C;

e) Chilled water supply temperature at consumer end: 6 °C ± 1 °C;

f) Chilled water return temperature at consumer end: 15 °C ± 1 °C;

g) Temperature drop in the chilled water return distribution network: 0.5 ºC to 1 ºC;

h) Chilled water return temperature at DCP: 14 ºC ± 1 ºC; and

j) Design pressure of the chilled water distribution network: 5 bar to 15 bar (g) (depends on the overall DCS design and building elevation).

7.1.3 *Energy Transfer Station*

An energy transfer station (ETS) serves as a bridge between a district cooling (DC) service and consumers' air conditioning systems. Energy transfer shall be direct or indirect transfer. In district cooling plants where there is uniform time of operation of all spaces and the cooling service provider and end user have no need for decoupling then direct transfer that is supply of chilled water to all air handling units shall be applied. In all other cases indirect heat transfer via an ETS shall be applied.

The ETS transfers thermal energy generated at the central plant to buildings. Within the ETS, heat exchangers allow buildings to utilize this energy for space conditioning. Key components include pumps, isolation valves, and control elements. Proper sizing ensures meeting cooling demand without redundancy. Consideration for equipment access, maintenance, and transport pathways shall be done. Controls, such as pressure independent control valves, help in maintaining efficiency.

7.1.4 *Instrumentation, Monitoring and Control System* (*SCADA*)

A DC instrumentation and control system shall be designed, installed, and commissioned to monitor and control various system components for enhancing operational efficiency of the DC system. The main components of an instrumentation and control system are a programme logic controller (PLC), human machine interface (HMI), and distribution control system. The control system shall be designed to maintain the entire DC plant operations and functionality, and integration with ETSs to maintain transparency in operations. The control system shall monitor comprehensive chiller plant parameters, cooling tower parameters, TES parameters, chemical treatment equipment parameters, building management system (BMS) of the DC plant building, firefighting status of the plant building, etc and may be integrated on SCADA.

7.1.5 *Measurement and Billing System*

The measurement and monitoring system shall facilitate real time monitoring of kW/TR of the plant. Infrastructure for continuous measurement and logging of cooling production and consumption (TR-h) and complete breakdown of all associated power demand (kW, voltage, ampere, power factor), and energy consumption (kWh) is crucial for district cooling (DC) systems. Separate BTU meters for each cooling consumer, installed at the Energy Transfer Station (ETS), generate monthly cooling bills. Individualizing BTU metering by consumer or apartment enhances responsibility for thermal energy consumption. Properly sized BTU meters accurately measure the entire cooling load range. All BTU meters shall be calibrated annually.

7.2 Design Approach for DCS

7.2.1 *Site Selection Criteria*

Site selection involves careful evaluation of various aspects with different degrees of importance. A methodology should be prepared to ensure that the critical aspects are not overlooked. The aim is to define a set of criteria that helps in shortlisting the most optimum site, which has the following characteristics:

a) resource-efficient;

b) minimum environmental impact;

c) cost-effective;

d) adequate in terms of logistics;

e) ensures maximum efficiency;

f) offers possibility of easy future expansion;

g) proximity to utilities (power and STP infrastructure) and drainage; and

h) proximity to load centre of large multi tower developments.

The first stage of site selection is determining the study area and indicators. The second stage involves the diagnosis process, wherein indicators are ranked and weighted according to benchmarks, guidelines, and preferences. Furthermore, this stage involves analysis of data collected for various indicators. The last stage is decision making, where potential sites are ranked, followed by the development of a feasibility plan. The process shall take place via the traditional method of site suitability analysis or using computer-based applications and the major factors influencing DCS implementation are given in Table 15.

7.2.2 *Sizing Philosophy for DCS*

The sizing of both mechanical and electrical systems shall ensure optimal performance, energy efficiency, and reliability of the district cooling system.

7.2.2.1 *Mechanical system sizing* (*chiller sizing, network and delta T*)

In sizing a chiller for a district cooling system, following critical factors shall be considered.

a) First, the required cooling capacity based on the peak cooling load and combined load diversity. This load shall vary significantly depending on the specific application (for example, residential, commercial, or industrial) and local climate conditions.

b) The desired temperature difference between the inlet and outlet water is to be decided. This difference affects the chiller's efficiency and overall performance.

c) The ambient conditions, such as the local climate and ambient temperature. Hotter climates may necessitate larger chillers to handle higher cooling demands effectively.

d) Assess installation constraints, such as available space, and any limitations related to the chiller's physical placement within the district cooling network proper chiller sizing is crucial for achieving efficient and reliable district cooling operations.

The successful implementation of district cooling systems depends greatly on the ability of the system to obtain high-temperature differentials that is delta temperatures (T) between the supply and return water. It is crucial to ensure that the district cooling system shall operate with reasonable size distribution piping and pumps to minimize the pumping energy requirements.

The pipe sizing is governed by four key factors:

1) the system's delta T;

2) maximum allowable flow velocity;

3) distribution network pressure at the design load conditions; and

4) minimum differential pressure requirements to service the most remote customers.

NOTES

1 Generally, it is most cost-effective to design for a high delta T in the district cooling system because this allows for smaller pipe sizes in the distribution system. The system operating efficiency also increases with an increased delta T due to the reduced pumping requirements caused by the reduced flow rates and the reduced heat gains/losses in the distribution system. The system's delta T is typically limited to 8 ºC to 11 ºC.

2 The maximum allowable flow velocities are governed by pressure drop constraints and critical system disturbances caused by transient phenomena (that is water hammer effects). Generally, velocities higher than 2.5 m/s to 3.0 m/s should be avoided unless the system is specifically designed and protected to allow for higher flow velocities.

Table 15 Major Factors Influencing DC System Implementation

(*Clause* 7.2.1)

Building Design and Use (1)	Building Energy Demand (2)	Local Context (3)	Resource Requirement (4)	Policy and Governance (5)
a) Availability of space for distribution centre or possibility of extension	a) Peak demand	a) Topography	a) Financial assistance	a) Existing policies, programmes, and missions
b) Floor Area Ratio or Floor Space Index	b) Demand density	b) Slope and contours	b) Capital Investment	b) Proactiveness of local government
c) Carpet area	c) Delivery density	c) Existing and proposed utility lines	c) Rate of return	c) Administrative capacity
d) Total floor area	d) Time distribution of energy demand over days, weeks, months and years.	d) Water	d) Payback period	d) Ease of getting permissions and clearances
e) Diverse use of buildings	e) Potential future cooling demand	e) Drainage	e) Labour and other resources	
f) Ownership		f) Telecom, PNG line, electricity line, etc.	f) Availability of skilled labourers	
g) Availability of water and power to meet current and future demand		g) Access to natural cold-water body	g) Availability of machinery	
h) Electricity and water cost		h) Access to renewable energy and/or waste energy source	h) Time	
		j) Road network	j) Project timeline	

7.2.2.2 *Electrical system sizing (transformers, diesel generators and substation)*

For efficient and safe functioning of DCS, the electrical supply system plays a critical role. The sizing of electrical supply system components such as transformers, diesel generator and substation shall be designed considering the parameters listed below:

a) *Transformers* — Transformers play a critical role in stepping up or down voltage levels within the distribution network. Sizing shall be done considering:

   1) system voltage level requirements;

   2) capacity for transformer selection;

   3) diversity considerations;

   4) efficiency/losses; and

   5) redundancy/outage considerations.

b) *Diesel generators* — DG is a power backup during emergency when main power supply not available. Sizing shall be done considering:

   1) backup voltage level requirements;

   2) quantum of backup power required when the main power is not available;

   3) allowable loading during continuous operation;

   4) redundancy/outage considerations; and

   5) allowable noise considerations as per CPCB guidelines.

c) *Substation design* — Substation design involves planning, engineering, and constructing electrical substations for efficient power transmission and distribution. It needs to be done based on district cooling plant (DCP) capacity requirement. Accurate sizing ensures efficient and reliable electrical operations in district energy systems. Here are some key points about substation design:

   1) voltage and power capacity requirements;

   2) component selection;

   3) CapEx and OpEx; and

   4) footprint requirements.

7.3 General Requirements

These requirements ensure that DCS installations meet operational efficiency, safety, and performance standards.

7.3.1 *Specific Power Consumption for DCS*

The specific power consumption shall be measure as ratio of kW electric power to kW thermal output the system efficiency of a DC chiller plant shall not be less than 0.85 input kilowatts per TR (ikW/TR). However, depending on system size and detailed economic analysis, there are opportunities to improve the efficiency levels of DCS.

7.3.2 *Testing and Commissioning Procedures for Hydrotesting and Pipe Conditioning*

Necessary hydro testing shall be carried out for the distribution network. The distribution pipes should be subjected to pressure testing as per the design specifications and guidelines approved by the owner and their design consultant representatives. Where required for certain equipment like chillers, factory testing will be required to ensure design conditions are being complied with. Once the individual equipment is all put together as a system, proper testing of the complete system should be carried out.

The procedures for hydrotesting and flushing of pipes during the testing and commissioning phase for district cooling systems:

7.3.2.1 *Hydrostatic testing*

The strength and integrity of piping system shall be tested by hydrostatic testing at water pressure equivalent to 1.5 times the design operating pressure for stipulated time.

a) *Hydrostatic pressure testing procedure* – The hydrostatic pressure test shall be conducted as mentioned below:

   1) *Step* 1 – Filling the System

      i) Fill the entire piping network with water.

      ii) Ensure that all air pockets are removed.

   2) *Step* 2 – Pressurization

      i) Gradually increase the water pressure to at least 1.5 times the design pressure.

      ii) Maintain this pressure for a specified duration (usually a few hours).

   3) *Step* 3 – Inspection

      i) Inspect the entire system for leaks.

      ii) Pay attention to joints, welds, and connections.

   4) *Step* 4 – Record Keeping

      i) Document the test results, including pressure readings and any observed leaks.

   5) *Step* 5 – Depressurization

      i) Gradually reduce the pressure and drain the system.

b) *Safety considerations*

   1) Ensure safety protocols are followed during pressurization and depressurization.

   2) Personnel should be aware of potential hazards.

c) *Pipe conditioning*

   Pipe conditioning removes debris, dirt, and contaminants from the pipes and to form a protective anti corrosive layer on the inner surface of the pipes. The procedure for pipe conditioning is as follows:

   1) *Step* 1 – Preparation

      i) Ensure the system is clean and free from construction debris.

   2) *Step* 2 – Flushing Process

      i) Flush the pipes with water to remove loose particles.

      ii) Use stipulated high-velocity flow to dislodge any remaining debris.

      iii) Passing criteria to next step is to get clean water after flushing.

   3) *Step* 3 – Chemical cleaning

      i) Flush the pipes with water mixed with cleaning chemicals.

   - ii) Use stipulated high-velocity flow to dislodge any remaining debris.
   - iii) Passing criteria to next step is to get clean water and to meet certain water parameters at the end of chemical cleaning.

4) *Step* 4 – Passivation
   - i) Circulate the water mixed with passivation chemicals for stipulated period
   - ii) Passing criteria is to get clean water and to meet certain water parameters at the end of passivation
   - iii) Minimum quantity of passivation chemicals shall be ensured at the end of passivation and throughout the operation period.

5) *Step* 5 – Verification
   - i) Verify that the system is clean and ready for operation.

6) *Step* 6 – Record Keeping
   - i) Document the pipe conditioning process.

7.3.2.2 *Performance testing of DCS*

Performance tests fall under two categories, operational performance and availability performance. Operational performance is to ensure that during operation plant is meeting the designed electrical and water performance. Availability test is to ensure that availability of the plant equipment is meeting the availability and reliability conditions set forth over a stipulated time without any downtime.

Following indices shall be used to establish performance of a DCS:

Overall plant efficiency	kWh/TR-h
Water consumption	litre/h
Cooling tower water discharge	litre/h

Table 16 shall be used for benchmarking of performance of DCS.

Table 16 Recommended Performance of DCS

(*Clause* 7.3.2.2)

Sl No.	DCS Plant Type	TES	Condenser Cooling	Water Source	Max kW/ TR-h
(1)	(2)	(3)	(4)	(5)	(6)
	Energy Consumption				
i)	New	Chilled Water	Cooling Tower	Recycled/City supplied	0.87
ii)	New	None	Cooling Tower	Recycled/City supplied	0.91
iii)	New	Ice	Cooling Tower	Recycled/City supplied	1.17
iv)	New	None	Cooling Tower	Sea Water	0.96
v)	Existing	Chilled Water	Cooling Tower	Recycled/City supplied	1.00
	Condenser Water Consumption				litres/TR-h
i)	New/Existing	Ch Water/None	Cooling Tower	City Supply	8.00
ii)	New/Existing	Ch Water/None	Cooling Tower	Recycled	11.00
	Cooling Tower Water Discharge				
i)	New/Existing	Ch Water/None	Cooling Tower	City Supply	1.5 to 2.0
ii)	New/Existing	Ch Water/None	Cooling Tower	Recycled	4.5 to 5.0

7.4 Operation and Maintenance of DCS – Best O&M Practises

Practices as given below shall be followed for operating and maintaining a district cooling system:

a) Regular inspections and maintenance:
   1) Conduct routine inspections of equipment, pipelines, and components;
   2) Address minor issues promptly to prevent major failures; and
   3) Implement PPM strategies

b) Water treatment and quality:
   1) Maintain water quality in chilled water and hot water systems:
      i) Regularly clean and treat cooling towers to prevent scaling, corrosion, and biological growth.

c) Energy efficiency measures:
   1) Optimize the operations of chillers, pumps, cooling towers etc;
   2) Monitoring and control strategies; and
   3) Implement variable flow systems and energy-efficient equipment.

d) Leak detection and repair:

  1) Monitor for leaks in distribution networks and fix them promptly; and

  2) Leaks waste energy and reduce system efficiency.

e) Thermal storage optimization:

  1) Use thermal energy storage (TES) effectively to balance supply and demand; and

  2) Charge TES during off-peak hours and discharge during peak demand.

f) Metering and billing accuracy:

  1) Ensure accurate metering for billing purposes; and

  2) Individualize metering for end-users where possible.

7.5 Economics of DCS [Business Model for DCS – CaaS (Cooling as a Service)]

Cooling as a service (CaaS) is an innovative business model where end-users subscribe to cooling services without owning the infrastructure. The district cooling provider finance, build and maintains the cooling plant, promoting energy efficiency and sustainability. Users benefit from reduced upfront costs and simplified operations, while the provider ensures reliable service delivery. CaaS shifts the focus from ownership to access, fostering efficient and sustainable cooling solutions

7.5.1 *Tariff Structure - Fixed and Variable Charges + Connection Charges*

The tariff structure for district cooling systems is monthly and typically includes the following components. The recovery mechanism shall be tailored based on the various models in the real estate market say lease, sale, hybrid model etc and hence various contract strictures shall be tailored between real estate developer, DCS developer and end users:

a) *Connection charge* — It's a one-time fee paid by users when connecting to the district cooling system.

b) *Contract capacity charges* — These charges are effectively availability fees, covering capital expenditures (CapEx) and fixed operation and maintenance (O&M) costs. They ensure that the district cooling provider maintains the capacity to deliver cooling services.

c) *Consumption charge* — The consumption charge covers variable O&M costs, including chemicals, electricity, and water (potable or treated sewage effluent) consumed by the end users.

7.5.2 *Service Level Agreement* (*SLA*) *and Key Performance Indicators* (*KPI*)

These ensure clear expectations and measurable standards for the performance and maintenance of district cooling systems:

a) *Service level agreement* (*SLA*) — A Service level agreement (SLA) outlines the expected level of service between a service provider (district cooling plant) and its customers. Key components of an SLA for a district cooling plant might include:

  1) cooling capacity commitment;

  2) reliability and availability; and

  3) penalty terms basis performance matrix.

b) Key Performance Indicators (KPIs):

  1) Coefficient of performance (COP);

  2) Chilled water supply and return temperature (CHWST/CHWRT);

3) Chilled water return temperature (CHWRT); and

4) Water usage efficiency (Litre/TRh).

8 SUPPLY AIR DUCTS AND RETURN AIR DUCTS

Following provisions to be considered for supply air ducts and return air ducts construction:

a) duct Systems are a continuous passageway for the transportation of air which, in addition to the ducts, may include duct fittings, dampers, plenums, grilles and diffusers and such other accessories as may be required. Leak tightness, adequate supporting and proper installation are important requirements;

b) due to aerodynamic considerations, it is recommended that the aspect ratio of rectangular ducts (height to width ratio) be kept within 1 : 4;

c) designer shall specify the material of ducts, appropriate standard to be followed, maximum permitted velocity of air in the duct and the required pressure class as indicated in Table 17 and Table 18;

d) the duct supports shall be designed to handle the load and also to take into account seismic considerations;

e) if false ceiling is provided, the supports for the duct and the false ceiling, shall be independent. Collars for grilles and diffusers shall be taken out only after false ceiling/boxing framework is done and frames for fixing grilles and diffusers have been installed; and

f) where a duct penetrates the masonry wall, it should either be suitably covered on the outside to isolate it from masonry, to prevent vibration transmission. Refer Part F ‘Fire and Life Safety’ of this NBCS for safety requirements.

For more details on duct construction and installation, refer to the latest edition of accepted standard [D-3(14)].

Table 17 Classification by Internal Pressure and Pressure Range

(*Clause* 8)

Sl No.	**Classification by Pressure**	**Normal Service Pressure** Pa		**Pressure Limits** Pa	
		Positive Pressure	Negative Pressure		
(1)	(2)	(3)	(4)	(5)	(6)
i)	Low Pressure Duct	P ≤ + 500	– 500 ≤ P	+ 1 000	– 750
ii)	Medium Pressure Duct	+ 500 < P ≤ + 1 000	– 500 > P ≥ – 1 000	+ 1 500	– 1 500
iii)	High Pressure Duct	+ 1 000 < P ≤ + 2 500	– 1 000 > P ≥ – 2 000	+ 3 000	– 2 500

Table 18 Recommended *Max* Duct Velocities

(*Clause* 8)

Sl No.	Application	Controlling Factor Noise Generation Main Ducts	Controlling Factor - Duct Friction			
			Main Ducts		Branch Ducts	
			Supply	Return	Supply	Return
		m/s	m/s	m/s	m/s	m/s
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	Residences	3	5	4	3	3
ii)	Apartments	5	8	7	6	5
iii)	Hotel Rooms	5	8	7	6	5
iv)	Hospital Rooms	5	8	7	6	5
v)	Private Offices	6	10	8	8	6
vi)	Directors Rooms	6	10	8	8	6
vii)	Libraries	6	10	8	8	6
viii)	Theatres	4	7	6	5	4
ix)	Auditoriums	4	7	6	5	4
x)	General Offices	8	10	8	8	6
xi)	Restaurants	8	10	8	8	6
xii)	Stores	8	10	8	8	6
xiii)	Banks	8	10	8	8	6
xiv)	Cafeterias	9	10	8	8	6
xv)	Industrial **	13	15	9	11	8

NOTE — ** For specific industrial applications, refer to customer specific needs and choose a velocity to optimize energy consumption requirements.

8.1 Space Air Distribution

Space air distribution shall be classified by:

a) their primary objective; and

b) the methods by which the objectives are attempted to be accomplished.

The objectives of space air distribution shall be classified as one of the following:

1) providing occupant thermal comfort;

2) to support processes within the space; or

3) a combination of (i) and (ii).

The occupied zone is a space in any location where occupants normally reside and may differ from project to project. It may be application-specific and should be carefully defined by the designer. The occupied zone is generally considered to be the room volume between the floor level and 1.8 m above the floor level. For additional information special publication may be referred.

NOTE — Special publication maybe ANSI/ASHRAE Standard 55 and Standard 62.1 for further information.

Space Air Distribution methods shall be classified as one of the following:

i) fully mixed systems (for example, overhead air distribution) which have zero or very little thermal stratification of air in the occupied zone or process space.

ii) fully stratified systems (for example, thermal displacement ventilation) have practically no air mixing in the occupied zone or Process Space.

iii) partially mixed systems (for example, most underfloor air distribution designs) provide limited air mixing in the occupied zone or process space.

iv) unidirectional air flow system (for example a laminar flow system) is designed to ensure no mixing and maintain a consistent air flow pattern, ensuring that air always moves from a clean to less clean areas.

v) personalized system (for example task/ambient air distribution systems) is an air distribution strategy that combines two different air supply methods to optimize IAQ, thermal comfort and energy efficiency.

8.1.1 *Fully Mixed Systems*

In mixed air systems, comfort is maintained by mixing of high velocity supply air with the room air. The air mixing, heat transfer and velocity reduction should occur outside the occupied zone. The three fundamental characteristics of the system are:

a) the supply air outlets are located far away from the occupied zone;

b) the supply air temperature is considerably lower than the room temperature (the normal ΔT between supply air and room air would be of the order of 11 °C to 12 °C). When supplying heated air from overhead outlets, ensure that the ΔT between supply air temperature and room air temperature is not more than 8 °C to 9 °C to avoid stratification; and

c) the supply air (SA) outlet velocity should be much higher than the desired occupied zone air velocity. The supply air outlet velocity should be of the order of 3.5 m/s to 5.0 m/s. The resultant occupied zone velocity should be between 0.2 m/s to 0.25 m/s for cooling, and not more than 0.15 m/s for heating. When SA outlets are used at the perimeter with vertical projections for heating and/or cooling, they should be located near the perimeter surface. Outlet selection shall be done on the basis of the isothermal terminal velocity of 0.75 m/s extends at least half way down the surface or 1.5 m above the floor (whichever is lower) thus ensuring that the warm air mixes with the cool downdraft on the perimeter surface, to reduce draft in the occupied zone.

8.1.2 *Fully Stratified Systems*

Systems that discharge cool air at low sidewall or floor locations with very little entrainment of room air into the primary air stream create vertical thermal stratification throughout the space. The three fundamental characteristics of the system are:

a) the supply air outlets are located directly in the occupied zone;

b) the supply air temperature is much closer to the room temperature (the normal ΔT between supply air and room air would be of the order of 3 °C to 6 °C); and

c) the supply air (SA) outlet velocity should be of the order of 0.25 m/s to 0.35 m/s.

In spaces where the internal heat gain density exceeds 120 W/m^2, care should be taken to ensure comfort by providing supplementary localized cooling terminals to address the higher heat gain densities. Care should be taken to limit downward drafts driven by cold walls or windows. The vertically stratified temperature field needs to be stable for proper functioning.

Ensure that the design provides for appropriate measures for maintaining the RH within the specified levels.

Stationary occupants should not be subjected to discharge velocities exceeding about 0.2 m/s. SA outlets shall not be located closer than 1 m from any occupant. SA outlets should not be located behind furniture and other obstructions that impede airflow.

Stratified systems shall not be used in conjunction with mixed air systems because mixing destroys natural stratification that drives displacement ventilation.

8.1.3 *Partially Mixed Systems*

Supply air (SA) (usually from the floor) is discharged vertically at relatively high velocities and entrains room air akin to SA outlets in fully mixed systems. Underfloor air distribution systems (UFAD) shall be classified as partially mixed systems. The cavity below the access floor tiles is generally pressurized and used as SA Plenum.

As with fully stratified systems, the partially stratified systems in humid climates should ensure that the design provides for appropriate measures for maintaining the RH within the specified levels.

SA outlets should be of the swirl type with a high-induction core which promotes quick reduction in velocities and temperature gradients.

SA outlets should be located far enough from stationary occupants to ensure that they are not exposed to drafts and noise causing discomfort.

SA temperature in the access floor cavity should be kept at or above 16 °C to minimize the risk of condensation and consequent fungal growth.

Access floor plenums should be well sealed to prevent air leakages. Exterior walls should be well insulated and have proper vapour retarders. Night/holiday temperature set-backs should be avoided (or at least reduced) to minimize plenum condensation and thermal mass effect problems.

Return static pressure drop should be relatively equal throughout the space being served by the plenum. This reduces the chances of unequal pressurization within the Plenum.

Partially stratified systems shall not be used in conjunction with mixed air systems because mixing destroys natural stratification that drives displacement ventilation.

8.1.4 *Unidirectional Air Flow Systems*

A unidirectional air flow system is a type of ventilation system that provides a controlled, one-way flow of air through a facility or room. This system is designed to minimize contamination, reduce air turbulence, and improve indoor air quality.

Key features of this system are:

a) air flows in a single direction, from the cleanest area to the most contaminated area;

b) air flows in a smooth, parallel stream, reducing turbulence and mixing (laminar flow);

c) air is filtered to remove particles and contaminants before entering the space;

d) the space is maintained at a positive pressure to prevent outside air from entering; and

e) contaminated air is exhausted directly outside, without recirculation.

The key benefits of the unidirectional air flow system is improved air quality, reduced risk of cross-contamination, enhanced particle count control thus leading to easier regulatory compliance in required applications like cleanrooms, laboratories, healthcare facilities (operating room, isolation rooms), food processing facilities and the like.

8.1.5 *Personalized Systems*

Task/Ambient air distribution systems is an air distribution strategy that combines two different air supply methods to optimize IAQ, thermal comfort and energy efficiency.

Following are the two methods:

a) *Task air* — Supplies conditioned air directly to the breathing zone (directly via special outlets inbuilt in the seating systems/workstations). The SA is very precisely tempered to the correct temperature and humidity; and

b) *Ambient air* — Supplies to the overall space above and out of the breathing zone so as to maintain a comfortable thermal environment and air quality.

Such personalized systems, by separating the air components into task and ambient, offer several benefits including improved air quality, enhanced thermal comfort and increased energy efficiency.

8.1.6 *Supply Air Outlet* (*Airflow Mixing*) *Types and Ventilation Effectiveness*

The Table 19 and Table 20 below provides an understanding of the various types of systems, their ventilation efficiencies.

Table 19 Various Types of Systems and Their Ventilation Efficiencies

(*Clause* 8.1.6)

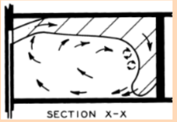
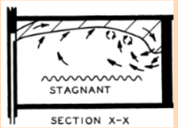
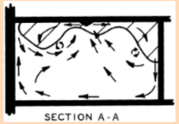
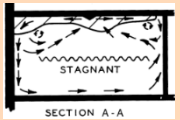
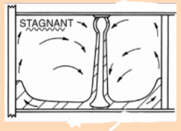
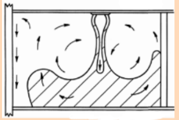
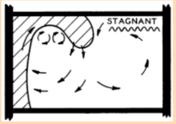
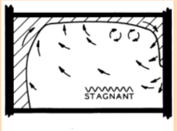
Sl No.	Methods	Suitable Air Outlet	Zone Air Distribution/Change Effectiveness (E_z)		
			Cooling	Heating	Features
(1)	(2)	(3)	(4)	(5)	(6)
i)	Fully Mixed System, Entrainment from Sidewall	High Sidewall Grilles, Sidewall Diffuser, Nozzle and similar outlet providing ceiling attached flow	 E_z=1 (Ideal)	 E_z =0.8 (Ideal)	Suitable for summer cooling and minor winter heating (temperature difference +10K warm air). Velocity in the occupied zone should be less than 0.35 m/s
ii)	Fully Mixed System, Horizontal Discharge from Ceiling	Ceiling Diffuser, Linear Ceiling Diffuser or similar outlets with Horizontal diffusion pattern	 E_z =1 (Ideal)	 E_z =0.8 (Ideal)	Suitable for summer cooling and minor winter heating (temperature difference +10K warm air). Velocity in the occupied zone should be less than 0.35 m/s
iii)	Fully Mixed System, Vertical Downward Air Projection from Ceiling	Adjustable Grille, Jet Nozzle, Ceiling Spot Diffuser, Linear Ceiling Diffuser or similar outlets with vertical downward air projection	 E_z =1 (Ideal)	 E_z =1 (Ideal)	Suitable for either cooling or heating with increased terminal velocity in order to project warm air up-to the occupied zone.
iv)	Partially Mixed System, Non Spreading Vertical Jet in or near floor	Floor Diffuser, Sidewall Grilles, Sidewall Diffuser or similar outlets with fixed vertical spread pattern.			Suitable for cooling and heating both at terminal velocity ~ 0.75 m/s (ideal). Outlet shall be placed at 150 mm distance from wall.

Table 19 (*Concluded*)

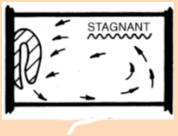
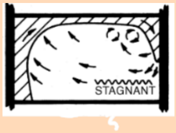
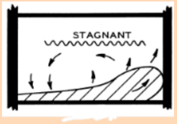
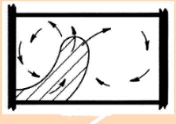
Sl No.	**Methods**	**Suitable Air Outlet**	**Zone Air Distribution/Change Effectiveness (E_z)**		
			Cooling	Heating	Features
(1)	(2)	(3)	(4)	(5)	(6)
			E_z =1 (Ideal)	E_z =1 (Ideal)	
v)	Partially Mixed System, Spreading Vertical Jet in or near floor	Floor Diffuser, Sidewall Grilles, Sidewall Diffuser with adjustable spread pattern or similar outlets			Suitable for severe heating and minor cooling requirements (temperature difference -8K cool air). Velocity at 1.4m above floor i.e. occupied region should be less than 0.25 m/s
			E_z =1 (Ideal)	E_z =1 (Ideal)	
vi)	Fully Stratified System, Low Horizontal Discharge near floor	Baseboard or Low sidewall Grille, Displacement Diffuser or similar outlets			These outlets direct high velocity total air directly into the occupied zone and therefore not recommended for particularly summer cooling. Terminal Velocity <1.5 m/s and mostly suitable for process installations where controlled air velocities are desired.
			E_z =1.2 (Ideal)	E_z =1 (Ideal)	
vii)	Unidirectional Airflow System, Plug type from ceiling exhausted through wall	Laminar Flow Diffuser with perforated/helical face plate			Generally, a preferred choice for use in a cleanroom for manufacturing, healthcare and research. Other performance parameters such as colony forming unit and room class affects its choice and selection

Table 20 Recommended Supply Air Outlet Selection

(*Clause* 8.1.6)

Outlet Types	**Fully Mixed**			**Fully Stratified**		**Partially Mixed**		
	Outlet Location							
	Ceiling	Wall	Floor	Wall	Floor	Ceiling	Wall	Floor
Grilles								
Adjustable Blade	☑	☑	NR	NR	NR	NR	NR	NR
Fixed Blade	NR	☑	NR	☑	NR	NR	NR	NR
Linear Bar Grille	NR	☑	☑	☑	☑	NR	NR	☑
Jet Nozzle	NR	☑	NR	NR	NR	NR	NR	NR
Diffusers								
Round	☑	NR	NR	NR	NR	NR	NR	NR
Square	☑	NR	NR	NR	NR	NR	NR	NR
Perforated Face	☑	NR	NR	NR	NR	NR	NR	NR
Louvered Face	☑	NR	NR	NR	NR	NR	NR	NR
Plaque Face	☑	NR	NR	NR	NR	NR	NR	NR
Laminar Flow	☑	NR	NR	NR	NR	NR	NR	NR
Slot Diffuser	☑	☑	NR	NR	NR	NR	NR	NR
Swirl Diffuser	☑	NR	NR	NR	☑	NR	☑	☑
Displacement	NR	NR	NR	☑	☑	NR	NR	NR

NOTES

1 Obstructions, vane adjustments, and other ceiling elements influencing airflow patterns shall affect comfort and efficiency.

2 Personalised system will increase E_z when used in combination with the above listed methods up to 1.5

3 During partial load, VAV systems shall affect E_z by reducing the air velocity at the outlet. Minimum airflow should be considered so that velocity in the occupied region does not go below 0.1 m/s while designing such systems and other performance criteria such as outdoor air intake and critical space CO_2 concentration should be monitored and controlled (demand control ventilation). Additionally, a dual duct system, fan powered and reheat terminal may be used in combination with VAV systems where precise and wide climate control range is required without affecting the E_z.

8.1.7 *Return Air Inlets*

Return air intake affects room air motion only immediately around the inlet. the selection of return air inlets should be based on performance data and not merely based on aesthetic and architectural considerations. The Table 21 below provides the recommended face velocities across Inlets based on their location.

Table 21 Recommended Face Velocities Across Inlets Based on their Location

(*Clause* 8.1.7)

Sl No. (1)	Inlet Location (2)	Velocity Across Inlet m/s (3)
i)	Above occupied zone	> 4
ii)	In occupied zone (not near seats)	3 to 4
iii)	In occupied zone (near seats)	2 to 3
iv)	Door/wall louvers	1 to 1.5
v)	Through door under-cuts	2 to 1.5

8.2 Airflow Measurements in Space Air Distribution Systems

Air flow measurement requirements and methods of air distribution systems aim to ensure adequate indoor air quality, energy efficiency, and occupant comfort in the occupied space. These requirements vary depending on the specific standard in use, but there are common elements that are often addressed. Understanding and adhering to these requirements and methods ensures that air distribution systems in buildings provide adequate ventilation, maintain indoor air quality, and operate efficiently. It is recommended that the airflow measurement should be conducted to meet the following requirements.

8.2.1 *System Balancing*

Air distribution systems shall be balanced to ensure each space receives the designed air flow. This typically involves testing, adjusting, and balancing (TAB) procedures to verify system performance. Airflow measurements using one of the following methods should be conducted in each space to achieve the designed values within a band of ± 5 percent. Proper documentation of all measurements, adjustments and maintenance activities shall be maintained. The following describes various airflow measurement methods to comply with the above requirements of system balancing:

a) *Anemometers* — Anemometers are used to measure the velocity of air flowing through ducts or at registers/diffusers.

b) *Barometers/flow hoods* — Barometers or Flow hoods are used to measure the airflow directly at the supply air outlets.

c) *Duct traverse method* — Duct traverse method involves measuring air velocity at multiple points across the duct cross-section using a pitot tube or hot-wire anemometer and calculating the average velocity to determine airflow rate.

d) *Pressure measurement* — Differential pressure measurements across known resistances (for example, orifice plates, flow hoods) shall be used to determine airflow rates.

e) *Tracer gas method* — Trace gas method introduces a tracer gas into the airflow and measures its concentration downstream to determine the airflow rate based on dilution principles.

For airflow measurements within ducts, it is recommended to use an air flow measuring station. Such air flow measuring station should ideally be located with a clear straight duct length of at least 4 times the equivalent duct diameter (of the duct in which they are installed), at the inlet of the air flow measuring station.

8.3 Flow Control – Volume Control Dampers

A damper is a valve or plate that stops or regulates the flow of air inside a duct, and other air-handling equipment.

Manual dampers are operated by a handle on the outside of a duct. Automatic dampers are used to regulate airflow constantly and are operated by electric or pneumatic motors, in turn controlled by a thermostat or the building automation system.

Dampers are customized in terms of size to suit the openings, where they are to be installed. A right choice of volume control dampers/s shall result in energy conservation.

8.4 Variable Air Volume (VAV)

Variable air volume terminal units are devices that regulate the amount of air supplied to a specific zone or space in a building. They are an important component of fully mixed systems, which help to optimize energy efficiency and indoor air quality.

By optimizing air flow and conditioning, VAV terminal units play a crucial role in creating a comfortable, efficient, and sustainable indoor environment. When using VAV terminal units, observe the following guidelines to ensure safe and efficient operation:

a) Wherever possible, a straight duct inlet connection with a minimum length of three duct diameters and the same internal diameter as the inlet should be provided.

b) Never insert a duct inside the Inlet or control calibration will be adversely affected.

c) Ensure accurate sensor calibration to maintain precise control and avoid oscillations.

d) Balance airflow to prevent uneven distribution, reduced efficiency, and increased energy consumption.

e) Inlet air velocity should not exceed 12 m/s at max flow and should not be below 2 m/s. Ensure unit sizing is adequate to meet flow range and also meets noise criterion for the space.

f) When using terminals equipped with re-heat elements, to avoid compromising zone ventilation effectiveness, the discharge temperature should not be more than 8 °C warmer than the zone it serves. If electrical re-heat is being used, ensure all safety controls (like air stats/flow switch and other safety cut outs) as required by local codes are provided.

g) Ensure proper access is provided for the unit (like adequately sized access doors).

8.5 Thermal Beams

Chilled beams are a type of convection HVAC system used to heat or cool rooms they are air distribution devices with integral coils designed to heat or cool large buildings. Chilled beams shall be classified into two main categories, passive and active.

Passive chilled beams work using the phenomenon of natural convection, and they do not require any primary air supply.

Active chilled beams consist of a primary air supply connection that provides conditioned/dehumidified air and enhances air induction through the coil.

8.5.1 *Application Considerations*

Chilled beams are intended to operate without condensation. Consequently, active chilled beam supply water temperatures should be maintained at or above the room dew point temperature to prevent condensation on the coil. Passive chilled beam should be kept slightly above the room dew point temperature. In both cases, the chilled water piping shall be adequately insulated to prevent condensation on the pipe itself. Where adequate control of space humidity levels shall not be ensured, higher supply water temperatures and/or suitable condensation control should be considered.

Heating with passive beams is not effective. For heating, the hot water temperature serving the beam’s coil shall be selected to limit the discharge air temperature to less than 8 °C above the room design set point.

8.6 Air Curtains

An air curtain unit acts as a controlled barrier for environmental and thermal separation and wind resistance when a building's doors or windows are opened. Air curtains create an invisible barrier at openings and doors which separates different temperature zones without limiting access for people and vehicles. Air curtains are used where it is not feasible to have an engineered air lock.

8.6.1 *Application Considerations*

Air curtain unit selection depends on the opening's width and height. To maximize effectiveness, the air curtain unit shall at least cover or slightly overlap the entire opening and have a minimum velocity projection of 2 m/s at the target surface. The air curtain unit discharge shall have a free and clear path to the entire opening for optimum performance.

9 AIR FILTRATION AND ALTERNATE AIR CLEANING METHODS

With people spending a significant portion of their time indoors, ensuring good indoor air quality (IAQ) is paramount for occupant health, productivity, and overall well-being. The provisions related to indoor spaces that are regularly occupied and are either naturally or mechanically ventilated are covered. Following are the aspects to be considered for air filtration and alternate air cleaning methods.

9.1 Threshold Levels for Pollutants

Threshold values are made available for different pollutants depending on the severity of the health hazard that a pollutant shall create for the occupants. For details of threshold values for the different pollutants encountered in indoor air refer to **3.6.2**.

9.2 IAQ Monitoring

IAQ is a critical component in ensuring the health, comfort and productivity of occupants in commercial buildings. Monitoring IAQ involves the assessment of various air quality parameters. Some critical pollutants and air quality parameters are monitored continuously, while some are monitored/tested periodically. Continuous monitoring and periodic testing data are required for interpreting the indoor environment and initiating necessary mitigation measures.

9.2.1 *Continuous Real Time Monitoring*

Pollutants for continuous monitoring include CO_2, TVOC, PM2.5, and ozone. These pollutants should be monitored continuously in all regularly occupiable areas of the building. Regularly occupiable areas may be defined as spaces intended for human occupancy within commercial buildings, excluding areas like the pantry, toilets and store rooms. When determining compliance, missing measurements and data loss will be interpreted as a threshold/range exceedance for that period.

9.2.1.1 *Sampling frequency*

For continuous monitoring of temperature, relative humidity, CO_2, TVOC, PM2.5 and O3, the sampling frequency should be at least once every 5 minutes. Monitoring of these parameters should be done on a 24 h basis to establish a trend. This provides insights into indoor air quality, leading to possible actions for improvement. PM1.0 (particulate matter $\leq$ 1.0 µm) is increasingly recognized for its potential health impacts and may also be considered for monitoring as an emerging best practice.

9.2.1.2 *Deployment of sensors/monitoring devices*

Deployment refers to the position and the number of sensors/monitoring devices installed in the indoor space. Ideally, the sensors/monitoring devices should be installed in the breathing zone. The breathing zone is defined as that region of the indoor space between the horizontal planes at 1.1 m and 1.7 m height above the finished floor level. Sensors/monitoring devices may be installed under the ceiling if the ceiling height is restricted to 2.13 m. In such cases, it is necessary to ensure that the air distribution in the room is uniform so that the air parameters at the ceiling will be similar to those in the breathing zone. Sensors/monitoring devices should be installed at least 0.9 m from exits, window openings and air conditioning vents. Every enclosed place, such as cabins or meeting rooms occupied for an average of 50 percent of the daily working hours, shall have dedicated monitoring devices. General office and common areas shall have at least one device for every 450 m^2 floor area.

9.2.1.3 *Calibration of sensors*

All sensors and pumps used in the monitoring devices shall be calibrated to ensure that the accuracy levels are maintained as specified by the manufacturer and to identify any measurement errors. Calibration should cover the parametric range the sensors are expected to experience in real service. Sensors measuring PM2.5 and TVOC values should be recalibrated or replaced annually. CO_2 sensors utilising the automatic baseline correction method shall be recalibrated or replaced once every three years. Sensors measuring thermal comfort parameters shall be recalibrated or replaced once every three years. Field calibrations using a reference sensor are acceptable, provided the master sensor is similar in range, accuracy, least count and resolution to the sensor being calibrated. Moreover, the calibration procedure should be such that the master sensor will perform within the manufacturer's specified range and accuracy. The master sensor should have been calibrated at a laboratory. The calibration process shall capture a sufficient range and contaminant concentration using known span gases or exposure to ambient pollution to perform adjustments accurately. The calibration activity should be properly documented, and traceability certificates shall be provided wherever applicable. Appropriate calibrations of PM1.0 sensors may be done if provided.

9.2.1.4 *Display of IAQ data*

All IAQ parameters, under the purview of continuous monitoring, should be prominently displayed in a format that provides easy viewing and understanding to all occupants of the building. Having at least one common electronic data display on each floor/section showing the real-time snapshot of all the devices on that particular floor/section is recommended. Alternatively, there could be one common display at the main entrance that provides a real-time representation of the IAQ data for the entire building.

9.2.1.5 *Recommended sensor specifications for continuous monitoring*

The selection of the sensors is a crucial requirement for obtaining reliable and accurate measurements. Improper sensor selection will lead to erroneous data on IAQ. The Table 22 provides details about the type of sensor to be used and their recommended range, accuracy, and resolution to capture meaningful IAQ data.

Table 22 Required Range and Accuracy of Sensors Used for Continuous Monitoring

(*Clause* 9.2.1.5)

Sl No. (1)	Parameters (2)	Unit (3)	Range (4)	Accuracy (5)	Resolution (6)
i)	PM10	µg/m³	0 µg/m³ to 1 000 µg/m³	± 10 percent of reading	1 µg/m³
ii)	PM2.5	µg/m³	0 µg/m³ to 1 000 µg/m³	± 10 percent of reading	1 µg/m³
iii)	CO_2	ppm	400 ppm to 5 000 ppm	± 50 ppm or ± 5 percent of reading (whichever is greater)	1 ppm
iv)	TVOCs	ppb	0 ppm to 5 000 ppb	± 20 ppb or ± 15 percent of reading (whichever is greater)	1 ppb
v)	Temperature	°C	0 °C to 100 °C	± 1 °C	0.1 °C
vi)	Relative humidity	percent	5 percent to 95 percent	± 5 percent of reading	1 percent
vii)	Ozone	ppb	20 ppb to 500 ppb	± 10 ppb at 0-100 ppb	5 ppb

9.2.2 *Periodic Monitoring/Testing*

Periodic monitoring refers to measuring pollutants at a reasonably low frequency, typically several months apart. Pollutants for periodic monitoring include CO, SOx, NOx and HCHO. Sampling locations for periodic monitoring shall be representative of occupied spaces and should be located in the breathing zone as defined in **9.2.1.2**. Testing should be carried out under regular building conditions. Any test conducted without occupants or when the occupancy is considerably lower than on regular days shall be avoided.

9.2.2.1 *Sampling Frequency during periodic monitoring/testing*

Based on the pollutant's characteristics, the constraints in their monitoring technology, and their occurrence indoors, some pollutants are assessed periodically. The periodicity of such tests may be defined as "at least once every six months" (may be considered by NABL Labs). Building operators may resort to a more frequent periodicity if the test results warrant the same.

9.2.2.2 *Procedure for periodic monitoring/testing*

a) HCHO — The test shall be in accordance with best practices1). The sampling duration should be a minimum of one continuous hour or the equivalent duration of the sampling procedure special publication2) may be referred.

b) CO — The sampling shall be carried out for at least one continuous hour (10 minutes of acclimation followed by 50 minutes of measurement time), with measurements recorded at least once every minute. Recommended procedures are the special publications3) may be referred. (CO by gas bag sampling).

c) NOx — NOx is measured gravimetrically using the modified Jacob and Hochheiser method and the chemiluminescence test. The monitoring of NOx shall be carried out in accordance with best practices4).

d) SOx — SOx shall be monitored gravimetrically using the improved West and Gaeke method and Ultraviolet Fluorescence in accordance with best practices5).

1) best practices maybe ISO 16000-3 for HCHO.

2) Special publication maybe ISO16000-3 for sampling procedure in case of HCHO.

3)Special publication for recommended procedures for CO maybe NIOSH Manual of Analytical Methods (NMAM), Fifth Edition,1997, OSHA Methods ID 209: 1993 (CO by direct-reading monitor) and OSHA Methods ID 210: 1991.

4) best practices maybe ISO 16000-15 for NOx.

5) best practices maybe ISO 16000-1 for SOx.

9.2.2.3 *Recommended sensor specifications for periodic monitoring/testing*

During periodic monitoring/testing, appropriate measuring instrument shall be used to obtain reliable and accurate measurements. The following Table 23 provides details about the type of instrument to be used and their recommended range, accuracy, and resolution to obtain factual test results.

Table 23 Sensor Specifications for Periodic Monitoring/Testing

(*Clause* 9.2.2.3)

Sl No. (1)	Parameters (2)	Unit (3)	Range (4)	Accuracy (5)	Resolution (6)
i)	CO	ppm	0.1 to 25	± 3 percent or ± 1 ppm (whichever is greater)	0.1 ppm
ii)	NOx	ppb	0 to 500	± 20 ppb or ± 15 percent of reading (whichever is greater)	1 ppb

Table 23 (*Concluded*)

Sl No. (1)	Parameters (2)	Unit (3)	Range (4)	Accuracy (5)	Resolution (6)
iii)	SOx	ppb	0 to 500	± 5 percent of reading	1 ppb
iv)	Formaldehyde	ppb	20 to 1 000	± 20 ppb	1 ppb

9.3 Air Filters for Removing Pollutants in Indoor Spaces

Air filters shall be used in HVAC systems to remove airborne pollutants from indoor air and prevent outdoor pollutants from entering the building through outdoor air intakes.

The filters shall be as per accepted standards [D-3(15)], [D-3(16)], [D-3(17)] and [D-3(18)] for classification and performance requirements may be referred.

9.3.1 *Classification of Air Filters*

Air filters are classified mainly based on their ability to filter out pollutants. Due to the differences in the methods for determining this ability, air filters shall be classified in multiple ways. Air filters are classified based on their gravimetric efficiency, particulate matter efficiency or fractional particle size efficiency.

9.3.1.1 *Classification of air filters*

The accepted standard [D-3(15)] shall be adopted to classify air filters based on particulate matter efficiency. This method of specifying the performance of air filters applies to fine filters. It is a preferred method of classification while specifying air filters for general human health and wellness applications (comfort applications), as particulate matter concentrations inside buildings directly correlate with the adverse health effects on the occupants. The test method mentioned in the standard determines the initial efficiency of the air filter in both the "as-manufactured" condition and the discharged condition to calculate the minimum and average particulate matter efficiency. The filter class is reported as ISO ePMx (y percent), where x is the particle size referred to (1 µm, 2.5 µm or 10 µm) and y is the particulate matter efficiency. Classification of air filters based on particulate matter efficiency as per accepted standard [D-3(15)] is given Table 24.

NOTE — The symbol ePMx describes the efficiency of an air cleaning device to particles with an optical diameter between 0.3 µm and x µm.

Table 24 Classification of Air Filters based on Particulate Matter Efficiency

(*Clause* 9.3.1.1)

Sl No. (1)	Group Designation (2)	Requirement $ePM_{1,\,min}$ (3)	Requirement $ePM_{2.5,\,min}$ (4)	Requirement $ePM_{10,\,min}$ (5)	Class Reporting Value (6)
i)	ISO Coarse	NA	NA	< 50 percent	Initial gravimetric arrestance
ii)	ISO *e*PM10	NA	NA	≥ 50 percent	ePM_{10}
iii)	ISO *e*PM2.5	NA	≥ 50 percent	NA	$ePM_{2.5}$
iv)	ISO *e*PM1	≥ 50 percent	NA	NA	ePM_1

9.3.2 *Resistance to Airflow in Air Filters*

The resistance to airflow is measured as the differential pressure across the air filter in a test setup. The resistance vs airflow rate characteristics are established at 25 percent, 50 percent, 75 percent, 100 percent and 125 percent of the rated flow of the air filter. Procedures mentioned in accepted standard [D-3(17)] shall be followed to determine the same. The resistance as a function of airflow rate provides useful information on the selection and performance of an air filter.

9.3.3 *Air Filters Using Electrostatically Charged Fibrous Media*

Some air filters use fibrous media that carries an electrostatic charge. The charge helps in improving the filtration efficiency of smaller particles. This will help achieve higher filtering capabilities at a lower initial resistance for a given airflow rate, thereby reducing operating costs. However, should the charge be compromised for any reason, the filtering capability of these air filters will be drastically reduced. Hence, when electrostatically charged fibrous media air filters are used, it is recommended that suitable monitoring systems be used for measuring the indoor particle concentrations so that any reduction in the filtering capability of the air filter shall be noticed and suitable actions shall be taken.

9.3.4 *High-Efficiency Filters*

High-efficiency filters shall be used in critical industrial, scientific and research applications that demand stringent control of airborne solid and liquid phase pollutants. They are classified based on their filtration efficiency at most penetrating particle size (MPPS). The MPPS is defined as the particle size of the challenge aerosol that will offer the lowest efficiency when challenged onto an air filter. The accepted standard [D-3(19)] shall be used to classify high-efficiency filters. This standard classifies high-efficiency filters based on their overall efficiency and local efficiency (leak scan test). (*see* Table 25)

Table 25 Classification of High-Efficiency Air Filters

(*Clause* 9.3.4)

Sl No. (1)	Filter class (2)	Overall Efficiency at MPPS percent (3)	Local Efficiency at MPPS percent (4)
i)	ISO 15 E	≥ 95	NA
ii)	ISO 20 E	≥ 99	NA
iii)	ISO 25 E	≥ 99.5	NA
iv)	ISO 30 E	≥ 99.90	NA
v)	ISO 35 H	≥ 99.95	≥ 99.75
vi)	ISO 40 H	≥ 99.99	≥ 99.95
vii)	ISO 45 H	≥ 99.995	≥ 99.975
viii)	ISO 50 U	≥ 99.999	≥ 99.995
ix)	ISO 55 U	≥ 99.999 5	≥ 99.997 5
x)	ISO 60 U	≥ 99.999 9	≥ 99.999 5
xi)	ISO 65 U	≥ 99.999 95	≥ 99.999 75
xii)	ISO 70 U	≥ 99.999 99	≥ 99.999 9
xiii)	ISO 75 U	≥ 99.999 995	≥ 99.999 9

9.3.5 *Air Filters for Removing Airborne Molecular Contamination*

A gaseous state pollutant in the air is called an airborne molecular contamination. Many gas phase pollutants are detected in the indoor air of buildings, and they shall be broadly classified as acid gases, base gases, aldehydes, oxidising gases, VOCs and other miscellaneous gases. Adsorption and chemisorption filters are used in HVAC systems and outdoor air intakes to remove these pollutants (for example H_2S, NH_3, HCHO, O_3, VOCs, NOx, SOx, Cl_2, CO etc.) from indoor air. These filters use adsorbents, known as molecular sieves, to remove the pollutants from the air stream through physical adsorption. Activated carbon, activated alumina and zeolites are the commonly used adsorbents. Additionally, the adsorbents are impregnated with suitable chemicals that react with the adsorbed pollutant to prevent their desorption. This process is called chemisorption. Molecular sieves are available as granules, pellets, and powders coated on fibrous media; hence, they shall be constructed as packed bed filters and extended surface pleated filters. For additional information special publications may be referred to assess the performance of these air filters.

NOTE — Special publications maybe ISO 10121-2 : 2013 and ISO 10121-3 : 2022.

The fundamental criteria for air filter selection is based on its:

a) filtration efficiency at the particle size range of interest;

b) gravimetric, particulate matter, or fractional particle size efficiencies;

c) resistance the air filter offers at its rated airflow; and

d) test dust capacity.

9.3.6 *Installation of Air Filters in HVAC Systems*

Most air filter installations in HVAC systems comprise of multiple air filters in a single system. The installation of air filters is vital since improper installation could lead to filter bypass, compromising the overall filtration system's efficiency even though the individual air filters may be good. Proper mounting arrangements and usage of gaskets to avoid filter bypass for ensuring the proper installation of an air filter.

9.3.7 *Field Testing of Air Filters*

Since the test results from standard laboratory tests shall vary from performance results in real service, conducting a filtration performance test in situ under real service conditions will help understand the actual performance. For *in-situ* testing purpose special publications may be referred, which provides the method for *in-situ* field testing of air filters and systems, shall be adopted.

NOTE — Special publication maybe ISO 29462 : 2022.

9.4 Alternate Air Cleaning Technologies

To ensure the indoor concentration of these pollutants within the safe levels as mentioned in **3.6.2**. The following text provides functional principle and instructions for use of various types of air cleaning technologies.

9.4.1 *Electrostatic Precipitators*

Electrostatic precipitators (ESP) use the principle of electrostatic attraction to trap particles. They are commonly used in industrial applications with high particle concentrations where mechanical (fibrous media extended surface) air filters may not be practical. ESPs have been used in comfort HVAC/AHU applications to reduce indoor PM2.5 concentration. ESPs also efficiently remove oil mist, such as in kitchen smoke and certain other industrial applications.

Ionization of the air stream may lead to ozone generation. When using ESPs, it shall be ensured that the ozone concentration in occupied spaces does not exceed the values mentioned in **3.6.3**. To ensure this, it is recommended to use suitable "ozone removal/reduction" technologies as a part of the system. ESPs shall be designed with safety interlocks to avoid electrical shocks and to stop the power module in case of less airflow.

The pressure loss of the electrostatic precipitator is very low and stays nearly constant. However, the filtration efficiency decreases as the collection plates accumulate with particles. Hence, the ionization and collection sections need to be cleaned regularly. ESPs are preferably located upstream of AHU cooling coils.

9.4.2 *Ultraviolet Germicidal Irradiation*

Ultraviolet germicidal irradiation (UVGI) systems in buildings shall be installed inside air handling units (AHUs) or air ducts. Additionally, they shall be installed as upper-zone UVGI systems (UZ-UVGI). The upper zone units have uniquely designed baffles that irradiate the upper zone of the room towards the ceiling. A gentle air movement in the room makes the upper zone unit more effective. For UZ-UVGI systems, the UV equipment/lamp shall be out of the line of sight for the occupants from all parts of the room. To meet the safe exposure limit of 60 J/m^2 for an 8-hour exposure period, the UV radiation intensity at the occupied zone shall be less than 0.002 W/m^2.

The use of UVGI for the heat transfer coils of air conditioning equipment is found to be very effective in eliminating biofilm build-up on coils and condensate drain pans, thereby improving heat transfer efficiency and hygiene inside air conditioning equipment.

Direct and visual contact of humans with UVGI systems shall be avoided. Service personnel shall wear the required safety goggles and aprons while attending to any service issue in AHU fitted with UVGI systems. The HVAC equipment fitted with UVGI shall have visible stickers on the equipment mentioning 'UVGI installed inside'.

> NOTE — The degradation of materials used in HVAC equipment like AHUs due to UV exposure is another important aspect to consider when installing UVGI systems. Material compatibility with UVGI shall be assessed during design or subsequent retrofits.

9.4.3 *Photocatalytic Oxidation*

Photocatalytic oxidation (PCO) is a light-mediated redox (oxidation and reduction) reaction of gases and biological matter. This is achieved by impinging ultraviolet rays on a catalyst material and giving out hydroxyl radicals and super oxides, commonly referred to as reactive oxidative species (ROS).

9.4.4 *Photo-Hydro Ionization*

Photo-hydro ionization (PHI) is a light-mediated active air cleaning method similar to PCO. Removes bioaerosols (bacteria, viruses, fungi, etc), VOCs, formaldehyde and certain odour-causing chemicals from the air.

9.4.5 *Air Ionizers*

The use of air ionizers helps easier removal of particles by agglomeration.

9.4.6 *Plasma Air Ionization*

Ions are formed as air passes over the ionization tubes. Pollutants, including bioaerosols coming in contact with the ions, are oxidized and destroyed. Additionally, the generated ions encourage the agglomeration of particles, allowing them to be more easily removed through gravitational settlement and by the air filtration systems.

10 OTHER COMPONENTS OF CENTRAL HVAC SYSTEM

These components are required for the efficient functioning and regulation of heating, ventilation, and air conditioning in a centralized system.

10.1 Cooling Tower

Cooling towers are used to dissipate heat from water cooled refrigeration, air conditioning and industrial process systems to the atmosphere. Cooling is achieved by evaporating a small proportion of the recirculating water to the atmosphere. Cooling towers shall be installed at a place where free flow of atmospheric air is available.

Range of a cooling tower is defined as temperature difference between the entering and leaving water. Approach of the cooling tower is the difference between leaving water temperature and the ambient air wet-bulb temperature.

10.1.1 *Selection of Cooling Tower*

Following factors shall be considered for selection of cooling tower:

a) recirculating water flow rate;

b) design wet-bulb temperature;

c) approach, the designer shall endeavour for reducing the approach for maximizing energy conservation in the chiller;

d) range;

e) water quality and;

f) outside air quality for cooling tower;

g) height limitation and aesthetic requirement;

h) location of cooling tower considering possibility of easy drain back from the system;

j) placement with regard to adjacent walls, windows and other buildings, and effects on these from any water carried over by the air stream, also known as drift;

k) sound levels, particularly during silent hours;

m) material of construction of the tower; particularly considering the nature/quality of ambient air and recirculating water;

n) direction and flow of prevailing wind; to minimise recirculation and interference; and

p) quality of water used for make-up; maintenance and service space availability.

10.1.2 *Selection Criteria*

These factors ensure the optimal performance, efficiency, and suitability of cooling towers for specific HVAC system requirements.

10.1.2.1 *Location of the cooling tower*

Location of cooling tower shall be determined by one or more of the following:

a) architectural compatibility;

b) rigging limitations;

c) structural support requirements;

d) cost of bringing auxiliary services to the cooling tower; and

e) noise transmission, plume, and drift considerations.

These are best handled by proper site selection during the planning stage. Cooling tower shall be installed raised above the mounting surface by 0.45 m to 1.25 m to permit installation of pot strainer in condenser water line from cooling tower sump; also, to provide easy drainage and maintenance of mounting surface as follows:

1) Cooling tower accessories shall be project-specific and shall include such items as walking platform; stairs and ladder safety cage; bird screen; tower loading and supporting structure; and variable speed drive fan motor. However, variable speed drives should be used only in very specific instances as allowing the cooling tower fan to run at full speed during periods of low load is generally more beneficial due to the lower water temperature achieved by the cooling tower that results in higher condenser efficiency and, hence, lower power consumption in the air-conditioning plant.

2) Cooling tower installation shall include installation of conductivity controller, flow meter on the makeup water line, overflow alarm and low-level alarm.

3) The recommended floor area requirement for various types of cooling tower is as given below:

   Mechanical draft cooling tower : 0.014 to 0.28 m^2/kW (0.05 to 0.10 m^2/TR)

   NOTE — The recommended floor area above does not include the area required around the tower for unobstructed air flow.

4) Structural provision for the cooling tower shall be taken into account while designing the building. Vibration isolation shall be an important consideration in structural design.

5) Special care should be taken in design where noise transmitted to the adjoining building shall be of serious concern. Special vibration control and sound attenuation devices may be required in that case. Appropriate sound insulation and noise control measures shall be taken in such cases in accordance with Part D 'Building Services, Section 4 Acoustics, Sound Insulation and Noise Control' of this NBCS.

10.1.2.2 *Water quality*

Water is commonly used as a heat transfer medium to remove heat from the refrigerant vapour in the condenser. A cooling tower is used to dissipate the heat from the air-conditioning system to atmosphere. A cooling tower shall cool condenser water to within 2 °C to 3 °C of the ambient wet-bulb temperature, with modern cooling towers even achieving approach as low as 1 °C. Therefore, a water-cooled system operates at a condenser temperature that could be more than 20 °C in a corresponding air-cooled system, resulting in considerably improved efficiency and significantly reduced energy consumption.

Where make-up water is expensive, or not available at all or in limited quantities only, the use of an adiabatic cooler should be considered. An adiabatic cooler allows the use of water-cooled air-conditioning plant with water consumption 70 percent to 90 percent lower than that of a conventional cooling tower.

Certain amount of water is lost from circulating water in the cooling tower, as given below:

a) *Evaporation loss* — It is approximately 1 percent of the rate of water circulation per 6 °C of range.

b) *Drift loss* — The drift loss shall be below 0.1 percent of the rate of water circulation.

c) *Blow-down/bleed-off* — The amount of blow-down shall be below 0.8 percent of the total water circulation. If simple blow-down is inadequate to control scale formation, chemicals may be added to inhibit corrosion and limit microbiological growth.

Provision shall be made to make-up for the loss of circulating water. Provision for make-up water tank to the cooling tower shall be made. Make-up water tank to the cooling tower shall be separate from the tank serving drinking water. Makeup water should be sourced from treated water from sewage treatment, wastewater treatment plant, or from rain water harvesting.

Make-up water having contaminants or hardness, which shall adversely affect the refrigeration plant life, shall be treated. Treated water where hardness as ppm of $CaCO_3$ is reduced to 50 ppm or below is recommended for air conditioning applications. Water with pH value less than 5 shall also need to be treated. For treatment of water for cooling towers good practice [D-3(20)] shall be referred.

Cooling tower should be so located as to eliminate nuisance from drift to adjoining structures. Cooling tower approach and minimum efficiency shall be as per Table 26.

Table 26 Cooling Tower Approach and Minimum Efficiency

(*Clause* 10.1.2.2)

Sl No. (1)	**Building** (2)	**Chiller** kWr (3)	**HWT** ºC (4)	**CWT** ºC (5)	**WBT** ºC (6)	**Efficiency** kW/LPS (7)
i)	All others	Any	36.4	30.8	28.3	0.35
ii)	24 × 7 facilities	Any	35.6	30.0	28.3	0.35

10.1.2.3 *Installation of cooling tower*

The cooling tower shall be mounted on a set of four or six numbers of reinforced cement concrete pillars (structural foundation) as per manufacturer's recommendations. Height of these pillars shall be not less than 1 m, actual height is decided at site as per space required to install a pot strainer below the water level in cooling tower sump, drain pipe and valve for complete drainage of sump, and to permit maintenance of slab upon which structural foundation is installed.

Cooling tower should be located at a well-ventilated place, preferably on the terrace of the building, in consultation with the structural consultant. Dynamic structural loading on the terrace shall be considered. Cooling tower shall be installed in such a way that its dynamic load is transferred directly to the building structural columns, for which necessary mild steel I-section may have to be provided. Anticorrosive coating such as epoxy coating shall be applied required for these mild steel I-sections. Suitable thickness of vibration isolation pads shall be placed between the tower and the I-sections to avoid transfer of vibration to building structure. Sufficient space shall be left all around the cooling tower support structure for efficient operation of the cooling tower.

When cooling tower is installed at ground level, contiguous to the utility services block, great care has to be exercised to prevent users and visitors from coming in close proximity to the cooling tower. This is necessary to avoid their exposure to legionellae bacteria which shall hibernate in the cooling tower sump, if operator does not follow strict instructions for regular bleed-off and chemical treatment of condenser water.

Also, the bleed-off tap should be given in the return line to cooling tower, instead of only providing in the sump to ensure the desired water quality.

10.1.2.4 *Safety aspects* (*while designing tower installation*)

a) Access to and from maintenance access doors, top of tower access platform with handrail system should be provided;

b) Ladders (either portable or permanent) to gain access to the discharge level or maintenance access doors should be provided;

c) Surrounding area should be clear;

d) Provision for lockout of mechanical equipment should be provided;

e) Safety cages around ladders should be provided;

f) Cooling tower shall be with appropriate electrical earthing;

g) Motor terminals shall be provided with appropriate enclosure for appropriate ingress protection; and

h) Bird cages shall be provided from all sides to prevent birds entering into the cooling tower.

10.1.2.5 *Testing of cooling tower*

Upon completion of installation, the cooling tower shall be tested for performance. The entering and leaving water temperatures, the entering air wet-bulb temperature, and the flow rate of water through the condenser water circuit shall be measured. The fan power consumption shall be checked from measurements at the fan motor. The tower capability shall then be calculated using the measured values and the manufacturer's performance curves given with the technical submittal of the cooling tower and shall not be less than 95 percent.

10.1.2.6 *Critical parameters for cooling tower*

For cooling tower system following are the critical parameters:

a) Water flow rate;

b) Water temperature:

   1) *Inlet temperature* — Measures the temperature of the water entering the tower; and

    2) *Outlet temperature* — Measures the temperature of the water leaving the tower.

c) Cooling range measures the difference between inlet and outlet water temperatures;

d) Wet-bulb approach measures the difference between the outlet water temperature and the ambient wet-bulb temperature;

e) Fan power consumption monitors the energy used by the fan;

f) Water level;

g) *p*H level;

h) Conductivity/Total dissolved solids(TDS); and

j) Drift rate.

10.1.2.7 *Water quality management in HVAC system*

The objective of cooling water treatment is to:

a) increase production;

b) reduce downtime;

c) lower operating and chemical costs; and

d) reduce your operation's impact on the planet

Treatment of cooling water will be different depending upon the kind of system in use. Here are the basic types:

1) Once-through;

2) Open recirculating;

3) Closed recirculating; and

4) Specialized.

NOTE — A specialized cooling system might utilize compression or absorption-type refrigeration or air conditioning systems or it might include the use of industrial air washers in which air is filtered, sprayed and then forced through a series of mist eliminators.

Water quality is crucial in HVAC systems to prevent scaling, corrosion, and microbiological growth, which shall lead to reduced efficiency, equipment damage, and health risks.

Water treatment should be considered to prevent scaling, corrosion, and biological fouling of the condenser and circulating system.

Large system shall be provided with fixed continuous-feeding chemical treatment system in which chemicals, including acids for *p*H control, are diluted, blended and pumped into the condenser water system.

Corrosion-resistant materials should be required for the treatment of system components that come in contact with these chemicals. In piping system design, provision for feeding the chemicals, blow down, drain, and on-line testing should be included.

Treatment system design should incorporate mainstream filtration without separate pumping system.

Additionally, side stream filtration incorporation in the system design should be considered especially when the primary make-up water is from an un-clarified water source (bore well-tanker water, STP effluent etc) that is high in suspended solids and/or iron.

10.1.2.8 *Recommended methods to control scale formation*

a) *Elimination at source* — Limit the concentration of scale-forming minerals by controlling cycles of concentration, or by removing the minerals before they enter the system;

b) *Monitoring cycle of concentration* — The ratio of makeup water rate to the sum of blow down and drift rate. The cycle of concentration shall be monitored by calculating the ratio of chloride ion, which is highly soluble in the system water, to that in the makeup water;

c) Mechanical changes in the system, like increasing water flow and providing exchanger with larger surface area, to reduce the chances of scale formation;

d) Feed acid to keep the common scale forming minerals, like, calcium carbonate, in dissolved state. Organic acid based specialty chemical formulations (*p*H reducers) are best suited for *p*H reduction in cooling water systems in terms of reducing the risk of acid induced corrosion; and

e) Treat with chemicals designed to prevent scale. (for example, scale inhibitors, dispersants and crystal modifiers).

For treatment of water for cooling towers, good practice [D-3(20)] shall be referred.

10.2 Closed-Loop Water System Treatment

Cooling and heating systems harness the power of water and refrigerant to transfer heat. Open circuits use cooling towers, while closed loops enclose water in pipes, cooling it through tubes and refrigerant, ensuring efficient temperature control in three precise steps.

Closed-loop systems have a reduced chance of contamination, but they are not maintenance free. Neglecting maintenance of a closed system promotes the growth of sludge and deposits. The most common problem with these systems is black magnetic iron oxide mud deposits. Over time, magnetic iron oxide particles bind together and collect on narrowed parts of the system. The most common place for this sludge is narrowed pipes, heat-transfer surfaces, cooling or heating coils and AHU and fan coils

The *p*H level of the water drops leads to bacterial growth or a system leak. Bacteria shall lead to pinhole leaks in the pipes, which shall affect both the water levels and chemistry. In addition to leaks, bacteria or mineral deposits shall reduce the ability of the system to transfer heat by coating the surfaces of the parts. Regular care of your components through water testing and chemical maintenance prevents the corrosion of the interior components of the system. In the closed system, effect of corrosion shall not be diagnosed.

While open systems need monitoring of water levels and watching for particulate matter from the environment in the water, closed circuit systems need control of the water's chemistry.

10.2.1 *Chemical Treatment of Closed Loop Systems*

To prevent corrosion in carbon steel components, the water shall maintain a high, or alkaline, *p*H. To keep the correct chemical balance, water treatment professionals have several options at their disposal:

a) *Polymers* — Prevent corrosion and scale by dispersing harmful components in water, without environmental impact;

b) *Corrosion inhibitors* — Form a protective film on system surfaces, reducing corrosion, buffering *p*H, and reacting with oxygen; and

c) *Biocides* — Eliminate bacteria, preventing organic growth, biofilms, and Legionella bacteria, which shall contribute to corrosion.

10.3 Chilled and Condenser Water Pumps

Radial flow centrifugal pumps are recommended for use in HVAC systems for circulation or transfer of water or water/glycol solutions. Direct coupled pump assembly and inline pump should be used for smaller flow applications. Higher flow rate requiring motor size above 7.5 kW, pumps shall be coupled with high efficiency (IE3 and above) motors. Mono-block pumps shall be used up to 7.5 kW.

The split case horizontal pump shall be used in larger applications. Pumps shall be provided with the tapping on bearing housing for mounting of Vibration and temperature sensors, which shall be used for condition monitoring. For these pumps minimum IE3 (high efficiency class) motors are recommended.

Cavitation shall be avoided by selecting suitable location of pump with respect to the cooling tower, so as to always meet the net positive suction head (NPSH) requirement of condenser water pump.

10.3.1 *Selection Criteria and Types of Pumping System*

Pump shall be selected for optimized efficiency over the load profile, to operate at or near the best efficiency point (BEP) not more than 5 percent from the maximum efficiency curve to achieve energy efficiency. Pump shall be selected for optimized efficiency over the load profile, to operate at or near the best efficiency point (BEP) not more than 5 percent from the maximum efficiency curve to achieve energy efficiency. Wherever there is variable speed application, the pumps shall be with motor mounted VFDs or integrated drives with inbuilt intelligent IOT controls. IoT based controls shall have pump predictive analysis function with alert mechanism through SMS/email for various operational parameters.

Pump motor shall be energy efficient, having minimum IE3 (high efficiency class) motors, totally enclosed, fan-cooled, Class-F insulation and suitable for operation on AFD. Motor shall be specially designed for quiet operation. The motor rating shall be such as to ensure non overloading of the motor throughout its capacity range. Motor shall be suitable for 3-phase 415 percent + 10 percent volts, variable frequency power supply.

For water pumps, available net positive suction head (NPSH) shall exceed required NPSH to avoid pump cavitation.

The possible types of chilled water recirculation pumps are as given below:

a) Constant speed pumping system;

b) Variable speed pumping system (VSPS):

    1) Parallel VSPS configuration;

    2) Zoned VSPS configuration; and

    3) Primary secondary tertiary pumping system (P-S-T).

c) Primary only variable speed pumping system (PVF).

In order to improve energy efficiency of larger systems, where pumping energy amounts to 5 percent to 9 percent of total energy consumption in a building, glass flake coatings for large size pumps may be considered, based on life cycle cost assessment as it reduces friction improves and sustain efficiency.

Chilled water circulation system having pump motor larger than 3.7 kW rating are generally designed for variable fluid flow to offer large savings in operating cost.

10.3.2 *Installation of Pump*

The vertical in-line pumps do not require concrete pump foundation as they are of pipe mounted design. They become integral part of the piping system when installed as per manufacturer's instructions. Installation of efficient suction guide and triple duty valves shall also eliminate many piping accessories, resulting smaller installed footprint, as well as lowest embodied and life cycle carbon.

The horizontal base mounted pump base frame shall be mounted on concrete block which in turn shall be mounted on machinery isolation cork or any other equivalent isolation material. More than one pump set shall not be installed on a single base or on a single cement concrete block. Foundation bolts are required, shall be embedded correctly. Before the bolts are grouted and the coupling bolted, the base frame level shall be checked before proceeding with work.

The pump motor shall then be mounted on base frame, alignment checked and shall then be connected to the pump with flexible coupling and with guard, both for the condenser and chilled water pumps.

The insulation for chilled water pump shall be carried out in a manner so that it allows maintenance of the pump without causing damage to the insulation. After installation of the complete system and before testing, the pump shall be lubricated in strict accordance with the manufacturer's instructions.

10.3.3 *Testing of Pump*

Upon completion of installation, capacity of the pump shall be checked by measuring water flow, using the balancing valve in fully open position, motor current and pressure differential between the inlet and outlet. The readings shall be compared with actual performance identified in the technical submittal of the pump.

10.3.4 *Critical Parameters for Pumping System*

a) Pumps for condenser/chilled water:

   1) Water flow rate as established from pump curves based on suction/discharge pressure;

   2) *Head pressure* — Measures the pressure generated by the pump;

   3) *Current and power consumption* — Monitors the current drawn and energy used by the pump;

   4) *Vibration* — Tracks the mechanical vibration of the pump;

   5) *Temperature* — Monitors the pump's and motor's operating temperature;

   6) *Discharge pressure* — Measures the pressure at the pump outlet;

   7) *Suction pressure* — Measures the pressure at the pump inlet; and

   8) *Efficiency* — Calculates the pump's efficiency based on flow rate and power consumption.

10.4 Air Handling Unit (AHU)

All-air system is commonly used for comfort, healthcare, pharma, process applications. The provisions do not apply to AHUs used for data-center application.

10.4.1 *Selection Criteria*

The designer shall select the air handling unit on the basis of supply air temperature and volume; outdoor air requirement; desired space pressure; heating and cooling coil capacity; humidification and dehumidification capacity; return, relief, and exhaust air volume requirement; filtration levels, and the corresponding pressure capability of the fan(s). Controls may be added as required for project specific requirements.

Air handling unit shall be as per accepted standard [D-3(21)] of AHU. It should be verified or certified for the compliance of the standard through an third part certifying agencies for compliance as per the accepted standard [D-3(21)]. Selection criteria should include the sound levels of the AHU like casing radiated, supply and return to help acoustic engineers.

10.4.2 *Fan*

Fan selection should be based on efficiency and sound power level throughout the anticipated range of operation, as well as on the ability of the fan to provide the required flow at the anticipated static pressure.

Fans used in AHUs, with motor power exceeding 0.37 kW shall be of minimum mechanical efficiency and minimum fan motors efficiency requirements as specified in below table or as per ESCBC whichever is stringent:

System Type	*Fan Type*	*Mechanical Efficiency*	*Motor Efficiency* {*As per* [D-3(22)]}
(1)	(2)	(3)	(4)
Air- Handling unit	Supply, return and Exhaust	65 percent	IE3 and above

In addition, all fans used in AHUs having shaft power 2.5 kW or higher shall meet or exceed the FEI requirements of > 1.1.

a) Fan speed modulation control should be considered to save energy using duct static pressure signal; and

b) The power consumed by the AHU to be declared in the selection output and that should be part of the critical parameter for validation and measurement.

10.4.3 *Cooling Coil*

Cooling coil shall be designed as per the sensible and latent load. Number of rows of coils shall be determined as per the dehumidification requirements. Provisions shall be made to modulate the chilled water flow rate in the cooling coil for achieving high energy efficiency.

10.4.4 *Reheat Coil*

Reheat coil is heating coil placed downstream of a cooling coil. Reheat system is strongly discouraged, unless recovered thermal energy is used. Reheat coil is used to provide precise humidity control, which is generally not required for comfort conditions in most applications. Either reheat or desiccant is usually required to dehumidify outdoor air.

Reheating is necessary for specific applications like, laboratory, health care, or similar applications where temperature and relative humidity shall be controlled accurately. Hot-water coil, which provides a very controllable source of reheat energy, and thereby accurate relative humidity control is the preferred option for reheat coil. Condenser water recirculation through reheat coils may be considered for energy saving.

10.4.5 *Humidifier*

Humidifier shall be installed as part of the air handling unit only where close humidity control of selected spaces is required. For comfort installations requiring humidity control, moisture shall be added to the air by mechanical atomizer or point-of-use electric or ultrasonic humidifier placed in the conditioned area.

10.4.6 *Air to Air Energy Recovery Devices*

All hospitality and healthcare occupancies with energy recovery systems shall have air-to-air heat recovery equipment with minimum 60 percent recovery effectiveness at design conditions.

To prevent the wheel media from transferring exhaust air to the supply air duct, the heat wheel shall be fitted with an adjustable purging sector, with adjustable angle provision. The center of the wheel media shall consist of a hub with a shaft and bearings with efficient seal provided in the clearance between the rotor and the casing to minimize leakage between the supply air and exhaust air. Recommended higher face velocity limit is 3.5 m/s.

The outdoor air correction factor (OACF) and exhaust air transfer ratio (EATR) have direct impact on the energy consumption of the fans. The OACF should be in the range of 0.9 to 1. The EATR > 5 percent should not be acceptable.

10.4.7 *Fan Coil Unit* (*FCU*)

FCU shall be in accordance with accepted standard [D-3(21)].

10.4.8 *Air Filters*

Air filters used in AHUs shall be in accordance with accepted standards [D-3(15)], [D-3(16)], [D-3(17)] and [D-3(18)]. It is recommended to use ISO ePM1 50 percent in combination with ISO coarse and ISO ePM1 80 percent as second stage, for comfort applications (apart from critical applications like healthcare and cleanroom etc).

AHU filters shall be tested for filter bypass leakage in accordance with the accepted standard [D-3(21)].

10.4.9 *Vibration Isolation*

Where floor mounted fans are used, the AHU shall have an internal vibration isolation system by mounting fan, motor and drive assembly on suitable deflection type anti-vibration mountings as well the fan discharge shall be connected to the AHU casing through canvas connection to prevent vibration transfer.

10.4.10 *Dampers*

The exhaust air damper/s shall not allow inflow of outdoor air under any circumstances. Dampers should be modulated via an automated control system.

10.5 Installation of Air Handling Unit (AHU)

Following provisions to be considered of installation of air handling units:

a) Floor mounted air handling unit is generally installed on a set of precast PCC blocks to raise it off the mounting surface to permit easy drainage of the AHU drain pan and cleaning of the mounting surface. A set of 4 or 6 numbers of 0.20 m × 0.20 m × 0.20 m blocks are generally used for AHUs up to capacity of 10 000 m^3/h airflow, and 6 or more 0.30 m × 0.30 m × 0.30 m blocks for higher capacity AHU;

b) Floor trap shall be provided in the AHU room for disposal of condensate which accumulates in the drain pan during operation of AHU. AHU room floor should slope in the direction of floor trap to avoid the accumulation of water in AHU room. The condensate drain piping shall be connected with U-trap of the floor drain to avoid odour carry over with the return air;

c) AHU location shall be marked on the AHU floor as per approved shop drawings/manufacturer's details. Co-ordination with contractors for civil works and other services shall be checked prior to installation;

d) Easy accesses and sufficient clearance shall be ensured for servicing and maintenance, that is, for cleaning of filters, maintenance of strainer/valve packages, tightening of fan belts, and repair as well as possible replacement of fan motor;

e) Duct flexible connection made of fire-proof material, shall be fixed on air outlet of the AHU, and if possible, also in perpendicular direction in main ducts within AHU room, to avoid vibration transmission along the ducts beyond the AHU room;

f) The valve package and piping connections shall be completed as per approved shop drawings;

g) Installation of ceiling suspended air handling unit shall be done with rod and fasteners as per the procedure stated above, barring the PCC blocks required for floor mounted AHU, and that insulated condensate drain pipe shall be laid in slope within ceiling space terminating into the U-trap of the nearest floor drain; and

h) Since the AHUs have the tendency to vibrate, both floor mounted and ceiling suspended AHUs shall be isolated from the structure by suitable rubber or spring-based isolators.

10.5.1 *Installation of Air Washer Unit (AWU)* – Air washer unit (AWU) components are similar to those of AHU, except for water spray section with in-line recirculation pump, which replaces the cooling coil. Installation of AWU shall follow the same steps as described above for AHU. Ceiling suspended AWU should be avoided.

10.6 Thermal Insulation

10.6.1 Air conditioning and water distribution systems, carrying chilled or heated fluids/air shall be thermally insulated to prevent undue heat gain or loss and to prevent internal and external condensation. Vapour seal shall be provided on chilled water pipes to avoid possibility of condensation.

10.6.2 The thermal insulation material shall be selected based on following physical characteristics:

a) *Fire properties* — Insulating materials shall be fire resistant and, in case of fire, shall not produce noxious smoke and toxic fumes;

b) Materials and their finishes should inherently prohibit rotting, mould and fungal growth, attack by vermin, and should be non-hygroscopic;

c) Material should not give rise to objectionable odour at the temperature at which they are to be used;

d) It should not cause a known hazard to health during application, while in use, or on removal, either from particulate matter or from toxic fumes;

e) It should have a low thermal conductivity throughout the entire working temperature range;

f) It should have good mechanical strength and rigidity, otherwise it should be cladded for protection; and

g) The insulation material selected should be non-hygroscopic and naturally resist the ingress of water vapour without any vapour barriers.

10.6.3 *Material*

Selection of material shall be as per design requirement, such as, closed cell flexible elastomeric foams, expanded/extruded polystyrene (EPS/XPS) and phenolic foam. Insulation should be flexible in natural to ease of handling, should be able to take contours of the surface on which it is installed, and thickness of insulation should be calculated for each project. For additional information special publication may be referred. The fire rating of insulation material for Class 0 for fire propagation test and Class 1 for surface spread of flame test may be referred from special publication for additional information.

NOTE — Special publication maybe DIN EN 12667 and EN ISO 8497 for testing thermal conductivity, EN 13501 and BS 476 Part 6 : 1989 for fire rating Class 0 for fire propagation test and BS 476 Part 7, 1987 for fire rating Class 1 for surface spread of flame test.

Insulation should possess the self-extinguishing property and it should not drip or spread the flames. Insulation should have zero ozone depletion potential, zero global warming potential, dust and fibre free. Insulation should have good resistance to ozone, oil and chemical. Insulation material should be compatible to various covering options like metal, polymeric, glass cloth, silver polymeric laminate etc.

The guidelines for insulating with fibre glass are given below; for other insulation materials, manufacturers' recommendations for installation should be followed.

10.6.4 *Thermal Insulation of Duct*

Insulation material for ducts shall be anti-microbial to ensure the indoor air quality. For microbiological growth on insulation surface and bacterial resistance special publications may be referred.

NOTE — Special publications maybe ASTM G-21 for Microbiological growth and ASTM 2180 or EN ISO 846 Method A and Method C for bacterial resistance.

The insulation materials shall be phenolic foam {as per accepted standard [D-3(23)]} closed cell flexible elastomeric foam/ fibre glass based. The insulation materials should be non-hydroscopic. PUF/Polyurethane shall not be used.

Elastomeric foam tubes, due to its vulnerability to fire, should be used only with full protection fire against with full cladding to smaller size pipes, and not on ducts.

The thermal insulation material should be wrapped around the duct with facing on outer side. Joints of insulation should be properly sealed with either same type of material or tape of 50 mm width on all longitudinal/transverse joints. Finally, straps should be fixed at suitable interval to ensure that the insulation is properly fixed with the ducts. Thermal insulation of the ducts, surface of duct, on which the external thermal insulation is to be provided, shall be thoroughly cleaned with wire brush and rendered free from all dust and grease. Then, one coat of cold-setting adhesive, should be applied over the duct surface and one coat of adhesive to be applied on insulation.

The facing of the insulation should be determined based on the site conditions. Facings can be plain, alufoil, polymer based, Glass cloth, PVC based or non-metallic composite cladding in case of flexible elastomeric foams depending on application area. In case of fiber glass insulation, metal claddings after wrapping polyethylene as vapor barrier is to be used to prevent fiber migration and also regulate the water vapor ingress. Fiber Glass with only alufoil should not be used due to vulnerability of foil which is very thin and can be damaged during installation causing water vapor ingress and increased thermal conductivity over time.

The thermal insulation material should be installed around the duct with facing on outer side. Joints of insulation should be properly sealed with either same type of material or tape of 50 mm width on all longitudinal/transverse joints. Finally, PVC straps should be fixed at suitable interval to ensure that the insulation is properly fixed with the ducts in case of fiber glass insulation is being used.

10.6.5 *Acoustic Lining of Duct*

Acoustic lining of duct should be carried out as follows:

a) The inside surface of duct on which the acoustic lining is to be provided should be thoroughly cleaned with wire brush and rendered free from all dust and grease;

b) The materials to be used for duct lining should be 25 mm thick resin bonded fiberglass having density of 48 kg/m^3. Open cell flexible elastomeric foam having density of minimum 140 kg/m^3 specially formulated only for sound attenuation not for inside duct surfaces, due to its poor fire and smoke emission risks;

c) The insulation should be fixed inside the duct using suitable adhesive and covered with fibre glass tissue paper. Open cell flexible elastomeric Foam should be installed with eco-friendly low VOC adhesive elastomeric foam should pass the tests (for test procedure special publications may be referred) for 50 kW/m^2 exposure;

   NOTE — Special publications may be ISO 5659-2.

d) The plain insulation materials used should have an air erosion test certified so as no particles/fibres are dislodged with high velocity air and mix with conditioned air compromising indoor air quality. Materials used should have antimicrobial properties;

e) The insulation should then be covered with 0.5 mm thick perforated aluminium sheet with at least 20 percent to 40 percent perforation;

f) The insulation and aluminium sheet should be secured with cadmium coated bolts, nuts and cup washers/steel screws;

g) Finally, the ends should be sealed completely, so that no lining material is exposed; and

h) The lining of initial length of the duct may have to be done as per the requirement at site.

10.6.6 *Acoustic Lining in Equipment Room*

Acoustic treatment in equipment room to prevent noise transmission to adjacent occupied areas should be provided on the walls and ceiling of equipment room with acoustic lining of thermal insulation material. Acoustic lining shall be provided with performance levels adequate to achieve effective sound absorption and sound insulation, ensuring compliance with the acoustic comfort and noise control requirements of the space.

Acoustic lining of equipment may be carried out as follows:

a) A 610 mm × 610 mm frame work of 25 mm × 50 mm × 25 mm or 50 mm × 50 mm × 50 mm ‘U’ shape channel, for 25 mm for open cell flexible elastomeric foam or and 50 mm thick fiber glass acoustic lining respectively, made of 0.6 mm thick galvanized steel sheet may be fixed on to walls leaving 610 mm gap above floor (to prevent damage from flooding) by means of rawl plug in walls. Similar frame work may also be fixed on ceiling by means of dash fasteners;

b) Resin bonded glass wool/ Open Cell Elastomeric foam as specified, cut to size may be fitted in the frame work and covered with fibre glass tissue paper;

c) Surfaces may be finished by covering with 0.5 mm thick perforated aluminium sheet having perforation 20 to 40 percent with brass screws;

d) All horizontal and vertical joints may be covered with at least 25 mm wide, 1 mm aluminium strips held in position by steel or brass screws; and

e) For, Open Cell Elastomeric Foams, metal frame work is not required. 1m x 1m sheets of insulation to be directly applied to wall with suitable adhesive and finally two galvanized stainless steel metal strips of 0.6mm to be fixed in diagonally crossing each other with fasteners.

10.6.7 *Insulation of CHW/HW Refrigerant Pipes*

Pipe insulation Standard material should be EPS/XPS/PUF/closed cell flexible elastomeric foam/fibre glass as per requirement, specified with suitable density and thickness. Adhesive used for setting the insulation should be non-flammable, vapour proof, cold-setting, eco-friendly compound.

The insulation should then be finished as per the specific requirement of the site, as given below:

a) *Inside the building* — Insulation over the pipe work exposed in the building should be finished with specified thickness of aluminium sheet cladding, over a vapour barrier, with 50 mm overlap and tied down with lacing wire. For flexible elastomeric foams, suitable covering for mechanical protection can be used;

b) *Outside the building* — Insulation over the pipe work exposed to weather should be finished with vapour barrier, and 12 mm thick cement-sand plaster in two layers of 6mm thick each, followed by curing of minimum 48 h. For flexible elastomeric foams, suitable covering for mechanical protection can be used for UV resistance as per specialist literature;

NOTE — Specialist literature maybe DIN EN 4892-2 Method A artificial weathering test.

c) *Buried pipe insulation* — For pipes outside the building and laid underground, the insulation should be covered with suitable gauge polythene faced hessian, (the polythene facing outward), with 50 mm overlap. All joints should be sealed with bitumen. A layer of maximum 0.50 mm × 20 mm GI wire mesh netting should be provided over it butting all joint, and it should be laced down with GI wire. A 20 mm thick cement-sand plaster (1 : 4) should be provided in 2 layers of 10 mm thickness each and should be waterproofed by applying hot bitumen and fixing tar-felt over the plaster. It should be finally finished with a coat of hot bitumen;

d) *Pump insulation* — Chilled water pump should be insulated to the same thickness as the pipe to which they are connected, and application should be same as above. Care should be taken to apply insulation in a manner as to allow the dismantling of pumps without damaging the insulation;

e) *Insulation of valves and fittings in chilled water line* — All valves, fittings, strainers, etc, should be insulated to the same thickness and in the same manner as for the respective piping, taking care to allow operation of valves without damaging the insulation; and

f) The thermal insulation of VRF system should be flexible elastomeric rubber insulations with UV resistance.

10.7 Thermal Energy Storage for Demand Management

Thermal storage may be used for limiting maximum demand, by controlling peak electricity load through reduction of chiller capacity, and by taking advantage of high system efficiency during low ambient conditions. Thermal storage will also help in reducing operating cost by using differential time-of-the day power tariff, where applicable. TES system may be designed in accordance with specialist literature.

NOTE — Specialist literature maybe API-650/AWWA D-100.

TES systems should be carefully designed and installed, considering factors like:

a) *Location* — Central plant TES location shall be determined in consultation with the air conditioning engineer, ensuring optimal performance and efficiency;

b) *Structural Integrity* — Adequate structural provisions to accommodate TES system loads, open-area surface installations shall consider vertical system options, complete with approach ladders for manholes etc;.

c) *Buried Installations* — Designs shall account for vehicular loads and movements above the installation area. The tanks may be rectangular or Circular with RCC construction; and

d) *Insulation* — To meet the thermal performance specifications, the tank to be provided with adequate insulation and cladding.

Thermal storage tank should be technically evaluated for tank material selection, insulation, and sizing, as well as the selection of suitable thermal energy storage media like water, ice, or phase-change materials. System design and controls should also be optimized, including charging and discharging strategies, temperature control, and integration with building management systems. TES systems should be designed with scalability and flexibility, allowing for modular expansion and integration with various HVAC systems.

10.8 Thermal Energy Storage for Critical Facilities

During power outage, chilled water to be made available for the duration the DG set starts and chillers ramp up. TES tanks are to be installed in line with the chillers, so that chilled water flows through the TES tanks then to the load, this to ensure that the tanks are always in charged condition.

TES tanks to be pressurized cylindrical vertical, all welded CS vessels with upper and lower ellipsoidal dish heads. For designing, manufacturing, certification and testing of tanks special publications maybe referred.

NOTE — Special publication may be ASME Section VIII Div.1.

Pressure vessels TES tanks to be fitted with radial disk diffusers to maintain stratification of water to ensure that the chilled water is delivered at the designed temperature and duration.

Designing of TES system and radial disk diffusers may be referred from special publications.

NOTE — Special publication may be ASHRAE Handbook, HVAC Systems and Equipment, Chapter 51.

Pressure vessels to be adequately insulated to meet the thermal performance specifications. Insulation to be protected with cladding.

System controls should also be optimized for charging and discharging strategies, temperature monitoring, and integration with building management systems.

11 HEATING

The efficiency of a heating equipment shall never be more than 100 percent, while a refrigeration system for heating usage shall have the coefficient of performance (COP) than its cooling mode.

Heating Systems are mainly used for hot water generation and space heating for comfort applications and also for Industrial use. The various applications where heating shall be effectively used are:

a) sanitary hot water generation for residential, commercial and hospitality industry;

b) space heating for residential, commercial and industrial sector in winters/as required depending on location and climatic conditions; and

c) hot water generation for industrial requirements.

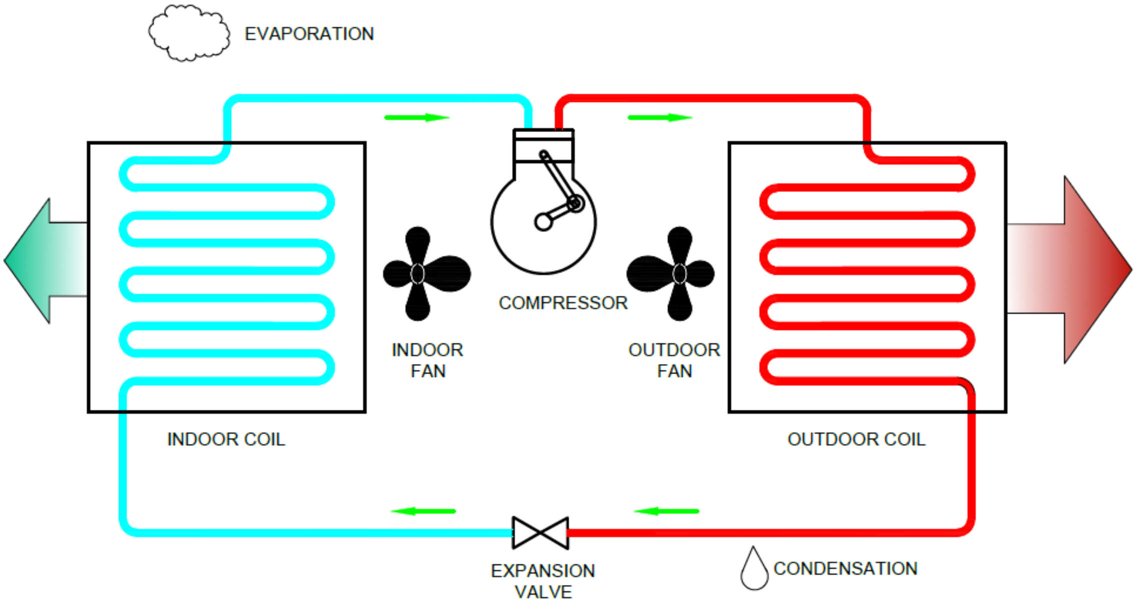
11.1 Various Heating Equipment/Systems

Various heating equipment/systems are described under 11.1.1 to 11.1.7. These heating equipment/systems shall be used for the building space and water heating applications based on their effectiveness, efficiency, and life cycle cost and installation process.

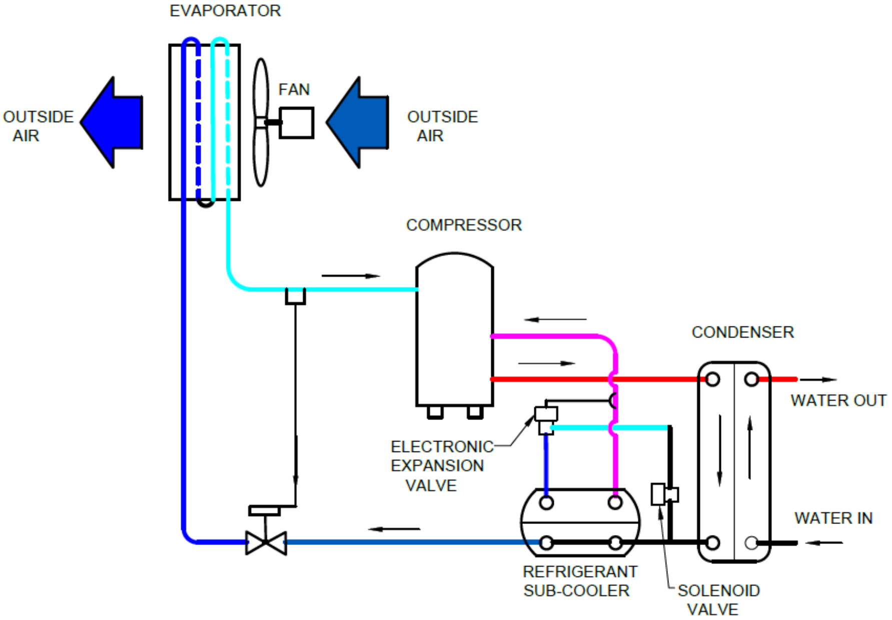
11.1.1 *Heat Pump – Air to Water and Air to Air and Water to Water Type*

There are two types of air source heat pumps. It extracts heat from the air and then transfers heat to either the inside or outside depending on the season is called air to air heat pump. The air-to-air heat pump shall be as per accepted standard [D-3(6)], [D-3(24)] or [D-3(25)] based on its capacity and type (*see* Fig. 3). The air to water heat pump shall be as per best practices given special publications. Water to water heat pump shall be as per standard [D-3(24)] (*see* Fig. 4).

NOTE — Special publication may be ISO 21978.


EVAPORATION
COMPRESSOR
INDOOR FAN
OUTDOOR FAN
INDOOR COIL
OUTDOOR COIL
EXPANSION VALVE
CONDENSATION

3A AIR -TO - AIR HEAT PUMP


EVAPORATOR
OUTSIDE AIR
FAN
OUTSIDE AIR
COMPRESSOR
CONDENSER
WATER OUT
ELECTRONIC EXPANSION VALVE
WATER IN
REFRIGERANT SUB-COOLER
SOLENOID VALVE

3B AIR -TO - WATER HEAT PUMP

FIG. 3 AIR TO AIR AND AIR TO WATER HEAT PUMP

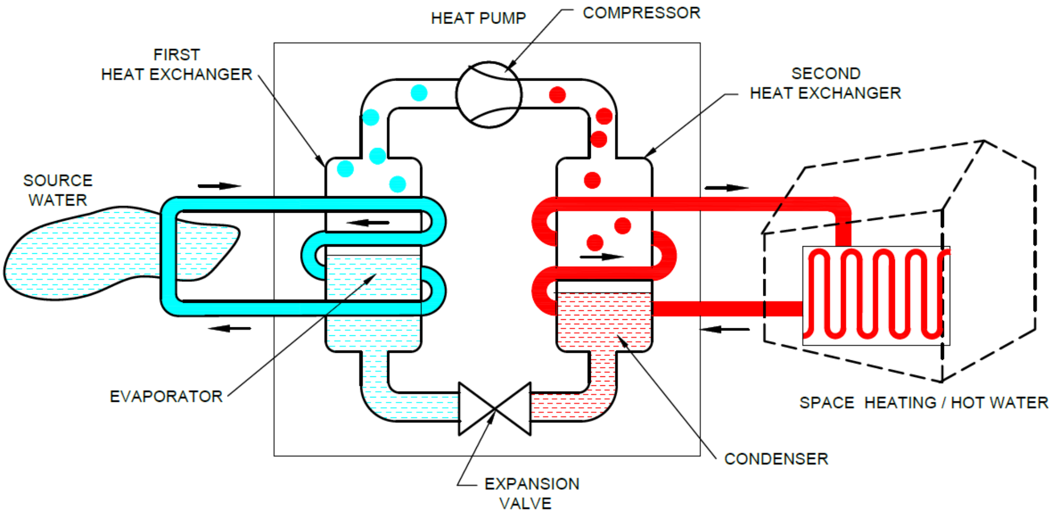

HEAT PUMP
COMPRESSOR
FIRST HEAT EXCHANGER
SECOND HEAT EXCHANGER
SOURCE WATER
EVAPORATOR
SPACE HEATING / HOT WATER
CONDENSER
EXPANSION VALVE

FIG. 4 WATER TO WATER HEAT PUMP

11.1.2 *Heat Pump – Ground Source*

Ground source heat pump uses the earth, or ground water, or both as the source of heat in the winter, and as the sink for heat removed from the conditioned areas in the summer. Heat is removed from the earth by using groundwater or an antifreeze solution; the liquid's temperature is raised by the heat pump; and the heat is transferred to indoor air. For year-round air conditioning, the process is reversed during summer months, heat is taken from indoor air and transferred to the earth, by the ground water. Fig. 5 illustrates the schematic of ground source heat pump. This shall be effectively used in locations having low temperature also.

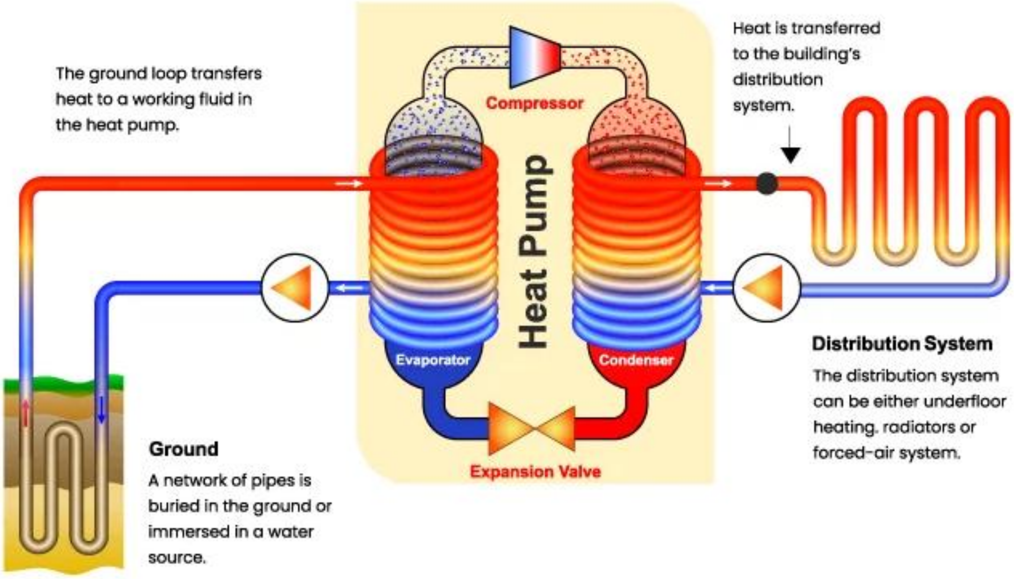

The ground loop transfers heat to a working fluid in the heat pump.
Compressor
Heat Pump
Heat is transferred to the building's distribution system.
Evaporator
Condenser
Expansion Valve
Distribution System
The distribution system can be either underfloor heating, radiators or forced-air system.
Ground
A network of pipes is buried in the ground or immersed in a water source.

FIG. 5 GROUND SOURCE HEAT PUMP

11.1.3 *Reverse Cycle Systems*

Air conditioner window and split type, VRF system and DX package units, these systems are available with reverse cycle operation mode which shall supply cold air for cooling in summer and hot air for heating in winter. The performance of window air conditioners shall be as per accepted standard [D-3(4)], the split air conditioners shall be as per accepted standard [D-3(6)], the ducted split air conditioners shall be as per accepted standard [D-3(25)]. The variable refrigerant flow systems shall be as per accepted standard [D-3(26)] and chillers shall be as per accepted standard [D-3(24)]. The following Fig. 6 shows the reversible heat pump both in heating and cooling mode of operation.

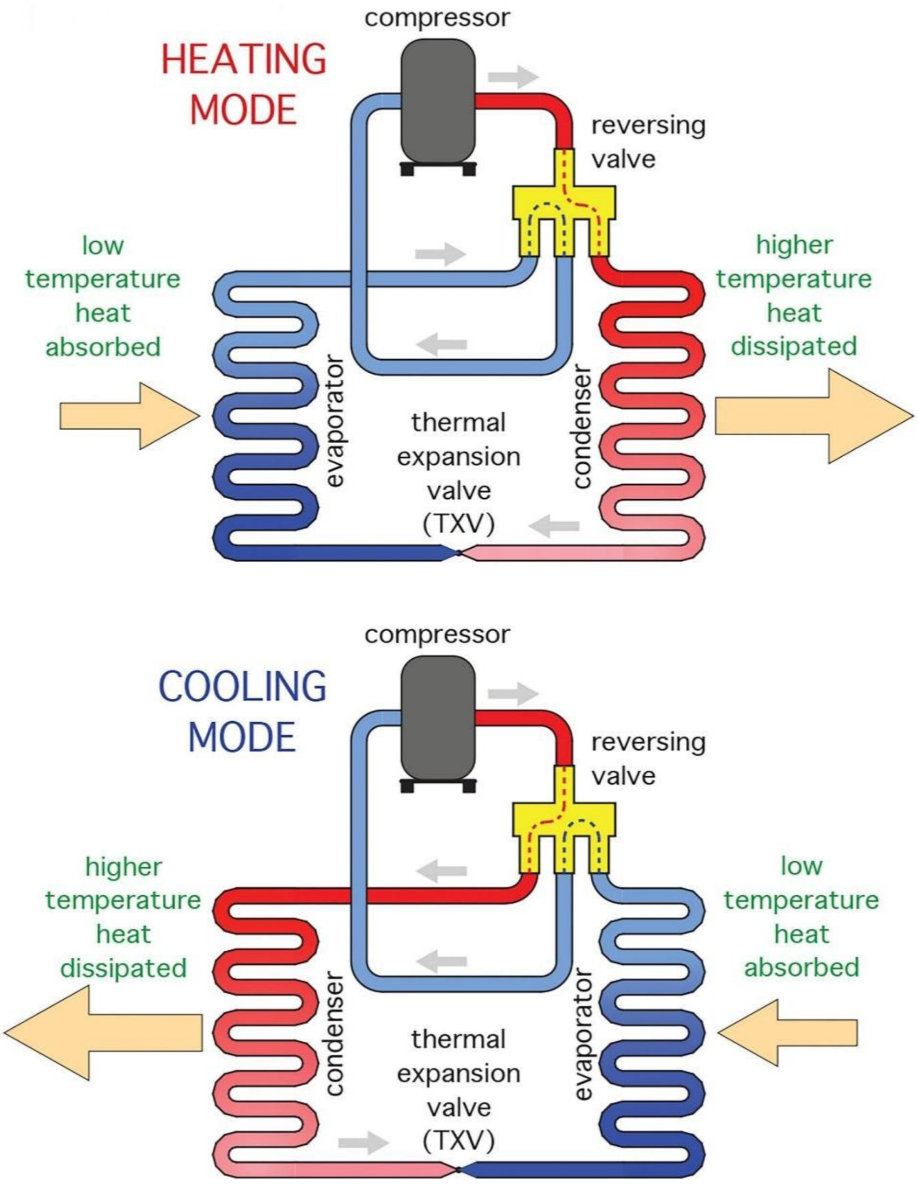

HEATING MODE
compressor
reversing valve
low temperature heat absorbed
higher temperature heat dissipated
evaporator
thermal expansion valve (TXV)
condenser
COOLING MODE
compressor
reversing valve
higher temperature heat dissipated
low temperature heat absorbed
condenser
thermal expansion valve (TXV)
evaporator

FIG. 6 REVERSIBLE HEAT PUMP

11.1.4 *Solar Water Heating* (*SWH*) *System*

SWH system converts energy content of solar radiation into heat energy for water heating using a solar thermal collector. In a close-coupled SWH system, the hot water storage tank is horizontally mounted immediately above the solar collectors on the roof. No pumping is required as the hot water naturally rises into the tank through thermal siphon flow. In a pump circulated system, the storage tank is ground or floor mounted and is below the level of the collectors; a circulating pump moves water or heat transfer fluid between the tank and the collectors.

SWH systems are designed to deliver hot water for most times of the year. However, in winter/monsoon, sometimes there may not be sufficient solar heat gain to deliver sufficient hot water. Therefore, alternative back up system is recommended to be used to meet hot water requirements.

Residential solar thermal installations fall into two groups; passive systems (sometimes called compact) and active systems (sometimes called pumped). Both typically include an auxiliary energy source (electric heating element or gas connection for the hot water storage tank, or fuel oil fired central heating system or heat pump) which is activated when the water in the tank falls below a minimum temperature setting such as 55 °C. However, it is recommended to use heat pump in active as well as passive systems to reduce carbon footprint and protect environment hence, hot water is always available. The combination of solar water heating and using the back-up heat from heat pump to heat water shall enable a hot water system to work all year round in cooler climates.

The amount of heat delivered by a solar water heating system depends primarily on the amount of heat delivered by the sun at a particular place, that is, the insolation. In tropical places, the insolation shall be relatively high, for example, 7 kWh/m^2 per day, whereas the insolation shall be much lower in temperate areas where the days are shorter in winter, for example, 3.2 kWh/m^2 per day. Even at the same latitude the average insolation shall vary a great deal from location to location due to differences in local weather patterns and the amount of overcast. The design, installation and performance evaluation of solar heating systems shall be in accordance with the good practice.

11.1.5 *Condenser Heat Recovery System*

Condenser heat recovery system captures energy that would otherwise be wasted in the atmosphere and converts this energy into useful heat. It is possible to capture this heat from the condenser and use it to generate hot water. By capturing this heat, overall system efficiency is considerably improved. Such a system should be used, wherever there is heating requirement concurrent with cooling demand. In a well-designed system this improves the performance of the cooling or refrigeration

11.1.6 *Solar Air Heating (SAH) System*

SAH system converts energy content of solar radiation into heat energy for air heating using a solar thermal collector. SAH systems shall be once through or of recirculating type. In the once through system fresh outdoor air is heated to a higher temperature of around 60 °C to 65 °C and supplied indoors through insulated ducting. This air mixes with the conditioned space air to maintain the indoor at a comfortable temperature typically between 18 °C to 22 °C. In the recirculating type, the conditioned space air is recirculated through the roof or wall integrated solar air heaters. In this case the air delivery temperatures shall be moderate at around 30 °C to 45 °C. Electric fans or blowers are used to enable circulation of the air. Solar air heaters shall offer solar collector efficiency in the range of 50 percent to 80 percent. Reversible air-to-air heat pumps powered with grid electricity shall be used as backup.

11.1.7 *Electric Heating*

Electric heating system are highly energy consuming and should be applied to specific application where other efficient Heating system shall not be applied due to technical/ location constraints. With all electric heating, care should be taken to preclude the risk of fire under abnormal conditions of operation, by the use of a suitably positioned temperature sensitive trip of the manual reset type, to cut off the electric supply in case of temperature rise beyond the specified limit.

It is recommended to avoid electrical heating to maximum extent possible for the building space or water heating applications.

12 BUILDING TYPOLOGY RELATED CONSIDERATIONS

The general guidance, for various selected building typologies, for the factors that usually influence the selection of the type, design and layout of the air conditioning or ventilating system, to be used are given in this section. The primary objective of these is to define the special provisions required for the air conditioning system, to ensure comfort conditions or defined conditions as the case may be for occupants in the respective applications.

These are the following typical building typologies normally envisaged in construction for different applications based on the usage factors:

a) Residential buildings;

b) Office buildings;

c) Campus buildings;

d) Hospitality buildings;

e) Healthcare buildings;

f) Underground metro stations;

g) Airport buildings;

h) Shopping complex buildings;

j) Industrial buildings; and

k) Tall buildings.

The following criteria shall be common to most of the building typologies:

1) *Building Layout and Orientation* — North-south orientation is often preferred to minimize direct sun exposure. The building orientation to be optimized to reduce heat gain. The design floor plans shall facilitate natural ventilation, air circulation and daylighting avoiding deep floor plans that limit these measures in case of naturally ventilated buildings.

2) *General Considerations* — Buildings may include both the outer and inner zones. The outer zone may be considered as extending from approximately 4 m to 6 m inwards from the outer wall of the building and is generally subjected to wide load variation owing to daily and annual changes in outside temperature and solar radiation. Ideally, the system(s) selected to serve an outer zone should be able to provide summer cooling and winter heating. During intermediate seasons, the outer zone of one side of the building may require cooling and at the same time, the outer zone on another side of the building may require heating. The main factors affecting load are usually window area and choice of shading devices.

   The other important factors are the internal gain owing to people, light, and other equipment loads. The choice of system may be affected by requirements to counteract down-draughts and chilling effects due to radiation associated with single glazing during winter. Cooling load for the inner zone is generally entirely from the heat gain from people, lights, and equipment, which is generally uniform throughout the year.

   Other important considerations in building applications may include requirements for individual room control, partitioning flexibility serving multiple tenants or residents, and the requirement of operating selected areas outside of normal working hours.

3) *Building Envelope* — The building envelope shall be designed to minimize energy use. Materials with low thermal transmittance (U-value) for walls, roofs, and selection of glass following a detailed study of solar heat gain coefficient (SHGC), U-value and visible light transmittance (VLT) shall be selected. For additional information on high-efficiency insulation materials, special publication may be referred.

   NOTE — Special Publication may be Energy Conservation and Sustainability Building Code (ECSBC) 2024

4) *Ventilation* — Minimum outdoor airflow rate based on occupancy and area requirements shall be provided as detailed in **3**. Comprehensive mechanical ventilation system with usage of energy/heat recovery system and CO_2 monitoring and control system to adjust airflow following indoor air quality norms shall be utilised. Also refer to **5.2.5** of Part D 'Building Services, Section 1 Lighting and Natural Ventilation' of this NBCS.

5) *Indoor Air Quality* (*IAQ*) *and Thermal Comfort* — For threshold values related to indoor air quality and requirements for thermal comfort, article on 'Basis of Design' to be referred.

12.1 Residential Building Typology

This classification helps in understanding the different types of residential buildings based on their design, usage, and structure.

12.1.1 *Room-Specific Design*

a) *Bedrooms* — Quiet AC operation and individual temperature control for better thermal comfort shall be ensured. Outdoor unit of the air-conditioner shall not be installed towards the room/living spaces/balconies. Hot air of the outdoor unit shall be directed toward open spaces/ambient.

b) *Living rooms* — Design of AC in living room shall be appropriate considering peak occupancy. For better thermal comfort and energy savings, AC and ceiling fan both shall be installed in living room.

c) *Kitchens* — Ventilation hoods to remove excess heat and gaseous contaminants shall be installed.

12.1.2 *Insulation and Thermal Mass*

a) *Insulation* — High-quality insulation in walls, roofs, and floors to reduce cooling loads shall be entertained.

b) *Thermal mass* — Materials with high thermal mass (for example brick) to stabilize indoor temperatures shall bring in better energy efficiency.

12.1.3 *Window Design and Shading*

a) *Glazing* — Glazing in residential houses refers to the installation of glass in windows, doors, skylights, and other transparent or translucent building components. The choice of glazing impacts energy efficiency, aesthetics, security, and comfort. Glass preferably of lower SHGC based on climatic zone shall be selected. Ratio of VLT/SHGC shall be more.

b) *Shading devices* — Install external permanent/movable shading devices (for example, shade, awnings, louvers) to block direct sunlight. Consider the use of trees and vegetation for natural shading. For large dwelling/projects, optimising shading shall lead to reduced cost and more benefits. Facade shall be designed with specific shading devices/solutions.

c) *Window placement* — Strategically placement of windows to maximize natural light while minimizing heat gain shall be encouraged.

12.1.4 *Ventilation*

a) *Natural ventilation* — Cross-ventilation by aligning windows and openings to allow air to flow through the building shall be envisaged. For a building to be naturally ventilated, it shall have operable windows that occupants shall adjust to maintain their thermal comfort. These windows may include dynamic components like louvers to regulate the amount of air exchange. Open door/window and operation of exhaust fan to ventilate during night, to cool the spaces and remove the heat that traps during daytime shall be worked out.

b) *Mechanical ventilation* — Mechanical ventilation systems shall be designed to complement AC systems, providing fresh air without compromising energy efficiency.

12.1.5 *Sustainability Measures*

a) *Passive cooling* — Passive cooling strategies such as orientation, providing buffer spaces, thermal chimneys, evaporative cooling, and night purging to reduce reliance on AC shall be included in the design.

b) *Landscaping* — Strategic landscaping (for example, planting trees, creating windbreaks) to naturally cool the building and reduce AC load shall be used.

12.1.6 *Cultural and Climatic Adaptations*

a) *Regional design adaptations* — Building design shall adapt to local climatic conditions, such as high humidity areas requiring enhanced dehumidification.

b) *Cultural preferences* — Cultural preferences in building layout and AC usage, such as preferred room temperatures and ventilation styles shall be investigated and included during design.

12.1.7 *Adaptive Reuse and Retrofitting*

a) *Historic buildings* — When retrofitting historic buildings, the preservation of architectural features with the integration of modern AC systems shall be balanced.

b) *Older homes* — Upgrading insulation, windows, and ductwork to improve the efficiency of new AC systems shall be envisaged.

12.2 Office Building Typology

Important considerations in office building applications may include requirements for individual room control, partitioning flexibility serving multiple tenants, and the requirement of operating selected areas outside of normal office hours. Areas such as conference rooms, board rooms, shall teens, etc., will often require independent systems.

12.2.1 *Specific Guidelines for Large/Small Office Buildings*

a) *Centralized HVAC systems* — Centralized HVAC systems shall be specifically considered for their high efficiency and flexibility in handling variable loads. Centralized systems shall provide cooling and heating based on the specific needs of different zones, enhancing overall energy efficiency;

b) *Demand-controlled ventilation (DCV)* — Implementing demand controlled ventilation (DCV) should be considered to optimize ventilation rates based on real-time occupancy and indoor air quality. This shall reduce energy consumption while maintaining a comfortable environment;

c) *Indoor air quality monitoring (IAQ)* — IAQ sensors shall be considered to continuously monitor and maintain optimal indoor air quality levels. These sensors shall measure parameters such as CO_2 levels, humidity, and volatile organic compounds (VOCs), there by maintaining and monitoring to ensure a healthy indoor environment;

d) *Air purification technologies* — Advanced air purification technologies such as UV-C light/bipolar ionization/other passive air purification methods should be used to reduce airborne contaminants of their levels exceed the threshold values given in **3.6.2**. These technologies shall be particularly beneficial in reducing the spread of airborne diseases and improving overall air quality;

e) *Predictive maintenance* — Predictive maintenance using IoT and smart sensors should be considered. This approach shall identify potential issues before they lead to system failures, reducing downtime and maintenance costs;

f) *Enhanced humidity control* — Desiccant dehumidification systems should manage high humidity levels, particularly in areas with high latent gains. Proper humidity control for maintaining comfort and improving indoor air quality;

g) *Energy recovery ventilation* (*ERV*) — ERV systems to improve indoor air quality inclusion shall enhance energy efficiency by recovering energy from exhaust air. ERVs shall significantly reduce the load on heating and cooling systems by pre-conditioning incoming fresh air. For additional information, special publication may be referred for the Energy recovery system;

NOTE — Special publication maybe ISO 16494.

h) *Advanced zoning strategies* — Implementing advanced zoning strategies for large office spaces should be considered by dividing office spaces into detailed zones based on occupancy and usage patterns and use of automated systems to adjust HVAC settings dynamically in different zones shall lead to energy efficiency to systems;

j) *Building management systems (BMS) and IoT integration* — HVAC systems should be integrated with building management systems (BMS) for centralized control and monitoring and utilizing IoT devices to enable real-time data collection and automated adjustments, shall optimize energy efficiency and system performance;

k) *Noise reduction measures* — Advanced soundproofing materials and design techniques to minimize the operating noise levels of HVAC equipment and further ensuring low noise levels enhances occupant comfort, especially in open office environments. Noise control measures shall be as per Part D 'Building services, Section 4 Acoustics, Sound Insulation and Noise control' of this NBCS; and

m) *Green building practices* — Green building practices such as incorporating renewable energy sources (for example, solar panels) to power HVAC systems and using sustainable building materials should be considered. This aligns with global trends towards environmental responsibility and sustainability.

12.3 Campus Building Typology

The provisions related to HVAC requirements for a large campus (facility consisting of multiple single or multi-use buildings or structures within a premise), including residential and (or) non-residential educational institutions, IT/ITES parks are covered. The design and implementation of heating, ventilation, and air conditioning (HVAC) systems for campus projects shall meet several key requirements to ensure efficient, effective, and sustainable operation.

12.3.1 *General Requirements*

These guidelines help in categorizing and designing buildings within a campus based on their function, layout, and structural needs.

a) *Scalability and flexibility* — The system design shall allow for future expansion as well as varying nature of usage of spaces by designing modular components for easy upgrades to ensure flexibility to adapt;

b) *Energy efficiency* — Central HVAC systems with advanced controls, with predictive maintenance and energy system for optimum energy use shall be designed. Centralized air-conditioning system with a diligent feasibility/viability study of a particular system invariably leads to better energy efficiency solutions. In case of mixed used buildings (residential, office, laboratories, etc) in the campus, the projects should consider choosing district cooling system for better resource efficiency and sustainability. The system design feasibility for district cooling systems or alternate energy cooling systems shall be referred in detail from **6** and **7**. Variable speed drives for motors and fans shall be used.

Life cycle analysis shall further support to demonstrate business case of selecting a particular system. Minimizing the ecological footprint of HVAC systems and use environmentally friendly refrigerants, implementation of systems that conserve water and other resources should be considered;

c) *Heating systems* — Heat pumps/high efficiency central heating system as detailed in **11** for space heating as well as water heating Integrate heating systems with building management/optimization systems (BMS) for optimal control;

d) *Zoning and control* — Multiple zones for different buildings or areas use advanced control systems for precise temperature and humidity levels and incorporate programmable thermostats and building management systems (BMS). Advanced zoning strategies for large campuses by dividing campus buildings into detailed zones based on occupancy and usage patterns, automated systems to adjust HVAC settings dynamically in different zones shall be standard practices. Occupancy diversity into zoning for better control and energy savings as well as thermal control strategies based on space type and usage shall be considered. For more details on building automation and zoning control refer to **15**;

e) *Occupancy and lighting schedules* — HVAC and lighting schedules with occupancy to optimize energy use shall be aligned. Automated lighting systems with daylight harvesting and occupancy sensors and scheduling HVAC operations before occupancy starts for optimal usage is preferred; and

f) *Urban heat island* (*UHI*) — Urban heat island (UHI) causes discomfort and increases energy consumption of air-conditioners. Mitigation measures to reduce the impact of UHI and its associated impacts shall be considered. Proper placement of HVAC equipment to avoid UHI and manage distance between equipment (especially air-cooled outdoor equipment) to release the heat and avoid creating local heat spots need a due consideration.

12.3.2 *Operation and Maintenance (O&M)*

These ensure the effective management, upkeep, and long-term performance of campus buildings and their systems.

a) *Energy management* — Energy management strategies within the BMS to minimize energy consumption by scheduling HVAC operations to match occupancy patterns and utilizing energy-efficient modes during non-peak hours and similarly system designed to showcase performance levels (square foot/TR) shall lead to better energy management;

b) *Maintenance* — As the energy consumption in the large campuses is huge, the predictive maintenance and cloud monitoring for advanced energy efficiency may be considered as part of the system for effective monitoring and for taking proactive measures. Advanced monitoring systems to track performance in real-time and scheduled maintenance based on predictive analytics will lead to lower down times. Detailed logs using a computerized maintenance management system (CMMS) shall be maintained; and

c) *Retro/re-commissioning* — Analysing HVAC system performance after one year of operation to compare design with actual performance. Necessary retro-re/commissioning to improve performance based on load profiles of several components for example fan/pump/motor, etc (following over/under load conditions) shall be undertaken.

12.3.3 *Specific Requirements for Campus Project*

These requirements address the unique operational needs and considerations for designing and managing campus buildings.

a) *Climate adaptation* — Implement HVAC system modifications for different climatic zones (hot and dry, warm and humid, composite, temperate, cold);

   Use adaptive thermal comfort models to enhance occupant comfort and energy savings.

b) *Water conservation* — Emphasize water-efficient HVAC systems, especially in water-scarce regions. Encourage the use of condensate recovery systems to reuse water in cooling towers or irrigation. Promote the use of water-efficient fixtures and fittings in all campus buildings;

c) *Sustainability practices* — Campus buildings are encouraged to use sustainability practices (green building guidelines) and sustainability standards shall follow for enhanced sustainability. Promote the use of recycled and sustainable materials in HVAC installations;

d) *Resilience and reliability* — HVAC systems that shall handle frequent power outages and voltage fluctuations shall be envisaged. The inclusion of backup systems to ensure continuous operation during power failures. Robust disaster recovery plans to maintain HVAC operations during emergencies shall be included; and

e) *Testing and commissioning* — Thorough testing, balancing, and commissioning procedures shall be followed. Standardized protocols for verifying system performance before handover shall be compulsory. For detailed guidelines refer 17.

12.3.4 *Educational Campus Buildings*

Special attention for the design of the HVAC systems shall be paid to meet the needs of every age group in this type of buildings. The equipment should be easy to operate and maintain and the design should provide no drafts. These facilities have two distinct occupant zones: (a) the floor level, where younger children play, and (b) normal adult height, for the teachers. The administrative and teachers' offices shall be considered as a separate zone.

Special consideration shall be given to operating schedule for setback. Supply air outlets should be positioned to avoid drafts. Proper ventilation and exhaust shall be provided for controlling odours and to prevent the spread of diseases. University and college campus having large diversity in cooling/heating loads, should be provided with large central utility plant or smaller mechanical rooms serving a cluster of buildings. The central utility plant shall supply chilled/hot water depending on the zonal requirement. The designer should consider site constraints, including geographic location. In addition to accommodating the mechanical and electrical equipment, central utility plant may also house engineering, operation and maintenance personnel. A central control room shall be provided for energy monitoring.

12.4 Hospitality Buildings Typology

It is critical to focus on guest comfort, energy efficiency, and system reliability. Each guest room or each zone shall be provided with not less than one thermostat capable of being set from 20 °C to 30 °C and capable of operating the system's cooling and heating. The thermostat or control system, or both, to have an adjustable dead band, the range of which includes a setting of 12 °C between cooling and heating, where automatic changeover is provided. Wall mounted temperature control shall be mounted preferably on an inside wall and shall meet the requirements given in **15**.

12.4.1 *Guest Rooms*

Guest room systems are required to be available for operation on a continuous basis. The room may be unoccupied for most of the day and therefore provision for operating at reduced capacity or switching off. Low operating noise level, reliability and ease of maintenance shall be taken care. Treated fresh air (TFA) is introduced through an independent TFA system, it is generally balanced with the bathroom extract ventilation, to ensure air circulation into the bathroom. Fan coil unit is generally found to be the most suitable for this kind of application with speed control for fan and motorized/modulating valve for chilled water control for cooling.

12.4.2 *Restaurant, Cafeteria, Bar and Night Club*

These applications have several factors in common; highly variable loads, with high latent gains (low sensible heat factor) from occupants and meals, and high odour concentrations (body, food and tobacco smoke odours) requiring adequate control of fresh air extract volumes, direction of air movement for avoidance of draughts and make up air requirement for associated kitchens to ensure an uncontaminated supply. This type of application is generally best served by the all-air type of system preferably with some reheat or return air bypass control, to limit relative humidity. Either self-contained packaged unit or split system, or air handling unit served from a central chilled system, may be used. Sufficient control flexibility to handle adequately the complete range of anticipated loads.

12.4.3 *Specific Criteria to be Adhered for Hospitality Buildings*

a) *Occupant (guest) comfort* — Air-conditioning system to maintain consistent temperature and humidity control in guest rooms, lobbies, restaurants, and common areas. There shall be individual temperature and ventilation controls in guest rooms for personalized comfort. Ensure rapid response to temperature adjustments for good comfort conditions;

b) *Energy efficiency* — Energy-efficient HVAC equipment such as high-efficiency chillers/cooling system, boilers, and heat pumps shall be needed. Occupancy sensors and smart thermostats reduce energy use in unoccupied rooms. Integrating energy recovery ventilation systems to reclaim and reuse waste heat or cooling shall bring in additional energy efficiency. Heat recovery system shall be sized based on floor/occupancy loading;

c) *Zoning and control* — HVAC systems cater to multiple zones with different activity areas of the hotel, such as guest rooms, dining areas, and conference rooms. Advanced control systems for precise temperature and humidity regulation as well as building management system (BMS) for centralized monitoring and control of HVAC operations shall be designed and used as detailed in **15**;

   It shall be necessary to avoid mixing of air of various type of zoning (corridor, guest rooms, guest areas where smoking allowed, kitchen ventilation, etc), designate smoking and non-smoking areas by pressure differentials between zones;

d) *Noise control* — Low-noise HVAC equipment shall be used to ensure a quiet environment. Necessary sound attenuation measures shall be installed in ductwork and mechanical rooms to reduce noise. Proper acoustic insulation in guest rooms and other sensitive areas for ensuring low/nil cross talk between areas shall be initiated. Noise control measures shall be as per Part D 'Building services, Section 4 Acoustics, Sound Insulation and Noise control' of this NBCS;

e) *Sustainability* — Integrating passive and active heating/cooling system to minimize greenhouse gas emissions and developing the hotel/hospitality project to incorporate sustainable design practices shall be followed;

f) *Reliability and maintenance* — Durable and reliable HVAC equipment to minimize downtime and maintenance issues shall be needed as the systems are generally required to function round the clock throughout the year. Systems should have easy-access for maintenance and repairs and a preventive maintenance schedule to ensure long-term system reliability and performance shall be implemented;

g) *Aesthetic integration* — HVAC design shall coordinate with the hotel's interior design to minimize visual impact and use discreet and aesthetically pleasing diffusers, grilles, and other HVAC components without compromising on functional effectiveness and air distribution patterns. HVAC components shall be selected to seamlessly integrated into the overall architectural design;

h) *Environmental impact* — The ecological footprint of HVAC systems shall be minimised by using environmentally friendly refrigerants and materials. Water conservation measures, particularly in cooling towers and other water-intensive components shall be a priority. Use of treated water for cooling tower and designing systems to reduce overall energy consumption and waste shall be adhered. Calculate environmental impacts of refrigerants used in air-conditioning/fire suppression system (calculate ODP – ozone depleting potential if applicable and GWP – global warming potential). Project to utilise new age refrigerant/natural refrigerant to minimize or avoid negative impact of refrigerants. For more details, refer to 5;

j) *Guest room control systems* — User-friendly interfaces for guests to control room temperature, ventilation, and other comfort settings shall be provided. Integrating with hotel management systems to optimize energy use based on occupancy and guest preferences and by offering customizable settings enhance the guest experience and also accommodates individual needs;

k) *Operation and maintenance of HVAC system* — Comprehensive training for facility managers and maintenance staff on the operation and maintenance of HVAC systems shall be provided. Ongoing support and service agreements with HVAC vendors for timely repairs and updates and constant skill upgradation for staff on energy-saving practices and the proper use of HVAC control systems shall be followed. Make provision to clean ducts periodically to offer hygiene conditions to guest, staff/occupants;

m) *Scalability* — HVAC systems shall be designed to accommodate future expansions or renovations, use modular components for easy upgrades and modifications. Ensure the system shall adapt to varying occupancy rates and seasonal changes; and

n) *Specialty areas* — HVAC systems shall be designed for specialty areas such as spas, kitchens, and conference rooms for meeting specific requirements. Adequate ventilation and humidity control in spas, pools, and fitness centres and robust exhaust systems in kitchens to manage odors, heat, and smoke effectively shall be provided.

12.5 Healthcare Building Typology

HVAC Systems in healthcare facilities provide a broad range of services in support of people who are vulnerable to an elevated risk of health, fire and safety hazard.

12.5.1 *Basic Classification of Health Care Facilities*

Health care facilities vary widely in the nature and complexity of services they provide and the relative degree of illness or injury to the patients treated-like clinic, diagnostic centers, medical centers, specialty hospitals, super specialty hospitals, etc. Environmental control requirements and the role of HVAC system in life safety and infection control becomes very important with the medical services provided.

Ventilation in healthcare buildings is crucial for maintaining air quality, controlling infections, and ensuring the comfort and safety of patients, staff, and visitors. Healthcare facilities have unique ventilation requirements due to the need to manage airborne pathogens, chemical contaminants, and varying needs of different areas.

12.5.2 *Design Criteria*

While designing HVAC for a healthcare facility, Patient therapy shall be the prime consideration, the plan shall include the following parameters which shall be taken into consideration:

a) temperature and humidity requirements of various spaces;

b) ventilation requirements/air changes requirements;

c) filtration requirements for contamination control;

d) restriction on air movement between adjoining spaces;

e) permitted tolerance on environmental conditions;

f) redundancy/backup;

g) fire and life safety;

h) efficiency bench marking on the equipment;

j) guidelines for parameters;

k) standards/ good practices; and

m) ease of installation and Maintenance friendly.

12.5.3 *Key Considerations*

These considerations ensure that healthcare buildings are designed to meet the specific functional, safety, and regulatory requirements for patient care and medical operations.

a) *Comfort conditioning* — Across health care facilities, health care practices often expose patients and staff to conditions that dictate unique environmental requirements. As in any other building, comfort of occupants is fundamental to overall well-being and productivity also it has a significant role in facilitating healing and recovery;

b) *Therapeutic conditioning* — Certain Medical functions, treatments or healing processes demand controlled environmental temperature and relative humidity conditions that deviate from the requirements for personal comfort. Operating rooms and other key areas require a range of room temperature spanning several degrees regardless of the season to best facilitate a given procedure or patient condition;

c) *Infection control* — Medical facilities are places where relatively high levels of pathogens are generated and concentrated by an infected patient population or by procedures that handle infected human tissues and bodily fluids. Filtration levels and air changes per hour (ACH) play a vital role in controlling the risk;

d) *Pressure differentials* — Implement negative pressure in airborne infection isolation (AII) rooms to contain airborne pathogens and positive pressure in operating rooms (OR)/protective environment (PE) rooms to protect patients from outside contaminants;

e) *Life safety* — HVAC systems are required to support special building compartmentation, opening protection, smoke control and smoke detection systems. Containment is facilitated by smoke and fire dampers and some cases restricting cross overs between smoke zones; and

f) *Noise control* — Noise control is of high importance because of negative impact of high noise levels on the patients and the need to safeguard patient privacy. Noise control measures shall be as per Part D 'Building Services, Section 4 Acoustics, Sound Insulation and Noise Control' of this NBCS.

12.5.4 *Energy Efficiency/Sustainability Considerations*

These guidelines focus on optimizing energy use and incorporating sustainable practices in the design and operation of buildings to reduce environmental impact.

a) *Role of building envelope* — The building envelope in healthcare facilities is a critical component that affects energy efficiency, indoor environmental quality, and overall functionality. Given the unique needs of healthcare environments, the building envelope shall be designed with stringent requirements to ensure patient safety, comfort, and operational efficiency;

b) *Energy-Efficient Window* — Windows with low solar heat gain may be used in order to minimize heat loss and gain shall be used. Windows shall have proper seals to prevent air infiltration;

c) *Air Tightness* — Building envelope shall be well-sealed to prevent air leaks by providing proper sealed building envelope. This shall be done for controlling indoor air quality and maintaining the efficacy of HVAC systems;

d) *Testing and Commissioning* — Apart from the procedures listed in**,** additionally shall conduct blower door tests and infrared thermography tests during commissioning to identify and rectify any air leakage points;

e) *Natural Light and Views Daylighting* — The building envelope shall be designed to maximize natural light, reducing the need for artificial lighting and creating a more patient friendly environment. This includes the strategic placement of windows, skylights, and light wells; and

f) *Glare Control* — Shading devices, low-E glass, or other technologies shall be incorporated to control glare and excessive solar heat gain, enhancing comfort and reducing cooling loads.

Guidelines for the above parameters for various functional spaces in a health care facility are given in Table 27 and Table 28.

Table 27 Guidelines for Parameters to be Considered for HVAC System Design for Health Care Facilities

(*Clauses* 12.5.4 *and* 12.5.5)

Sl No.	**Area/Functional Space**	**Temperature** °C	**Relative Humidity** percent	**Minimum Total Air Changes per Hour**	**Minimum Air Changes of Outdoor Air per Hour**	**Air Pressure in Relation to Surrounding Area/ All Room Air Directly Exhausted to Outdoors**
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	Operating theatres	20 to 24	20 to 60	20	4	Positive/NR
ii)	Cath labs	21 to 24	*Max* 60	15	3	Positive/NR
iii)	Delivery rooms	20 to 24	20 to 60	20	4	Positive/NR
iv)	Recovery room, ICU, treatment rooms	21 to 24	*Max* 60	6	2	Equal/NR
v)	Endoscopy, bronchoscopy	20 to 23	*Max* 60	12	2	Negative/NR
vi)	Patient rooms	21 to 24	*Max* 60	6	2	Equal/NR

Table 27 (*Concluded*)

Sl No.	Area/Functional Space	Temperature °C	Relative Humidity percent	Minimum Total Air Changes per Hour	Minimum Air Changes of Outdoor Air per Hour	Air Pressure in Relation to Surrounding Area/ All Room Air Directly Exhausted to Outdoors
(1)	(2)	(3)	(4)	(5)	(6)	(7)
vii)	Toilets	–	–	–	10	Negative/Yes
viii)	Protective environment rooms (Immuno suppressed patients)	21 to 24	*Max* 60	12	2	Positive/NR
ix)	Isolation room (for patients with infectious disease)	21 to 24	*Max* 60	12	2	Negative/Yes
x)	Corridors	–	–	2	2	Negative/NR
xi)	X-ray/Radiology	21 to 24	*Max* 60	15	3	Positive/NR
xii)	Laboratories (other than biochemistry and serology)	22 to 26	*Max* 60	6	2	Negative
xiii)	Biochemistry and serology labs and pharmacy	22 to 26	*Max* 60	6	2	Positive/NR
xiv)	Admission/waiting rooms	22 to 24	*Max* 60	6	2	NR/NR
xv)	Diagnostic/treatment OPD	21 to 24	30 to 60	12	2	NR/NR
xvi)	Sterilizer equipment room	NR	NR	10	–	Negative/Yes
xvii)	Sterilizer storage	22 to 26	*Max* 60	4	2	Positive/NR

Table 28 Guidelines for Minimum Filter Efficiency Requirement in Health Care Facilities

(*Clause* 12.5.4)

Sl No.	Category	Area/Designation	Filter Class (Efficiency)	
			Filter Bed 1	Filter Bed 2
(1)	(2)	(3)	(4)	(5)
i)	Category 1	a) Orthopedic OT b) Bone marrow transplant OT c) Organ transplant OT d) PE rooms including Burn Units	ISO Coarse 60 percent	ISO ePM2.5 80 percent and HEPA at outlets

Table 28 (*Concluded*)

Sl No.	Category	Area/Designation	Filter Class (Efficiency)	
			Filter Bed 1	Filter Bed 2
(1)	(2)	(3)	(4)	(5)
ii)	Category 2	a) General OT delivery rooms b) ICU, patient care rooms	ISO Coarse 60 percent	ISO ePM2.5 80 percent
iii)	Category 3	a) Treatment rooms b) Diagnostic areas	ISO Coarse 60 percent	Not required
iv)	Category 4	a) Laboratories b) Sterile storage	ISO Coarse 60 percent	Not required
v)	Category 5	a) Food preparation b) Laundry c) Admin, etc	ISO Coarse 60 percent	Not required

12.5.5 *Air Distribution System*

The fresh air changes per hour as well as the total air changes shall be minimum as per the guidelines given in Table 27 above.

For critical care areas, variable air volume systems shall be used for energy conservation by controlling supply, exhaust and return air and maintaining the pressure relationships as per standards and inside design conditions without any compromise. Critical areas in general are operating theatres, ICUs, isolation rooms, sterile areas, post-operative patient care; any place which houses medical surgical procedures and some of the laboratories.

For patient rooms and non-critical areas, variable air volume system shall be considered for energy conservation. However, when variable air volume systems are used, care should be taken to ensure that minimum ventilation requirements are not compromised and pressure balance is maintained even at minimum flow.

Active smoke control systems shall be used along with fire and smoke partitions to limit the spread of smoke in the event of fire. Smoke and fire management should be done in accordance with Part F 'Fire and Life Safety' of this NBCS and **19**. For health care facilities which provide ambulatory care to patients, safety from fire and smoke is a paramount design consideration and should be provided in accordance with Part F 'Fire and Life Safety' of this NBCS.

A separate exhaust system shall be provided for removal of anaesthesia gases from the operation theatre. Alternatively, proper isolation dampers may be provided in the air circulation system for removal of anaesthesia gases or fumigation effect if this system of fumigation is followed in health care.

Air handling devices shall be designed to prevent water intrusion and permit access for inspection and maintenance. Draw through air handling systems shall be used as moisture ingression is minimized in these systems. Lower face velocity across the coil in the range of 1.27 m/s to1.52 m/s shall be considered for better heat transfer.

When humidifiers are provided, they shall be located with-in the air handling unit or duct work in such a way that moisture accumulation on downstream components do not take place. Evaporative pan type humidifiers shall not be used.

Fibrous acoustic insulating material shall not be used as duct lining for critical spaces. Supply air ducts shall be externally insulated as required.

Multiple direct drive plenum fans may be used in air handling units serving critical areas. This provides redundancy and minimizes shut down of critical areas in case of single fan failure.

For critical areas, both supply air and return air shall be ducted. Ducts shall be sized for medium velocity and medium pressure drop 12 m/s and 4 mm for 10 m maximum. For applications like operation theatres and intensive care units, the preferred material for ductwork should be of corrosion resistive metal sheets.

Ultraviolet germicidal irradiation is recommended for air handling units serving health care facilities. Lamps may be installed either upstream or downstream of the evaporator coil but away from the filter media.

12.5.6 *Air Flow and Filtration*

Outside air intakes shall be located minimum 8 m away from exhaust stacks, cooling tower and/or any other polluting source. Bottom of an outdoor air intake shall not be located less than 2 m above ground level and 1 m above any roof terrace level.

Exhaust outlets shall be located at a minimum height of 3 m away from ground level and away from doors, occupied areas and operable windows. Locating exhaust outlets above the roof, projecting upwards, is preferred.

While installing filters, care shall be taken to see that there is no scope for leakage between frame and filters and between filter segments. Filters shall be as per tested to accepted standards [D-3(15)], [D-3(16)], [D-3(17)] and [D-3(18)].

All openings in ducting/diffusers collars shall be sealed to prevent infusion of dust and dirt. All slab openings shall be terminated in enclosed rooms and airflow systems shall be designed and balanced to create positive or negative air pressure with-in specified areas.

It is recommended that supply air outlets shall be located at or near the ceiling and return/exhaust is collected near the floor level. This is to ensure that clean conditioned air moves through breathing and working space to the floor area, for return/exhaust.

For operating room and procedure room, where patients are highly susceptible to infection, such as orthopaedic and cardiac operating theatres, laminar air flow system shall be considered. A unidirectional air flow pattern at a max velocity of 0.13 m/s to 0.18 m/s should be aimed for to prevent the thermal plume at surgical site getting disturbed. A vertical laminar flow system which will wash the patient on the operating table and flow downwards, to be collected near floor level, shall be chosen for such rooms. The area of laminar flow grid shall extend by a minimum of 0.450 m beyond the footprint of the operating table on all sides. If required, additional supply diffusers may be provided for achievement of required temperature and humidity.

Minimum two (2) exhaust grilles shall be provided at opposite corners of the room at approximately 0.200 m above the finished floor level.

12.5.7 *Pressure Differential*

Operating rooms where highly infectious patients are treated and isolation is required, an anteroom shall be provided between the operating room and external area. Anteroom shall be maintained at positive pressure with respect to both the operating room and the surrounding areas.

All air from operating rooms shall be recirculated with adequate fresh air changes and Total air changes per hours and filtration as per tables above or exhausted after energy recovery. Similarly, from all airborne infection isolation rooms, all air shall be exhausted directly to outdoors through high efficiency particulate air (HEPA) filters. Such rooms shall be maintained at a minimum negative pressure of 2.5 N/m^2 with respect to surrounding areas.

Protective environment rooms, such as, bone marrow transplants and organ transplants, shall be maintained at a positive pressure of 2.5 N/m^2 with respect to surrounding spaces.

12.5.8 *Conditioning Equipment*

Cooling equipment shall be central or local chilled water systems, direct expansion type condensing units or variable refrigerant flow systems. Indirect cooling systems using chilled water are preferred and, if direct cooling systems are used, required safety measures should be adopted. Heating equipment shall include heat pumps and heat exchangers.

Sizing and arrangement shall give adequate consideration to minimum loading and standby facility for critical areas. It shall be possible for the facility to operate even when one of the systems is under break down or maintenance.

Where specific areas are to be maintained at a low temperature coupled with low humidity, an additional direct expansion coil may be introduced downstream of the regular evaporator coil. In such cases, the control strategy shall ensure that the DX coil is energized only after the main evaporator coil is at full load.

When variable refrigerant flow systems are used, care shall be taken to see that minimum air change and pressure differential considerations are not compromised.

12.5.9 *Installation and Maintenance*

The air distribution system shall be provided with access panels to allow inspection and cleaning. Duct systems shall be cleaned of construction debris before commissioning.

Surfaces of air terminals shall be suitable for cleaning.

Access to equipment rooms shall be planned so as to avoid intrusion of maintenance personnel into critical care areas. Equipment room layout shall allow easy access to equipment for its operation and maintenance.

Operation and maintenance records shall include indoor temperature and pressure requirements as well as permitted tolerances for all spaces. It shall also include standard operating procedures for emergencies, such as power failure, equipment breakdown and fire situation.

Pressure differentials of operating rooms, protective environment rooms, and air borne infection isolation rooms with respect to surrounding areas, shall be verified and recorded semi-annually.

HEPA filters shall be replaced periodically based on pressure drop. Filters of fan coil units and air handling units (AHU) shall be cleaned according to a regular maintenance schedule. AHU/fan coil drain pans shall be of stainless-steel construction and shall be cleaned monthly.

Supply and return air ducts for critical areas shall be tested for air leakage and an air blow down process shall be undertaken before loading of filters. All areas served by the AHU shall be cleaned and mopped before the AHU is started. Filters shall be loaded in sequence. Pre-filters shall be loaded first followed by microvee or fine filters and finally HEPA filters. AHU shall be run with each set of filters for 24 h and the conditioned area shall be cleaned and mopped each time before the next set of filters is loaded.

After air balancing, and adjusting of air quantity, a validation process shall be carried out by recording temperature, humidity and pressure differentials. For critical areas, validation process shall be repeated and recorded at least once every year.

For operating rooms where validation is needed the air handling devices shall be run 24 h. However, the system deliverables shall be limited to maintaining minimum pressure differentials considerations with turndown procedures to control and limit contamination (unoccupied turn down is permitted subject to maintaining pressure differentials).

12.6 Underground Metro Station Buildings

A typical underground metro station generally consists of three underground levels i.e. concourse level, platform level and undercroft level. The first level at minus 1 being the concourse with a height ranging from 4.8 m to 5.5 m followed by Platform level at minus 2 of height varying from 4.5 m to 5 m. The third level that is undercroft level provided below the platform having minimum clear height of 1.8 meter is mainly used for the services like cables, fire pipes, escalator pits, seepage and sewage sumps etc. The ancillary building at metro stations is also provided outside the station building to house either cooling towers, air cooled chillers, water cooled chillers, etc.

The underground metro station is provided with environment control system (ECS). The ECS system shall serve following function:

a) station public area and ancillary room air conditioning;

b) mechanical ventilation of plant rooms;

c) smoke management system; and

d) staircase Pressurisation

12.6.1 *Station Public Area and Ancillary Room Air Conditioning*

12.6.1.1 *Station air conditioning design philosophy*

The underground stations of the metro corridor shall be designed to provide forced ventilation for removal of the large quantity of heat dissipated from train equipment, station electrical accessories and equipment, passenger body heat, obnoxious odours, and harmful gases such as CO_2. The station heat load shall be assessed by taking into account the provision of platform screen doors (PSDs) at the station. PSDs, which act as barriers between the station platform and the trackway, are provided for enhancing passenger safety, improving indoor air quality, and achieving energy savings. PSDs may be of two types, full Height PSD or half Height PSD, and their installation significantly influences the overall heat load profile of the station. The station heat load generally consists of a combination of unsteady train heat loads, passenger heat load, lighting and miscellaneous equipment loads, fresh air loads, transmission heat loads, and infiltration/exfiltration loads. The station heat load shall be considered as

a) *Unsteady heat load due to train movement* — The unsteady heat load at a station due to train movement is almost negligible when the full height PSD are provided between station trackway and station platform. In case of no PSD or half height PSD the unsteady heat load is the major source of heat for the station is from the train air conditioning systems and the train traction and braking systems. The air that gets pushed in to the tunnel due to the piston effect gets exhausted through separate gravity dampers provided at the top of tunnel. The simulation studies also evaluate the tunnel temperatures during the normal operation of the train movements. The underground stations with provision of full height PSD doesn’t allow the cool air of the station to go into the tunnel and the tunnel temperatures tends to be higher. The simulation studies inform the amount of tunnel cooling required for normal and congested operation of the train in the tunnel sections.

b) *Steady heat load*:

    1) *Passenger heat load* — The passenger occupancy at station is taken from peak hour peak direction traffic (PHPDT) data given in detail project report (DPR). Passenger heat gain shall be computed from the above data;

    2) *Lighting and miscellaneous equipment load* — It is based on lighting in public area and equipment like lifts, escalators and AFC Gates contributing to the heat load;

    3) *Fresh air loads* — Fresh air is supplied to the platform and concourse to meet the physiological requirements of the passengers. Fresh air quantity shall be calculated as per **3**;

    4) *Transmission heat loads* — The transmission of heat through the station walls between public and non-public areas, through concourse floor slab and heat transmission through PSD glass doors to be considered; and

    5) *Infiltration and exfiltration heat load* — Infiltration or ex-filtration of air at platform takes place through PSD doors from the trackway to platform and vice versa. The source of heat on trackway is heat rejected from train condenser, traction, braking, and airflow due to train piston effect. In order to maintain the required conditions in the station, the loss of cooling at station platform due to infiltration/exfiltration of air may be considered in station heat load estimation

12.6.1.2 *Design criteria*

Since the passengers stay in the stations only for a short period, a reasonable degree of comfort conditions, just short of discomfort conditions are considered appropriate. Station air conditioning system shall be designed to maintain specific design conditions.

Station air conditioning system design conditions are:

a) Platform, Concourse : 27 °C at 55 percent relative humidity

b) Outdoor : Summer and monsoon condition as per location

12.6.1.3 *System description*

The station environment control shall be by a central air conditioning system. Station shall have provision of fresh air intake and exhaust shaft. The station shall be supplied with conditioned air to concourse and concourse area via ductwork from air handling unit (AHU) located in plant room either at concourse or platform level. AHU shall be supplied with chilled water from water cooled/air-cooled chillers and its associated pumping system. The AHU shall be as per accepted standard [D-3(21)] and the liquid chillers shall be as per accepted standard [D-3(24)].

The trackway exhaust system shall be installed in the trainways of each station to capture both excessive tunnel airflows and the heat rejected by the vehicle propulsion/braking/air-conditioning systems as the train dwells in the station. An over track exhaust (OTE) duct is normally utilized to capture heat that is rejected from the vehicle propulsion/braking as well as the heat that is rejected from the above car area rooftop mounted air-conditioning units. An under platform exhaust (UPE) duct can also be utilized to capture heat from the train's undercarriage heat sources if the heat generated is significant. Openings in the OTE and UPE shall be located to be near the heat generating sources on the train.

For systems designed without PSD or half height PSD, the extracted air from the station trackway is used as a return air for the air-conditioning system during the close mode of operation. For stations with full height PSDs, the heat extracted through station trackway can be directly exhausted to the atmosphere or can also be used as return air as per the system requirements.

12.6.1.4 *Modes of operation*

There are namely two types of mode of operation:

a) *Open mode operation* — In open mode, 100 percent outside air is circulated in the stations. It is an economical mode of operation when the outside air enthalpy is relatively low and favourable for the inside condition (the best-case scenario is when the outside air enthalpy is same as the design AHU coil leaving air enthalpy). AHU shall draw the air directly from outside via fresh air shaft and deliver the air at platform level and concourse level. Trackway exhaust fans (TEF) shall extract the air from OTE and UPE and discharge it outside directly via exhaust shaft. The centralized chillers units shall remain shut down in this mode. This mode is known as 'Economiser Cycle' and is generally available during winter season;

b) *Closed mode operation* — In close mode, air is extracted from the public areas of the station and returned to the air handling units to be cooled and delivered back to the platform and concourse. Closed mode operation is proposed when the outside air temperature and humidity are high. In this operation, AHU shall recirculate the air of OTE and UPE with the addition of fresh air, brought in by fresh air fans (FAF). This mode is generally used during summer and monsoon season; and

c) During close mode operation in station with full height PSDs, the return air is taken from the station concourse and public areas and then again recirculated by the AHUs provided in the ECS plant rooms.

12.6.2 *Mechanical Ventilation of Plant Rooms*

The back of house area rooms are provided with mechanical ventilation supply, ventilation exhaust or both according to their use and particular requirements.

12.6.2.1 *Ancillary area air conditioning*

Air conditioning of back of the house areas and ancillary areas, that are occupied by staff and non-travelling persons, who are going to stay in these areas for considerable duration, shall be same as air conditioning system for commercial buildings.

12.6.3 *Smoke Management System*

The and trackway exhaust fans (TEF) are used for concourse and platform public areas either TEF can be used or separate smoke extract fans can be provided. In case of full height PSD as TEF is not available for concourse and platform smoke extraction, separate smoke extraction ducts and fans are compulsorily required for these areas. The fans with related equipment shall be suitably located at each end of the station. Where a smoke extract ducting passes through protected areas, it shall be rated to the same fire resistance as the walls of the compartments. Station smoke removal fans to provide a positive indication of the fan operation at the station control rooms (SCR) as well as operations control centres (OCC).

12.6.4 *Staircase Pressurization*

Pressurization of the firemen's staircase and emergency staircase should be done in accordance with Part F 'Fire and Life Safety' of this NBCS.

12.7 Airport Buildings

HVAC systems for airports shall address unique requirements due to the complexity, scale, and diverse usage of these facilities. The key considerations for airport typology as given below shall be followed for energy efficient and sustainable building.

12.7.1 *Passenger Comfort*

These recommendations focus on maintaining optimal air quality, temperature, and humidity levels to enhance the comfort and experience of passengers in airport terminals:

a) *Temperature control* — Consistent and comfortable temperatures to provide thermal comfort in passenger areas, considering high traffic and varying external conditions as detailed in **3** shall be ensured;

b) *Humidity control* — Optimal humidity levels to enhance comfort and protect electronic equipment shall be ensured. (*see* **3**); and

c) Indoor air quality shall be as per the requirements as specified in **3**.

12.7.2 *Energy Efficiency*

The equipment like variable air volume (VAV) Systems, energy recovery ventilation (ERV) systems, and BMS as specified in **15**, should be considered.

12.7.3 *Ventilation and Air Exchange*

The ventilation and air exchange rate shall refer to the **3** and **8**.

12.7.4 *Load Management*

These guidelines focus on optimizing energy consumption and ensuring efficient operation of HVAC systems in response to fluctuating passenger traffic and varying environmental conditions:

a) *Peak load handling* — Systems shall be designed to handle peak loads during busy periods without compromising comfort; and

b) Demand control ventilation should be implemented to adjust ventilation rates based on occupancy to reduce energy use during off-peak hours.

12.7.5 *Redundancy and Reliability*

These considerations ensure the continuous, uninterrupted operation of HVAC systems by incorporating backup systems and fail-safe mechanisms to handle critical airport operations:

a) *Backup systems* — Backup HVAC systems and power supplies shall be incorporated to ensure continuous operation during power outages or system failures as the systems are expected to operate continuously all 365 days of the year; and

b) *Maintenance access* — Easy access to HVAC components for regular maintenance and emergency repairs shall be envisaged.

12.7.6 *Special Considerations for Specific Areas*

For the following specific areas, special considerations should be taken:

a) *Control towers* — HVAC system shall be designed for precise temperature and humidity control along with high air quality. Design should be fail safe system with redundancy;

b) *Baggage handling areas* — Maintain moderate temperatures to protect mechanical systems and baggage handling equipment; and

c) *Retail and Dining Areas* — Adequate ventilation and temperature control to ensure comfort for patrons and staff shall be provided.

12.7.7 *Noise Control*

These recommendations focus on minimizing noise pollution from HVAC systems to ensure a quiet and comfortable environment for passengers and staff in airport terminals:

a) The acoustic design of HVAC system should be considered to lower the noise level;

b) *Sound attenuation* — Sound attenuators and low-noise equipment to control noise levels in critical areas should be used; and

c) Noise control measures shall be as per Part D 'Building Services, Section 4 Acoustics Sound Insulation and Noise control' of this NBCS.

12.7.8 *Advanced HVAC Technologies*

These technologies aim to enhance energy efficiency, air quality, and overall system performance, ensuring a more sustainable and comfortable environment for passengers and staff.

a) *Smart sensors* — Occupancy and air quality sensors to optimize HVAC operations dynamically should be used;

b) *Advanced controls* — Advanced control systems to automate and optimize HVAC performance based on real-time data should be implemented **15**; and

c) *High volume low speed fans* (*HVLS fans*) — These fans should be used in conjunction with air conditioning systems to provide better thermal comfort in high ceiling areas there by enhancing passenger comfort and energy efficiency.

12.7.9 *Scalability*

The system should be designed with flexibility in mind to accommodate future expansion needs. This includes providing sufficient capacity, space, and infrastructure to allow for easy integration of additional components, equipment, or systems as the airport's operations grow. It should also consider scalability in terms of power, cooling, and airflow requirements, ensuring that the system can be upgraded or modified without significant disruption.

12.8 Shopping Complex Buildings

HVAC systems for shopping complex buildings like malls shall be designed to handle the unique demands of large, complex spaces with varying loads and occupancy levels.

For a small shop and store, unitary split type air conditioning system shall offer many advantages, including low initial cost, minimum space requirement and ease of installation. For large department store a very careful analysis of the location and requirement of individual department shall be required as these may vary widely, for example, for lighting department, food halls, restaurants, etc. Some system flexibility to accommodate future changes should be attempted in design.

Generally, internal loads from lighting and people are predominate considerations shall be given to initial and operating costs, system space requirements, ease of maintenance and type of operating personnel operating the system.

The economical options of all-air type of system, with variable volume distribution from local air handling unit, shall be considered. Facilities to take all outside air, for 'free cooling' under favourable conditions, should be provided.

a) *Load Calculations* — The following considerations should be taken into account for load calculation:

   1) *Diverse spaces* — Malls include various spaces such as retail shops, food courts, fine dining restaurants, cinemas, play zones and common areas, each with different HVAC needs;

   2) *Peak occupancy* — Systems shall accommodate peak load times, such as weekends and holidays; and

   3) *Heat loads* — Due consideration for heat loads from lighting, equipment, and occupants shall be accounted.

b) *Zoning* —Proper zoning is required for ensuring optimal comfort and energy efficiency in HVAC systems which shall be ensured by adhering to following:

   1) *Multiple zones* — Separate zones for different areas to ensure comfort and efficiency shall be designed. For example, food courts, theatres, and individual stores should have their own control zones served by common or individual air handlers with distinct functioning options; and

   2) *Independent controls* — Each zone should have independent temperature and humidity controls.

c) *Ventilation* — The following considerations should be taken into account for ventilation:

   1) *Fresh air requirements* — Adequate ventilation to ensure indoor air quality, with proper intake of fresh air as detailed in **3** shall be followed; and

   2) *Exhaust systems* — Effective exhaust systems for areas with specific requirements, such as food courts and restrooms, shall be needed for controlling odour, and pollutants.

d) *Air Distribution* — Effective air distribution is crucial for maintaining consistent comfort and air quality across all areas of the space:

   1) *Even distribution* — The system should be designed for uniform air distribution; and

   2) *Diffusers and grilles* — These shall be appropriately selected and placed for efficient air distribution.

e) *Energy Efficiency* — The system should be designed for energy-efficient operation, aiming to minimize energy consumption while maintaining optimal comfort levels. Proper system sizing, effective load management, and routine maintenance practices to ensure the HVAC system operates at peak efficiency, reducing overall energy costs and environmental impact;

f) *Humidity Control* — The following considerations should be considered for humidity control:

   1) *Dehumidification* — Proper dehumidification to maintain comfort and prevent mould growth shall be planned in humid climates or areas located in zones with high humid ambient conditions; and

   2) *Humidification* — In colder climates, additional humidification strategies in air handlers shall be added to maintain comfort.

g) *System Redundancy* — To ensure system redundancy following recommendations to be considered:

   1) The design should consider backup systems for critical components to reduce downtime; and

   2) The system design should be for easy maintenance access.

h) *Building Management Systems* (*BMS*) — The design of BMS should focus on centralizing control and monitoring of various building systems to enhance operational efficiency and energy management by adhering to following:

   1) *Integrated control* — BMS should be planned for centralized control and monitoring and integrating various operating HVAC systems and other systems such as lighting controls, lift management, water pumping systems, DG sets and MCC panels as well as fire alarm system to provide comprehensive and energy efficient operations; and

   2) Real-time monitoring should be incorporated for feedback on the performance and provide opportunity for necessary alterations to achieve energy efficiency goals.

i) *Noise Control* — Systems should be designed to minimize noise as well as sound transfer from one zone to another, especially in common areas and near sensitive zones like screens in multiplex, conference areas etc;

j) *Monitoring and Diagnostics* — Should implement predictive maintenance strategies using data analytics to reduce downtime and maintenance costs;

m) *Commissioning and Re-Commissioning* — Thorough initial commissioning as well as ongoing recommissioning shall be carried out as detailed in **17**;

n) *Climate Resilience* — The systems shall be designed to withstand and operate efficiently during extreme weather conditions as per the weather data provided in this NBCS;

p) *Water Management* — Water management systems should be designed to optimize water usage, enhance efficiency, and support sustainability within the building's HVAC operations and overall facility management which shall be ensured through:

   1) *Condensate management* — This shall be ensured by efficiently managing and reusing condensate water from air conditioning systems; and

   2) *Cooling towers* — Principally all types of cooling towers need make up water as well as constant replenishment and to achieve better system efficiency lower approach, designing of cooling towers may be referred from special publication.

   NOTE — Special publication may be Energy Conservation and Sustainability Building Code 2024 (ECSBC).

q) *Operational Training* — Operational training to ensure that maintenance and operational staff are well-equipped, to manage the HVAC systems efficiently and respond effectively to emergencies and following may be adhered:

   1) *Staff training* — Comprehensive training shall be provided for maintenance and operational staff on system use and troubleshooting; and

   2) *Emergency procedures* — Emergency procedures shall be established with clear procedures for HVAC-related emergencies, such as system failures or fire/smoke instances.

r) *Tenant Coordination* — Effective coordination with tenants to ensure that their HVAC needs are addressed while maintaining overall system efficiency. The following points outline key aspects of this coordination:

    1) *Tenant integration* — Coordinate with tenants shall be done to ensure their HVAC needs are met without compromising overall system efficiency; and

    2) *Tenant fit-out* — Proper guidelines shall be provided for tenant fit-out to maintain compatibility with the central HVAC system installed.

s) *Other requirements* — Other requirements such as safety, system type and components, should be as per Part F 'Fire and Life Safety' of this NBCS. HVAC should be designed flexible to accommodate future expansion:

    1) The design shall ensure thermal comfort as defined in **3**. (Adaptive controls – Adaptive control algorithms that respond to real-time occupancy and environmental data should be incorporated);

    2) Demand control ventilation (DCV) should be considered as reference to the thermal comfort and Indoor air quality requirements defined in this section; and

    3) *Backup power* — Critical HVAC systems shall have backup power to maintain operation during power outages.

12.9 Industrial Facility Buildings

12.9.1 *Zoning*

Zoning of different spaces shall be planned according to the functionality. Based on the hazard classification of different entities, compartmentation measures and safe distances shall be maintained. Emergency exits and assembly points shall be planned in line with the local regulations.

Planning shall consider adequate ventilation and natural light ingress into majority of the working spaces.

12.9.2 *Indoor Conditions*

Indoor conditions of different spaces shall be planned in line with the functional requirements of the spaces in general. Temperature, relative humidity and air quality shall be planned as per guidelines.

Ventilation and air conditioning shall be planned based on the functional requirements of the industrial buildings in line with basis of design brought out in **3**.

In industrial buildings, acceptable working conditions shall be ensured rather than comfort as providing comfortable conditions in huge volumetric spaces will not be efficient in terms of energy usage and cost economics. However, the ancillaries and office spaces shall be planned for comfort conditions in line with the guidelines.

The ventilation systems may contain chemical compounds or toxic substances in concentrations crossing prescribed safe limits. Necessary precautionary arrangements shall be made to remove, contain, exhaust and maintain the hazardous pollutants within acceptable limits in occupied spaces.

Emergency preparedness includes fire safety measures, with designated smoke extraction and pressurization systems integrated for safe evacuation and emergency response capabilities. Additionally, industrial zones shall be equipped with specialized HVAC systems, ensuring operational continuity within sensitive areas such as equipment rooms, control centers, and personnel amenities.

12.9.3 *Energy Efficiency and Conservation*

Energy-saving initiatives such as variable air volume (VAV) systems in public and operational zones, optimizing airflow and energy consumption based on real-time demand, variable frequency drives (VFDs) control AHUs, pumps, air compressors and chillers, optimizing operational efficiency during fluctuating production cycles, enthalpy economizer cycle in 100 percent Fresh air scenario and adaptive thermal comfort approach should be considered.

12.9.4 *Fire Safety and Electrical Integration*

It should be as defined in the Part F 'Fire and Life Safety' of this NBCS.

12.10 Tall Buildings Typology

12.10.1 *General*

Tall buildings are defined as structures with a height greater than 100 m. Buildings that exceed 300 m are classified as super tall buildings. Furthermore, buildings taller than 600 m are categorized as mega tall buildings.

Important considerations for tall/super tall/mega tall buildings are:

a) The effect of ambient air temperature over the height of buildings especially for super tall and mega tall buildings;

b) Facades for tall Buildings, leakage rates and pressure resistance;

c) Natural ventilation for tall buildings;

d) Energy consumption/conservation and new trends in HVAC design for tall/super tall/mega tall buildings;

e) Stack effect; and

f) Green/Sustainable tall buildings.

12.10.2 *Architectural Consideration*

Following key points outline key aspects of architectural consideration:

12.10.2.1 *Core design*

Design of core areas determine the projects floor to floor heights. This reflects in the building cost and architectural as well as HVAC design. An important consideration for architecture shall be the core design comprising of the three commonly used cores – Central Core/Double Core/Single sided (or offset) core. For hot and humid as well as temperate climates the core is suggested to be located on the east and west facades to insulate the interior zones from ambient conditions. Also, the cooling loads are found to be minimal when the double core configuration with glazing is used on north south and south facade and core on east and west facades. The core incorporates the following minimum entities:

Fire escape stairs/vertical transportation elements/rest rooms/electrical closets/communication closets/local fan rooms/shafts for HVAC risers/shafts for HVAC and plumbing systems/electrical distribution and building management and fire alarm system cabling.

12.10.2.2 *Facade systems*

The orientation influences the either increased or decreased infiltration rates and solar loads through facades. This is specifically important for mega tall and super tall buildings as infiltration from wind loads shall be significant for very tall buildings since there may not be adjacent buildings to mitigate high winds.

A high-performance facade needs to be planned to minimize solar cooling load and allow for efficient performance of air-conditioning systems while maintaining thermal comfort.

Facade is to be designed to minimize solar gain to 10 percent to 20 percent of the incident radiation. A double skin facade with fan coil/chilled ceiling/chilled beam cooling systems with return air directed to the floor of the perimeter and up between exterior and interior windows could be used.

Different types of multi skin facades such as one story faced module/corridor facade/multiple story facade and shaft box facade shall be designed

12.10.3 *Shading Strategies*

Shading strategies are important especially for cooling load dominated climates. It is better to minimize window to wall ratio as shall be seen the difference between 40 percent window to wall ratio and 65 percent window to wall ratio as seen in most modern buildings (*see* Fig. 7).

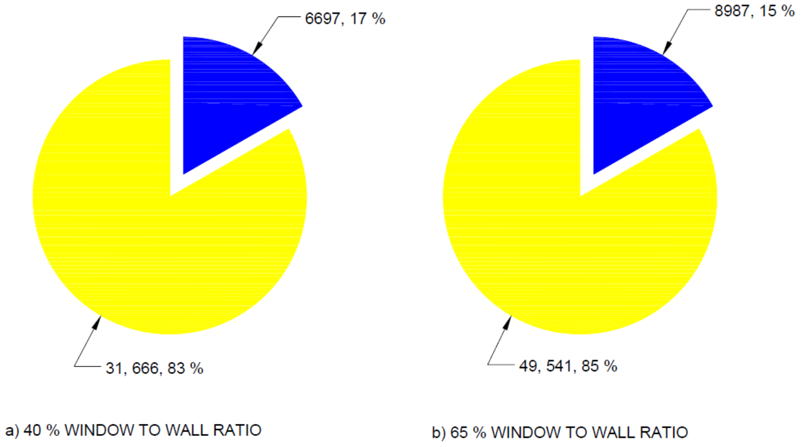


FIG. 7 IN 40 PERCENT THE HEAT TRANSFER THROUGH THE GLAZING IS 83 PERCENT OF THE LOAD TO THE SPACE AND IN 65 PERCENT IT IS 85 PERCENT TO THE SPACE.

12.10.4 *Facade Leakage Rates*

Envelope leakage depends on HVAC system operation. In pressurized buildings when HVAC systems operate the infiltration leakage could be very low. In accordance with the best practices of special publications recommended air leakage test of the completed building shall be with a leakage rate of not exceeding 2.0 l/s.m^2 at 75 Pa pressure differential.

As per special publication the recommended leakage rate value is 9.0 l/sm^2 at 75 Pa pressure differential.

The following are the two options as recommendations either as per special publications:

a) 2.0 l/s.m^2 at 75Pa; and

b) 9.0 l/s.m^2 at 75 Pa.

NOTE — Special publications maybe International Energy Conservation Code (IECC) and ASHRAE 90.1.

The leakage rate for tall building however shall vary with height. If the maximum leakage rate is achieved at a particular height, then at any height above this there will be facade leakage as infiltration load (*see* Fig. 8).

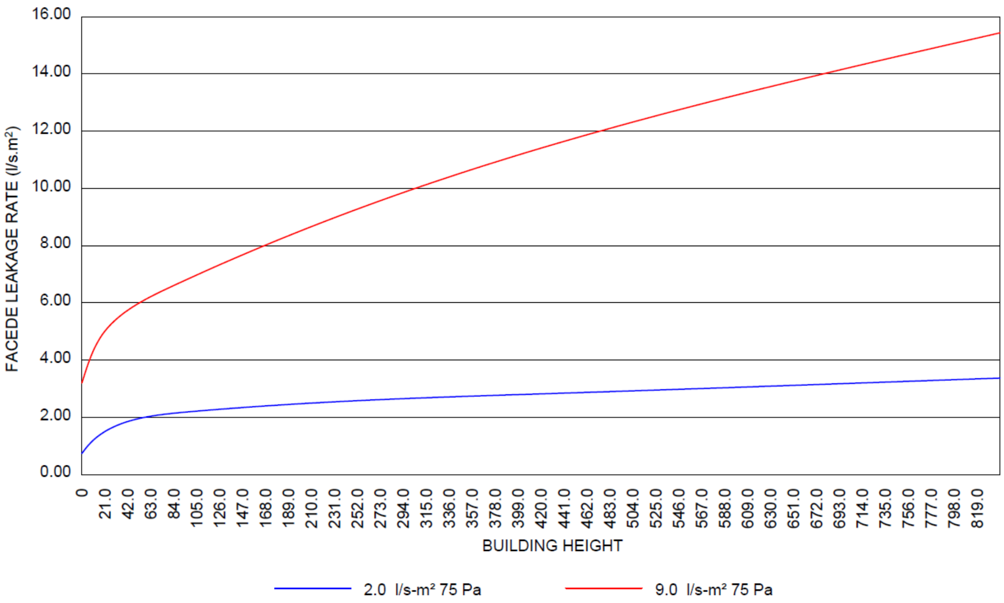


FIG. 8 CALCULATED LEAKAGE RATES FROM WIND SPEED IN CFM(L/S) OF FACADE AREA FOR TALL/MEGA TALL BUILDING

12.10.5 *Climate Data*

Generation of climate data at upper elevations is a shall. It could be achieved through:

a) Remote sensing technologies or ballon releases; and

b) Model using weather forecasting techniques.

Following are some of the calculation methods:

1) To obtain external temperature at different building heights use:

$$T = T_g - 0.006\,49\,h$$

where

T = temperature at height h (m);

T_g = Temperature at ground level F (°C); and

h = height from ground level (m).

2) External Pressure vertically with the building height is

$$P = 101\,325(1 - 2.255\,77 \times 10^{-5} \times h)^{5.255\,9}$$

where, P = pressure (kPa)

3) Density of air vertically with the height of the building shall be

$$\rho = \frac{P_{\text{abs}}}{0.286\,9\,(T + 273.1)}$$

where

T = absolute temperature (K);

P_{abs} = absolute pressure (Pa); and

ρ = air density (kg/m^3).

4) Wind speed and pressure are generally obtained from meteorological stations located away from urban environments. This wind speed shall be corrected for terrain conditions and for building height relative to wind measurement at that height. Approximate correction factor is:

$$v_z = v_m k Z^a$$

where

v_z = wind speed at the building height (m/s);

v_m = wind speed measures in open country at a height of 10 m (m/s);

Z = building height (m); and

k and a = constants dependent on terrain as per table below:

Wind speed terrain constants:

Sl No. (1)	*Terrain Category* (2)	*k* (3)	*a* (4)
i)	Open, flat country	0.68	0.17
ii)	Country with scattered wind breaks	0.52	0.20
iii)	Urban	0.35	0.25
iv)	City	0.21	0.33

12.10.6 *Stack Effect*

By convention, the stack pressure differences are positive when building is pressurized relative to outdoors which causes flow out of building.

When indoors is warmer than outdoors the base building is depressurized, and top is pressurized relative to outdoors. When the indoors is cooler than outdoors then the reverse becomes true. At some elevation in building the pressure indoors is equal to the outdoors and this height is known a neutral pressure level (NPL). NPL is influenced by leakage distribution and not necessarily at mid height of building.

The location of NPL (h) is expressed by:

$$h = H/(1 + (A_1/A_2)^2 T_i/T_o)$$

where

A_1 and A_2 = lower and higher leakage areas;

T_o and T_i = outdoor and indoor absolute temperatures; and

H = Building height.

12.10.7 *Heating and Cooling Loads*

Cooling and heating loads shall be calculated by dividing the building into sections. For example, splitting the building as 100 m sections and calculate heating and cooling loads in view of variable outside temperature, density and pressure over the building height as compared to constant parameters for other building typologies.

12.10.8 *Indoor Air Quality and Thermal Comfort*

The procedures and standards mentioned in **3** shall be followed. If this ventilation procedure does not yield adequate results to contain a specific contaminant or if the contaminant levels shall be attained with lower ventilation rates, then as an alternative indoor air quality procedure (IAQP) may be used.

12.10.9 *HVAC Systems*

All HVAC system options available for any building typology shall be applicable for use in Tall Buildings. These include:

a) All air variable air volume (VAV) systems;

b) Low temperature air VAV systems;

c) Underfloor air systems;

d) Air-water systems;

e) Radiant ceilings;

f) VRF drive fan coil units; and

g) VRF fan coils with 100 percent outdoor air ventilation.

12.10.10 *Exhaust Fan Pressures*

There will be considerable wind pressures at the air intake and exhaust locations shall be calculated as follows:

P_s intake = C_p intake [$\frac{\rho_a U_H^2}{2g_c}$ / 2.152]

P_s exhaust = C_p exhaust [$\frac{\rho_a U_H^2}{2g_c}$ / 2.152]

(P_s intake – P_s exhaust) + ΔP_{fan} = $F_{Sys} \frac{\rho Q^2}{A_L^2 g_C}$

$\Delta_{P_{wind}}$ = (C_p intake - C_p exhaust) [$\frac{\rho_a U_H^2}{2g_c}$ / 2.152]

where

ρ_a = outdoor air density at height h;

U_H = approach wind speed at upwind height h (m/s);

F_{Sys} = system flow resistance;

A_L = flow leakage area and; and

Q = system volume flow rate.

12.10.11 *Water Distribution Systems*

A major consideration in the design of a piping system in a tall building is the hydrostatic pressure created by the height of the building. The design of piping shall take static pressure on the piping system due to the height of into consideration. The piping network is divided into zones vertically separated by pressure breaks and served by heat exchangers and pumps with main chiller located at the utility complex in basement or an adjacent service building. The building pressure break shall be at equal interval at different heights separated using heat exchangers and tertiary pumps. It is needed that consideration to be given for different vertical zones in chilled water temperatures at the inlet to heat exchangers in each zone. In a typical scenario of 4 zones to serve chilled water at 6 °C at top of building following temperatures at each Heat exchanger will have to be maintained:

I Zone	1.5 °C
II Zone	3.0 °C
III Zone	4.5 °C
IV Zone	6.0 °C

Suggested piping materials shall be steel pipes schedule 40 with standard wall thickness for pipes up to 250 mm in diameter and for pipes 300 mm or larger a wall thickness of 9.5 mm. This by and large would accommodate the working pressures in tall buildings. However, a cross verification with accepted standard [D-3(27)] is preferred. Based on the working pressure valves and fittings also need to be selected. For steam condensate piping or for condenser water piping where corrosion is a possible concern pipe with heavier wall thickness shall be considered.

12.10.12 *Expansion and Contraction in Piping*

Design of piping shall take other factors including expansion and contraction and static and dynamic loads of the piping should be taken into consideration.

13 SPECIAL PLACES IN BUILDINGS

13.1 Cleanroom

The basic considerations in a cleanroom design are:

a) Cleanroom class;

b) Temperature;

c) Relative humidity;

d) Sound level;

e) Vibration;

f) Light spectrum; and

g) Electrostatic charge/static electricity.

NOTE — Number d, e, f and g are important for only selective cleanroom applications such as semiconductor, electronics and others.

13.1.1 *General Requirement*

a) Areas surrounding the cleanroom shall be less pressured than the cleanroom to avoid ingress of non-clean air to classified areas;

b) Airlock rooms shall be provided before clean room to maintain cleanroom integrity and reduce entry of contamination in classified areas:

    1) Separate change rooms shall be provided for male and female workers. multiple change rooms should be designed in series as per criticalness of application with primary change rooms designed as controlled not classified (CNC) and secondary change rooms (opening in cleanroom areas) designed under classified category; and

    2) A suitable door interlocking shall be used to ensure that both doors of airlock do not open “simultaneously” during usual operation time (except during emergency situations).

c) Air shower shall be used to reduce particles entry during human movement;

d) Dedusting tunnels or pass box should be used to reduce particles entry during material movement;

e) Existing Windows, cleanroom wall/ceiling panel joints shall be closed permanently using suitable sealants to avoid cross contamination;

f) Good smooth and scratch resistant flooring with skirting shall be provided;

g) All Corners and edges (ceiling to wall, wall to wall and wall to floor) shall be provided with coving to avoid dust accumulation and for easy cleaning;

h) The room shall be considered a restricted area. Only authorized personnel shall be allowed to enter during operation;

j) No paper products/cotton buds shall be allowed inside the cleanroom;

k) All personnel entering the clean room facility shall use 'cleanroom compatible gowning and shoes';

m) All personnel/visitors shall wear cleanroom garments while entering cleanroom; and

n) Cleanroom garments shall be stored properly in a laminar air flow storage cabinet:

    1) The cleanroom cleaning protocol shall be designed as per the product nature and contaminations to be removed. The cleaning agents shall also be compatible with cleanroom architecture; and

    2) Movement of materials from and to the cleanroom shall be as optimum as possible.

13.1.2 Selection of airborne particulate cleanliness classes for cleanrooms and clean zones as per special publication is given in Table 29.

Table 29 Airborne Particulate Cleanliness Classes for Cleanrooms and Clean Zones

(*Clause* 13.1.2)

Sl No.	ISO Classification Number	Maximum Concentration Limits (Particles/m^3 of Air) for Particles Equal to and Larger than the Considered Sizes Shown below:					
		$\geq$ 0.1 µm	$\geq$ 0.2 µm	$\geq$ 0.3 µm	$\geq$ 0.5 µm	$\geq$ 1 µm	$\geq$ 5 µm
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	ISO Class 1	10	2	–	–	–	–
ii)	ISO Class 2	100	24	10	4	–	–
iii)	ISO Class 3	1 000	237	102	35	8	–
iv)	ISO Class 4	10 000	2 370	1 020	352	83	–
v)	ISO Class 5	100 000	23 700	10 200	3 520	832	29
vi)	ISO Class 6	1 000 000	237 000	102 000	35 200	8 320	293
vii)	ISO Class 7	–	–	–	352 000	83 200	2 930
viii)	ISO Class 8	–	–	–	3 520 000	832 000	29 300
ix)	ISO Class 9	–	–	–	35 200 000	8 320 000	293 000

NOTE — Special publication may be ISO 14644-1.

13.1.3 The meanings of the cleanrooms classification is given in Table 30.

Table 30 Meanings of the Cleanrooms Classification

(*Clause* 13.1.3)

Sl No.	Class	Description
(1)	(2)	(3)
i)	Class 1	This Cleanrooms class is mainly used within the microelectronic industry when manufacturing integrated circuits which requires submicron resolution.
ii)	Class 10	This Cleanroom class is mainly used within the semiconductor industry using band widths below 2 micrometer.
iii)	Class 100	This cleanroom class is, according to many, the most useful critical cleanliness class. Cleanrooms class 100 are often, incorrectly, known as sterile rooms and are used when > bacterial free < and /or > particle free < environments are required. Cleanroom class 100 is used in aseptic manufacturing within the pharmaceutical industry, for example. This cleanroom class is frequently used during the manufacture of integrated circuits; and also during isolation and treatment of patients who are especially sensitive to bacterial infections, for example, after bone marrow transplantation.
iv)	Class 1 000	This cleanroom class is mainly used when producing high quality optics; When carrying out mounting work and testing of gyroscopes for aircrafts; and also, when mounting high quality miniature bearings.
v)	Class 10 000	Clean rooms of class 10 000 are used for mounting procedures in hydraulic or pneumatic equipment and on some occasions are also used within the food and beverage industry. Class 10 000 cleanrooms are also commonly used within the pharmaceutical industry.
vi)	Class 100 000	This classroom class is used by many industries, for example when working with optical products, when building large electronic systems based on smaller components, when building hydraulic and pneumatic systems and also within the food and beverage industry. The pharmaceutical industry also makes frequent use of this class of cleanrooms.

13.1.4 Air velocities and air changes in cleanrooms is given in Table 31.

Table 31 Air Velocities and Air Changes in Cleanrooms

(*Clause* 13.1.4)

Sl No.	Class of Cleanroom	Airflow Type	Average Velocity (m/h)	Air Changes per h
(1)	(2)	(3)	(4)	(5)
i)	ISO 8 (100 000)	N/M	18 to 146	5 to 48
ii)	ISO 7 (10 000)	N/M	183 to 274	60 to 90
iii)	ISO 6 (1 000)	N/M	457 to 732	150 to 240
iv)	ISO 5 (100)	U/N/M	732 to 1 463	240 to 480
v)	ISO 4 (10)	U	914 to 1 646	300 to 540
vi)	ISO 3 (1)	U	1 097 to 1 646	360 to 540
vii)	Better Than ISO 3	U	1 097 to 1 829	360 to 600

NOTES

1 Air Changes per hour = Average airflow velocity × room area × 60 min/h

2 Room Volume

3 N=non unidirectional; M= mixed flow room; U= Unidirectional flow.

13.1.5 The classification of filters given in Table 32 should be applicable.

Table 32 Classification of Filters

(*Clause* 13.1.5)

Sl No. (1)	**Filter Class** (2)	**Overall Value Efficiency** (percent) (3)	**Overall Value Penetration** (percent) (4)	**Leak Test Efficiency** (percent) (5)	**Leak Test Penetration** (percent) (6)
i)	H 10	85	15	–	–
ii)	H 11	95	5	–	–
iii)	H 12	99.5	0.5	–	–
iv)	H 13	99.95	0.05	99.75	0.25
v)	H 14	99.995	0.005	99.975	0.025
vi)	U 15	99.999 5	0.000 5	99.997 5	0.002 5
vii)	U 16	99.999 95	0.000 05	99.999 75	0.000 25
viii)	U 17	99.999 995	0.000 005	99.999 9	0.000 1

13.1.6 Schedule of tests to demonstrate continuing compliance is given in Table 33.

Table 33 Schedule of Tests to Demonstrate Continuing Compliance

(*Clause* 13.1.6)

Sl No. (1)	**Test Parameter** (2)	**Class** (3)	**Maximum Time Interval** (4)
i)	To demonstrate compliance by particle counting	≤ ISO 5	6 months
		> ISO 5	12 months
ii)	Schedule of additional	All Classes	12 months
iii)	Air flow velocity or volume		
iv)	Air pressure difference	All Classes	12 months
v)	Schedule of optional tests	All Classes	24* months
vi)	Installed filter leakage		
vii)	Airflow visualisation	All Classes	24* months
viii)	Recovery	All Classes	24* months
ix)	Containment leakage	All Classes	24* months

* = Suggested time interval

13.2 Refrigeration for Cold Stores

13.2.1 *Key Elements and Components of Cold Room*

a) *Product quality* — Design and operation of cold storages is governed by the level of quality control parameters as per the individual products.

b) *Temperature of cold room* — During the entire storage period, the temperature should remain as constant as possible:

   1) In case of some produces the rate of cooling for the freshly cooled products shall be considered, as per recommended cool down period. (Respiration loads, mainly from fruits and vegetables).

   2) Shall avoid putting into a room a large amount of goods at a temperature too different from that of goods already in the room. The cold-production equipment should be checked to make sure it shall handle this extra load. Within one room the temperature should be as uniform as possible, as this affects not just products that are sensitive to temperature variations, but also those with recommended temperatures near 0 °C. These optimum conditions shall be approachable without risk of freezing.

   3) Dead zones and regular drafts shall be avoided. Temperature sensors should be placed around the room on the basis of the accuracy, as indicated by the manufacturer, of the automatic devices. Cold store temperature shall be either recorded or read at regular intervals. Thermometers should be protected from impact and yet be easily accessible. Temperature should be read at more than one location. Moreover, the temperature of the products themselves should be taken.

c) *Measurement of temperature of food* — A thermometer/temperature measurement device that shall measure the internal temperature of food, like one with a probe that shall be inserted into the food is required. Food internal temperature shall be measured as the surface temperature may be warmer or cooler than the temperature of the rest of the food. The thermometer shall be accurate to ±0.5°C. The thermometer/temperature measurement device should be cleaned and sanitized before inserting it into food. The probe should be washed in warm water and detergent, sanitized according to the sanitizer instructions or the instructions that thermometer accompanies, and the probe should be allowed to air dry or thoroughly dried with a disposable towel.

For further details, refer [D-3(50)].

13.2.2 *Typical Design Inputs for a Standard Cold Room*

The criteria involved in designing a cold room are similar to any warehouse, that is, storage capacity, facilities for receiving and dispatching goods, interior operating space, location of cold room, selection and location of refrigeration units. While designing cold room, the difference between room temperature and product temperature should be kept at a minimum value.

13.2.3 *Heat Loads*

Refrigeration load includes:

a) Transmission load, which is heat transferred into the refrigerated space through its surfaces;

b) Product load, which is heat removed from and produced by products when these are brought into and kept in the refrigerated space;

c) Internal load, which is heat produced by internal sources (for example, lights, electric motors, defrost mechanism and people working in the space);

d) Infiltration air load, which is heat gain associated with air entering the refrigerated space; and

e) Equipment related load. For example, Air-cooling unit fan motors, fork lifts, etc.

The first four segments of load constitute the net heat load for which a refrigeration system is to be provided; the fifth segment consists of all heat gains created by the refrigerating equipment itself. Thus, net heat load plus equipment heat load is the total refrigeration load.

While other loads are quite similar to loads in regular HVAC system design, the product load includes the primary refrigeration loads from products brought into and kept in the refrigerated space, which includes:

a) Heat that shall be removed to bring products to storage temperature. In case of some produces the rate of cooling for the freshly cooled products shall be considered, as per recommended cool down period.

b) Heat generated by produces in storage such as respiration loads, mainly from fruits and vegetables.

In addition, another new aspect in heat load is the heat from defrosting where the refrigeration coil operates at a temperature below freezing and shall be defrosted periodically, regardless of the room temperature. In order to avoid system oversizing, and to take full advantage of load diversity, hour-by-hour load calculation or simulation method should be used.

13.2.4 *Considerations for Cold Room Selection*

The conditions within a closed refrigerated chamber shall be maintained to preserve the stored product. This refers particularly to seasonal, short shelf life, and long-term storage.

The four major concerns for product compatibility are temperature, moisture, ethylene, CO_2 and odour. Specific considerations include:

a) Uniform temperatures as much as possible in empty condition as well as with product loaded condition;

b) Length of air blow and impingement on stored product;

c) Effect of relative humidity;

d) Effect of air movement on employees working in cold store;

e) Controlled ventilation, if necessary;

f) Product entering temperature;

g) Expected duration of storage;

h) Required product shipping temperature when leaving cold store;

j) Traffic in and out of storage area;

k) Design of storage bins; and

m) Size of food product (L × W × H) or volume.

Rack systems are mostly related to retail store refrigeration and are not considered as part of building system.

13.2.5 *Installation and Maintenance of Cold Room*

All panels for thermal insulation of cold storage shall be as per the accepted standard [D-3(28)].

Refrigeration system has to be selected for a particular application based on a particular refrigerant keeping in mind environmental issues. Thus, the refrigerant shall be a natural refrigerant like ammonia, carbon dioxide, hydrocarbons, or synthetic refrigerants, with very low GWP. System shall have either a) unitary system or b) DX systems or c) integrated single or d) two-stage system depending on the application temperature. The entire design has to be done as per proper standards.

Refrigeration system shall be assembled as per proper specifications to ensure that no refrigerant leakage. It should have proper emergency measures in case of any accidental leaks. The building structure shall be designed with adequate safety factors and the thermal insulation has to be protected properly from any possible occurrence of fire. Emergency alarms should be provided in the cold store with switches in each chamber.

Safety is critical in the design, construction and operation of refrigeration systems for cold storage, especially with ammonia systems. Refrigeration system's safety standards shall meet requirements relating to safe design, construction, installation, and operation of refrigeration systems by establishing safeguards for life, limb, heath and property as per the applicable safety standards. This includes, but is not limited to, occupancy classification, restriction on refrigerant use, installation restrictions, design and construction of equipment and systems, and operation and testing. Equipment selection and their placement should be such so as to ensure safe and easy maintenance. A safety review of the engineered design and equipment layout is recommended with participation from the owner's site operations and maintenance (O&M) team. Personnel safety measures are required as part of the facility design. The designer should prepare a system safety plan with full hazard analysis.

13.2.6 *Cold Room Safety*

The cold temperatures inside a low temperature cold room shall cause increase in blood viscosity and risk to life unless proper precautions are taken. An audio alarm should be installed outside the cold room, powered through a UPS and the switch should be fixed prominently and within reach, inside the cold room. This will help any person trapped inside to alert those outside, for help.

The following safety provisions should be kept/taken care of, at the cold room site:

a) Firefighting equipment;

b) Safe handling of refrigerant leaks;

c) Safety devices, controls and alarm systems;

d) Emergency lighting in the cold chambers;

e) Lightning arrestor;

f) First aid kit;

g) Air filters/breathers;

h) Emergency assembly points;

j) Regular safety drills and training;

k) Water shower in ammonia plants; and

m) Avoiding ramps as they become slippery when wet or frozen.

13.2.6.1 *Precautions against getting trapped in freezing room*

In order to facilitate getting out of a person who may accidentally get locked in a cold room, emergency exits shall be provided. These shall have facility to be opened from inside, even when they are locked from the outside. In all cases, following shall be installed in the freezing room:

a) Doors which shall open manually both from the inside and the outside (for functioning during power shortages, etc). In case of rooms with large dimensions say more than 25 m, it is advisable to provide emergency doors with UPS/battery lit exit sign at both ends of the freezing room for easy exit;

b) A signage system outside the freezing room with a steady or blinking light, and a siren or buzzer, activated from the inside by pressing a UPS-lit button. This button should also be connected to the caretaker's apartment, where a monitoring board shows where the button has been pressed. These visible and audible alarms should always be connected to a self-contained electric circuit, operated with a permanently charged battery. The same circuit should also connect to an independent, battery-operated emergency lighting system or a phosphorescent signalling system, all the way to the nearest emergency exit from the area; and

c) Electric or pneumatic sliding or manual doors, capable of being operated both from outside and inside by push button or pull cords, easily accessible, in case of large freezing rooms, to the persons inside/outside.

13.2.6.2 *Precautions against refrigerant leaks*

Safety measures shall be taken against leak of liquid or gaseous refrigerant. Consideration should also be given to installing gas detectors and shut-off valves. The safety of the people should be considered by installing in traffic and public areas with which the refrigerant supply shall be cut long before the refrigerant concentration reaches the level which would affect the people or the stored products. The gaskets around the cold storage door should be periodically inspected and corrected for any damage.

In refrigeration applications with ammonia (if used) as per standard practice, there is a risk of a high concentration accumulating in an enclosed room. With 15 percent to 28 percent by volume, and an ignition source (of 582 °C), it is possible to create a fast-burning process which could be something like an explosion. So, a rapid dilution/containment system or an expulsion system that is emergency ventilation should be installed as per relevant standards.

Self-contained breathing apparatuses and protective clothing for entering a building with a concentration of ammonia greater than 50 ppm. Ammonia clouds shall be neutralized with dry ice (CO_2) or transformed by fog nozzle, but there is then a risk of water pollution. For safety requirements for cold stores as also for refrigerant gas related safety, relevant standards shall be followed.

13.2.7 *Cold Room in Various Segments and Requirements*

The recommended temperature ranges for various applications/product categories to be stored in modular cold rooms are given below (temperature range is to be finally decided based on the product intended to be stored):

Sl No. (1)	*Application/Product Category* (2)	*Recommended Temperature Range* (3)
i)	Horticulture (fruits and vegetables)	+ 2 ºC to + 8 ºC
ii)	Floriculture	+ 2 ºC to + 6 ºC
iii)	Hotels, restaurants, fast food chains	+ 2 ºC to + 6 ºC
iv)	Pharmaceuticals	+ 8 ºC to – 25 ºC
v)	Dairy	+ 4 ºC to – 25 ºC
vi)	Ice cream	– 20 ºC to – 25 ºC
vii)	Ripening	+ 12 ºC to + 20 ºC
viii)	Controlled Atmosphere	+ 1 ºC to + 3 ºC

The above temperature ranges are indicative only, and may tend to vary, based on specific application requirements and other conditions. The relative humidity in most of the cases are above 85 percent to 90 percent range except pharmaceuticals, seeds, dry products and frozen products, or as required for a specific case by the user.

13.2.8 *Refrigeration Technologies for Cold Storage*

The prime considerations for selection should be life cycle cost, ease of maintenance and controls. Designers may select unitary or centralized systems that comprise unitary off the shelf products, DX units, centralized refrigeration system - air cooled or water-cooled.

13.2.9 *Ammonia Refrigeration System*

Ammonia is one of the most efficient applications, with the application range from high to low temperatures. With the ever-increasing focus on energy consumption, ammonia systems are a safe and sustainable choice for the future.

Ammonia is the most environmentally friendly refrigerant. It belongs to the group of so called “natural” refrigerants, and it has both global warming potential (GWP) and ozone depletion potential (ODP) equal to zero.

Ammonia is a toxic refrigerant, and it is also flammable at certain concentrations. That is why it has to be handled with care, and all ammonia systems have to be designed with safety in mind. At the same time, unlike most other refrigerants, it has a characteristic odour that shall be detected by humans even at very low concentrations. That gives a warning sign even in case of minor ammonia leakages. In case it is necessary to reduce ammonia charge, combination of ammonia and CO_2 (as cascade or as brine) could be a good and efficient option. For ammonia refrigeration system, good practice [D-3(29)] to be referred.

13.2.10 *Freon Refrigeration System*

The refrigeration system shall be unitary and centralised systems. Condenser cooling may be either water-cooled and air-cooled.

13.3 Supermarket Refrigeration

Supermarket refrigeration systems include various types of equipment and condensing units designed for both remote and direct applications. The further clauses cover the different systems and components used in supermarket refrigeration.

13.3.1 *Type of Supermarket Refrigeration Equipment*

The following types of refrigeration equipment are commonly used in supermarkets, offering various configurations such as remote and plug-in systems:

a) Open multideck chillers, with remote refrigeration system;

b) Glass door upright freezers and chillers with remote refrigeration system;

c) Display cold room (Wall replaced with glass doors);

d) Plug and play solutions;

e) Serve-over counters, plug-in type;

f) Self-service counters, plug-in type;

g) Stainless steel fish counters, plug-in type;

h) Plug-in island freezers;

j) Visi-coolers – plug-in type;

k) Visi-freezers – plug-in type;

m) Confectionery displays or cake showcase;

n) Four-sided visi-tower;

p) Four-sided visi-frozen tower/visi freezer; and

q) Glass top freezers with sliding glass (plug-in type).

13.3.2 *Remote Condensing Units for Remote Application*

Various types of condensing units are listed and explained below:

a) *Rack system for supermarkets* — The multi-compressor rack system comes with various types of reciprocating, scroll, or screw compressors. It should be compact, solidly built, and enhance performance with minimal pipe work. Also, the addition of an inverter in the rack enhances its efficiency and increases the life of the system;

b) *Individual condensing units* — Glass-door cold rooms, supermarket open or closed-door chillers and freezers shall be connected with a variety of condensing units. Their selection is based on cold room size, temperature and usage. The selection of these units is critical and should be verified ahead of installation.

   Various types of Compressors are used in the condensing units as listed below:

   1) *Air cooled systems* — These are generally for small to industrial applications, excessive pipe run or vertical lift distances and speciality blast chilling and freezing applications. They are highly efficient and perform tirelessly; and

   2) *Water cooled systems* — These are generally for medium to industrial applications, these types of units are very effective in malls, where units are required to be installed in the basement or in a hidden area, were fresh air and exhaust facilities in not available. These are also suitable for chilling and freezing applications. They are highly efficient but need treated water and regular maintenance.

See accepted standard [D-3(7)] for more details.

13.4 Data Centre

13.4.1 *Location*

a) *Seismic considerations*:

   1) *Seismic zone mapping* — Consult the latest seismic zone map of India {*see* accepted standard [D- 3(30)]} to accurately assess the risk level of the proposed location; and

   2) *Structural design* — Engage qualified structural engineers experienced in seismic design for data centres. Adhere to the latest codes and standards, incorporating base isolation or energy dissipation systems if necessary.

b) *Proximity to utilities*:

   1) *Power grid stability* — Evaluate the historical reliability and voltage stability of the local power grid. Prioritize locations with minimal outages and voltage fluctuations;

   2) *Redundant power sources* — Having access to two independent power feeds from different substations for enhanced reliability;

   3) *Water availability* — Assess water availability throughout the year, accounting for seasonal variations. Consider water recycling and rainwater harvesting to reduce dependency on municipal supply; and

   4) *Distance to utilities* — Minimize the distance between the data centre and power/water sources to reduce transmission losses and infrastructure costs.

c) *Connectivity*:

   1) *Carrier diversity* — Ensure access to at least two diverse fibre paths from different carriers to avoid single points of failure;

   2) *Latency* — Consider the proximity to major internet exchange points (IXPs) and content delivery networks (CDNs) for low latency connections; and

   3) *Future expansion* — Plan for future connectivity needs by choosing locations with ample capacity for additional fiber optic cables.

d) *Environmental factors*:

Flood risk — Refer to flood zone maps and avoid areas prone to flooding. If unavoidable, implement appropriate flood mitigation measures (elevated platforms, watertight barriers):

1) *Cyclone and wind risk* — Consider the historical cyclone tracks and wind speeds in the region. Design the building to withstand wind loads as per local codes;

2) *Air quality* — Analyse the ambient air quality data to understand the levels of particulate matter (PM), dust, and other pollutants. Employ high-efficiency air filtration systems to protect sensitive equipment if required;

3) *Electromagnetic interference (EMI)* — Evaluate potential sources of EMI (power lines, radio towers, etc.) and implement shielding if necessary; and

4) *Environmental clearances* — Understand and comply with all environmental impact assessment (EIA) and pollution control norms relevant to data center construction and operation.

e) *Temperature and humidity*:

1) *Climate zone analysis* — Refer to India's climatic zone map (as per Part D 'Building Services, Section 1 Lightning and Ventilation' of this NBCS) to identify regions with favourable temperature and humidity profiles for data centre operations;

2) *Microclimate considerations* — Within a climatic zone, local variations shall exist. Investigate microclimates around the proposed site, accounting for factors like proximity to water bodies, elevation, and prevailing wind patterns;

3) *Historical weather data* — Analyze at least 10 years of historical temperature and humidity data for the location. Pay close attention to peak summer temperatures and humidity levels, which will drive cooling requirements;

4) *Wet-bulb temperature* — Evaluate wet-bulb temperature data as a critical indicator of evaporative cooling potential. Higher wet-bulb temperatures limit the effectiveness of evaporative cooling technologies;

5) *Climate change projections* — Consult climate change models and projections for the region to anticipate future shifts in temperature and humidity patterns. Factor these projections into long-term planning and design; and

6) *Adaptive cooling strategies* — Explore the potential for free cooling or hybrid cooling systems that shall leverage favourable ambient conditions to reduce energy consumption.

f) *Accessibility and logistics*:

1) *Transportation infrastructure* — Evaluate the quality and capacity of road networks, proximity to airports/railway stations, and availability of reliable freight transport for equipment delivery and maintenance;

2) *Manpower access* — Consider the ease of commute for staff and the availability of skilled IT professionals in the region. Plan to be in vicinity of a public transport infrastructure or provide common shuttle service; and

3) *Expansion space* — Ensure sufficient space for future expansion of the facility or campus, including considerations for power and network infrastructure upgrades.

g) *Security and risk mitigation*:

1) *Physical security* — Evaluate the overall security environment of the location, including crime rates and potential threats. Implement robust physical security measures for the data centre premises;

    2) *Cybersecurity* — Consider the proximity to potential cybersecurity risks and implement stringent network security protocols to protect data; and

    3) *Disaster recovery* — Develop a comprehensive disaster recovery plan that considers natural disasters, power outages, and other disruptions.

13.4.2 *Redundancy for Cooling Infrastructure*

a) *Chillers*:

    1) Implement N+1 redundancy for chillers, ensuring that the remaining chillers shall handle the full cooling load even if one unit fails. Consider 2N redundancy for critical facilities or those in hot climates;

    2) Size chillers based on peak cooling load with a safety margin to accommodate future expansion or equipment upgrades; and

    3) Implement preventive maintenance schedules and conduct regular inspections to ensure optimal performance and reliability.

b) *Precision air handling units* (*PAHUs*):

    1) Deploy N+1 redundancy for PAHUs, ensuring sufficient airflow even if one unit is offline for maintenance or repair;

    2) Consider zoning the data center and assigning dedicated PAHUs to each zone for better control and redundancy; and

    3) Equip PAHUs with variable speed drives (VSDs) to optimize airflow based on real-time cooling demands, improving energy efficiency.

c) *Power distribution for cooling*:

    1) Provide redundant power feeds (A+B) to critical cooling equipment, including chillers, PAHUs, and pumps;

    2) Utilize dedicated PDUs for cooling infrastructure with branch circuit monitoring to track power consumption and identify potential issues; and

    3) Implement emergency power off (EPO) functionality to safely shut down cooling systems in emergencies.

d) *Additional considerations for cooling redundancy*:

    1) If the climate permits, explore the use of free cooling (air-side or water-side economizers) to reduce reliance on mechanical cooling and improve energy efficiency;

    2) Design chilled water and condenser water piping systems with redundancy to prevent single points of failure and ensure continuous circulation;

    3) Implement N+1 redundancy for cooling towers or consider alternative cooling technologies like dry coolers or adiabatic coolers for water-scarce regions; and

    4) Deploy redundant chilled water and condenser water pumps with automatic switchover capabilities in case of a pump failure.

13.4.3 *Water Leak Detection* (*WLD*)

a) *Comprehensive coverage* — Install a water leak detection system with adequate coverage in all areas prone to leaks, such as under raised floors, near cooling systems, piping, and water entry points. Tailor the coverage to the specific layout and potential risks of each data centre;

b) *Sensor types* — Utilize a combination of sensor technologies to ensure comprehensive detection:

   1) *Spot Sensors* — Rope sensors or point sensors for localized detection in critical areas like under racks and near equipment; and

   2) *Zone sensors* — For broader coverage in areas like underfloor plenums or around piping systems.

c) *Sensitivity and response time*

   1) *Sensor selection* — Choose sensors with high sensitivity and rapid response times to enable early detection and minimize potential damage;

   2) *Calibration* — Regularly calibrate sensors and adjust sensitivity levels based on environmental conditions and potential risk factors;

   3) Alarms and Notifications;

   4) *On-site alerts* — Implement visual and audible alarms within the data centre to immediately notify onsite personnel of a leak; and

   5) *Remote Notifications* — Utilize remote notifications via email, SMS, or dedicated monitoring systems to alert responsible personnel even when they are off-site.

d) *BMS integration*

   1) *Centralized monitoring* — Integrate the WLD system with the BMS for centralized monitoring and control, enabling real-time visualization of leak locations and status; and

   2) *Automated responses* — Configure the BMS to trigger automated responses to leaks, such as shutting off water valves or activating backup systems.

13.4.3.1 A few additional considerations to be taken are:

a) *Regular testing and maintenance* — Conduct periodic testing and maintenance of the WLD system, including sensor checks, cleaning, and calibration;

b) *Documentation* — Maintain detailed documentation of the WLD system, including sensor locations, alarm thresholds, and maintenance records; and

c) *Emergency response procedures* — Develop and regularly review clear emergency response procedures for water leaks, ensuring staff are trained and prepared to act swiftly to mitigate damage

13.4.4 *Inside Acceptable Temperature and RH Condition*

a) *Temperature*:

   1) Maintain a temperature range between 18 °C to 27 °C for optimal performance and longevity of IT equipment;

   2) Consider higher temperature setpoints (closer to 27 °C) where possible to improve energy efficiency, ensuring equipment compatibility; and

   3) Minimize temperature fluctuations and avoid hot spots or cold spots through effective airflow management and cooling strategies.

b) *Relative humidity* (*RH*):

   1) Keep RH within the range of 8 percent to 60 percent to prevent condensation on equipment and electrostatic discharge (ESD) that shall cause damage;

      NOTE — The upper limit may be lower (50 percent or even 35 percent) depending on the presence of specific corrosive gases in the environment.

2) Monitor dew point temperature and ensure a safe margin between the dew point and the lowest surface temperature in the data centre; and

3) Employ humidification or dehumidification systems as needed to maintain RH within the desired range, especially in regions with fluctuating humidity levels.

c) *Monitoring and control*:

1) *Real-time visibility* — Implement a monitoring system that provides real-time visibility into all critical infrastructure components, including power, cooling, security, and environmental conditions.

2) *Data granularity* — Capture and store granular data at frequent intervals to enable in-depth analysis and trend identification.

3) *Multi-protocol support* — Ensure compatibility with various communication protocols (SNMP, Modbus, BACnet) for seamless integration of diverse equipment and systems.

4) *Centralized management*:

   i) *Unified platform* — Deploy a centralized management platform (BMS, DCIM) to aggregate data from all monitored systems, enabling holistic oversight and control of the data center environment;

   ii) *Remote access* — Provide secure remote access to the management platform, empowering authorized personnel to monitor and manage the data center from anywhere, anytime; and

   iii) *User-friendly interface* — Choose a platform with an intuitive and user-friendly interface for easy navigation and efficient operation.

5) *Advanced analytics*:

   i) *Predictive analytics* — Leverage AI-powered analytics to analyze historical and real-time data, enabling predictive maintenance, anomaly detection, and optimization of resource utilization;

   ii) *Machine learning* — Utilize machine learning algorithms to learn from data patterns and proactively identify potential issues or inefficiencies; and

   iii) *Data visualization* — Employ data visualization tools to present complex information in a clear and concise manner, facilitating decision-making and troubleshooting.

6) *Automated control*:

   i) *Threshold-based actions* — Configure the system to trigger automated actions based on predefined thresholds or events, such as adjusting cooling setpoints, initiating failover procedures, or sending notifications; and

   ii) *Workflow automation* — Streamline routine tasks through workflow automation, reducing manual intervention and human error.

7) *Alarms and notifications*:

   i) *Prioritized alerts* — Implement a multi-tiered alarm system to prioritize critical events and ensure prompt attention to potential issues;

   ii) *Multiple notification channels* — Utilize multiple communication channels (email, SMS, phone calls, mobile app) to ensure timely notifications reach relevant personnel; and

   iii) *Escalation procedures* — Define clear escalation procedures for critical alarms to ensure swift and appropriate action.

8) *Additional Recommendations*:

   i) *Cybersecurity* — Implement robust cybersecurity measures to protect the monitoring and control systems from unauthorized access and potential threats;

   ii) *Data retention and analysis* — Retain historical monitoring data for long-term analysis and trend identification, aiding in capacity planning and optimization efforts; and

   iii) *Training and skill development* — Provide comprehensive training to data center staff on the use and management of monitoring and control systems.

13.4.5 *Air Distribution Pattern with Positive Pressure*

a) *Hot/Cold aisle containment*:

   1) *Mandatory implementation* — Implement hot/cold aisle containment systems for all data centers to ensure efficient cooling and prevent hot air recirculation;

   2) *Containment types* — Choose between physical barriers (for example, aisle doors, curtains, or rigid panels) or chimney rack systems based on space constraints, future flexibility requirements, and desired level of containment efficiency; and

   3) *Bypass airflow control* — Minimize bypass airflow (air leakage around containment systems) to the lowest achievable level, ideally below 5 percent. Employ blanking panels, brush strips, and proper sealing to achieve optimal containment.

b) *Positive pressure*:

   1) *Pressure differential* — Maintain a slight positive pressure differential of 2.5 Pa to 5 Pa between the data centre and surrounding areas. This effectively prevents dust, pollutants, and other contaminants from entering the data centre;

   2) *Airlock systems* — Implement airlock systems at all entrances to further enhance pressure control and minimize air infiltration during door openings; and

   3) *Pressure monitoring* — Continuously monitor pressure differentials using differential pressure sensors and integrate them with the BMS for automated control and alarms in case of deviations.

c) *Computational fluid dynamics (CFD) analysis*:

   1) *Design optimization* — Utilize CFD modelling during the design phase to comprehensively optimize airflow patterns, identify potential hot spots, and ensure adequate cooling for all equipment under various operating scenarios; and

   2) *Validation and troubleshooting* — Use CFD analysis to validate the effectiveness of the implemented containment and airflow management strategies. It shall also aid in troubleshooting cooling issues and optimizing airflow distribution as the data centre evolves and equipment densities change.

13.4.5.1 Following are some additional considerations to be taken for airflow management:

a) *Raised floor plenum* — Design the raised floor plenum with appropriate airflow tiles and perforated tiles strategically placed to distribute cold air efficiently to IT equipment intakes;

b) *Cable management* — Implement meticulous cable management within racks and under raised floors to avoid airflow obstructions and maximize cooling efficiency; and

c) *Equipment placement* — Consider the airflow requirements of different equipment types during rack layout and placement within the data centre to ensure optimal cooling for all components.

13.4.6 *Commissioning and Retrofitting Guidelines for Data Centres*

a) *General principles*:

   1) *Adherence to standards* — Follow the commissioning process and relevant industry standards for commissioning and retrofitting processes;

   2) *Documentation* — Maintain thorough documentation throughout the project, including design intent, test plans, procedures, and results;

   3) *Independent commissioning agent* (*CxA*) — Engage a qualified and independent CxA to oversee the commissioning or retrofitting process. The CxA should be involved from the early design stages to ensure that the project meets its intended performance and efficiency goals; and

   4) *Collaboration and communication* — Foster effective collaboration and communication among all stakeholders, including the owner, design team, contractors, and CxA.

b) *Commissioning phases*:

   1) *Factory acceptance testing* (*FAT*):

      i) *Purpose* — Verify that equipment and systems meet specified requirements before shipment to the site;

      ii) *Scope* — Conduct functional and performance tests on major equipment (for example, chillers, UPS systems, generators, PAHUs) at the manufacturer's facility; and

      iii) *Documentation* — Document test procedures, results, and any identified issues for resolution before shipment.

   2) *Site acceptance testing (SAT)*:

      i) *Purpose* — Verify that installed equipment and systems function correctly and meet performance specifications on-site;

      ii) *Scope* — Conduct comprehensive testing of individual systems and components (electrical, mechanical, controls, fire protection) after installation but before integration; and

      iii) *Documentation* — Document test procedures, results, and any deficiencies for rectification before proceeding to the next phase.

   3) *Integrated system testing* (*IST*):

      i) *Purpose* — Verify the proper interaction and performance of all systems and components as an integrated whole under various operating conditions;

      ii) *Scope* — Conduct tests under normal, peak load, and simulated failure scenarios to assess system redundancy, failover capabilities, and overall performance; and

      iii) *Documentation* – Document test procedures, results, and any identified issues for resolution before final handover.

13.4.6.1 *Specific guidelines for retrofitting*

a) *Thorough assessment* — Conduct a detailed assessment of the existing data centre infrastructure, including its current performance, energy efficiency, capacity limitations, and potential risks;

b) *Clear objectives* — Define clear objectives for the retrofitting project, focusing on areas such as energy efficiency improvements, capacity upgrades, reliability enhancement, or technology modernization;

c) *Phased approach* — Consider a phased approach to minimize disruption to ongoing operations, allowing for gradual implementation and testing of new systems while maintaining service continuity;

d) *Compatibility and integration* — Ensure that new equipment and systems are compatible with existing infrastructure and shall be seamlessly integrated into the current environment; and

e) *Thorough testing* — Conduct rigorous testing of all retrofitted systems and components, both individually and in an integrated manner, to validate performance and ensure compliance with design intent.

13.4.6.2 A few additional recommendations for retrofitting are:

a) *Energy efficiency focus* — Prioritize energy-efficient technologies and design strategies during commissioning and retrofitting to reduce operational costs and environmental impact;

b) *Monitoring and control* — Implement comprehensive monitoring and control systems to enable real-time visibility, proactive management, and optimization of data centre performance; and

c) *Documentation and training* — Provide detailed documentation and training to data centre staff on the operation and maintenance of new or retrofitted systems.

13.4.7 *Electrical Safety*

a) *Earthing and bonding* — Effective earthing and bonding are crucial for personnel safety and equipment protection:

   1) *Earth resistance* — Achieve low earth resistance as per good practice [D-3(31)] for effective fault current dissipation. The specific requirements depend on voltage levels and earthing methods. Use multiple earth electrodes and ground enhancement techniques if needed. Regularly test and inspect the earthing system;

   2) *Automatic disconnection of supply* — Fault loop impedance of every circuit shall be lower enough to ensure automatic disconnection of supply as per good practice [D-3(31)]. If fault loop impedance is higher than the requirement of OCPD, RCDs shall be used. For equipment with 1 phase VFD's Type F RCD shall be used and for equipment with 3 phase VFD's Type B RCDs shall be used;

   3) *Bonding* — Ensure proper bonding of all conductive elements to create an equipotential environment and prevent electrical hazards. Use low-impedance bonding conductors and regularly inspect connections;

   4) *Lightning protection* — Protect your data centre from lightning strikes with a robust system complying with accepted standard [D-3(32)]. The LPS should include air terminals, down conductors, and earth termination networks. Install surge protection devices (SPDs) to safeguard sensitive equipment and ensure effective equipotential bonding for shielding effectiveness; and

   5) *Water pipes* — Avoid using water pipes as earth electrodes. Use of multiple earth electrodes are in violation to the recommendation of good practice [D-3(31)] and shall be avoided.

b) *Circuit protection* — Prevent overcurrent's and short circuits with appropriate circuit protection devices:

   1) *Circuit breakers and fuses* — Install appropriate circuit protection devices (MCBs, MCCBs, fuses) with suitable ratings to protect against overloads and short circuits;

   2) *Selective coordination* — Ensure selective coordination of devices to minimize disruptions caused by faults; and

   3) *Arc flash protection* — Conduct an arc flash hazard analysis and implement appropriate protective measures including appropriate personal protective equipment (PPE) and arc-resistant switchgear (for example, arc-resistant switchgear, personal protective equipment) to safeguard personnel from arc flash incidents.

c) *Regular inspections* — Regular inspections are vital for identifying and addressing potential hazards.

   1) *Scheduled inspections* — Conduct comprehensive inspections at least annually. Depending on the criticality of the equipment;

2) *Thermography* — Utilize thermography to identify hotspots and potential issues; and

3) *Corrective actions* — Address any identified deficiencies or potential hazards promptly to maintain a safe electrical environment.

13.4.7.1 Some of the additional considerations to be taken for electrical safety are:

a) *Design and installation* — Engage qualified professionals for design and installation with accepted standards [D-3(33)] and [D-3(34)] and the National Building Construction Standards;

b) *Power quality* — Monitor and maintain power quality parameters (voltage, current, harmonics) within acceptable limits;

c) *Emergency power off (EPO)* — Implement EPO systems for critical areas; and

d) *Training and awareness* — Provide regular electrical safety training to staff, including arc flash safety and lockout/tagout procedures.

13.4.8 *Periodic Maintenance/Predictive Maintenance*

a) *Periodic maintenance*:

  1) *Comprehensive schedule* — Develop and adhere to a comprehensive preventive maintenance schedule for all critical equipment, including:

    i) *Electrical systems* — UPS, generators, switchgear, PDUs;

    ii) *Mechanical systems* — Chillers, cooling towers, pumps, CRAC/CRAH units;

    iii) *Fire suppression systems* — Sprinklers, gas suppression systems, fire alarm panels; and

    iv) *IT equipment* — Servers, storage arrays, network switches.

  2) *Frequency* — Base the maintenance frequency on manufacturer recommendations, equipment criticality, and operating conditions. Generally:

    i) *Quarterly or as per OEM recommendations* — CRAC/CRAH units, air filters, UPS batteries;

    ii) *Semi-annually or as per OEM recommendations* — Generators, electrical switchgear; and

    iii) *Annually or as per OEM recommendations* — Chillers, cooling towers, fire suppression systems.

  3) *Qualified technicians* — Engage qualified and certified technicians for maintenance activities to ensure proper procedures are followed and equipment warranties are maintained.

  4) *Documentation* — Maintain detailed records of all maintenance activities, including dates, tasks performed, and any observations or issues encountered.

b) *Predictive maintenance*:

  1) *Sensor deployment* — Install sensors on critical equipment to monitor parameters such as vibration, temperature, humidity, current, and power quality;

  2) *Data collection and analysis* — Collect and analyse sensor data using advanced analytics platforms and machine learning algorithms to identify trends, anomalies, and potential failures;

  3) *Early warning system* — Set up alerts and notifications to proactively identify equipment degradation or impending failures; and

  4) *Proactive maintenance* — Schedule maintenance activities based on predictive insights, minimizing unplanned downtime and optimizing equipment lifespan. Adhere to recommended maintenance intervals or as per OEM recommendations.

c) *Thermal imaging*:

  1) *Regular inspections* — Conduct periodic thermal imaging inspections of electrical connections, switchgear, and IT equipment to identify hotspots and potential overheating issues;

  2) *Qualified thermographers* — Engage certified thermographers to perform inspections and interpret results; and

  3) *Corrective action* — Address any identified hotspots promptly to prevent equipment damage and potential fire hazards.

13.4.8.1 Some additional considerations to be taken for maintenance are:

a) *Spare parts inventory* — Maintain an adequate inventory of critical spare parts onsite to enable quick repairs and minimize downtime;

b) *Vendor support* — Establish strong relationships with equipment vendors and leverage their expertise for troubleshooting and support;

c) *Remote monitoring* — Utilize remote monitoring and management tools to gain real-time insights into equipment health and performance; and

d) *Training* — Provide ongoing training to data centre staff on maintenance procedures and predictive maintenance tools.

13.4.8.2 The specific considerations for the Indian context are:

a) *Dust and pollution* — In regions with high dust and pollution levels, increase the frequency of air filter replacements and AHU maintenance;

b) *High temperatures and humidity* — Pay close attention to the performance and maintenance of cooling systems during peak summer months; and

c) *Power fluctuations* — Implement measures to protect equipment from power fluctuations and surges, which shall impact equipment lifespan.

13.4.9 *Design for Future Expansion and Technology*

To consider for the future expansions scalability in below dimensions to be considered:

a) *Capacity planning*:

  1) Conduct a detailed capacity planning exercise, factoring in:

    i) Projected IT load growth based on business forecasts and technology roadmaps;

    ii) Anticipated storage requirements, including data growth rates and retention policies;

    iii) Network bandwidth demands considering increasing traffic and application needs; and

    iv) Time horizon for expansion planning (typically 5 years to 10 years).

  2) Utilize industry-standard tools and methodologies for capacity planning, such as data centre infrastructure management (DCIM) software and power/cooling modelling.

b) *White space and power provisioning*:

  1) Design the data centre with adequate white space to accommodate future rack installations and expansions:

    i) Consider factors like anticipated growth rate, rack densities, and desired aisle widths; and

    ii) Leave room for future power and cooling distribution infrastructure.

  2) Provision power capacity based on projected IT load growth and power densities:
    i) Factor in the power requirements of new technologies and potential increases in rack densities; and
    ii) Account for inefficiencies in power distribution and cooling systems.

c) *Modular power and cooling*:
  1) Implement modular UPS systems, PDUs, and cooling units that shall be easily scaled up as IT load increases. This allows for incremental expansion and avoids upfront overinvestment; and
  2) Consider using modular power skids and containerized cooling solutions for flexibility and rapid deployment.

d) *Network infrastructure*:
  1) Design a flexible and scalable network architecture with ample capacity for future bandwidth requirements:
    i) Evaluate the need for higher-speed network technologies to accommodate future demands.
  2) Deploy high-density fiber optic cabling and modular network switches to facilitate seamless upgrades and expansions.

14 VENTILATION SYSTEMS

Ventilation is the process of changing air in an enclosed space. A portion of the air in the space shall be continuously withdrawn and replaced by fresh air drawn from outside to maintain the required level of air purity, health, comfort and safety of building occupants.

Ventilation shall be done either by mechanical systems or through natural means. Mechanical ventilation usually consists of fans, filters {accepted standards [D-3(15)], [D-3(16)], [D-3(17)] and [D-3(18)]}, ducts, air diffusers and outlets for air distribution within the building. Natural ventilation and natural exhaust are covered in Part D 'Building Services, Section 1 Lighting and Ventilation' of this NBCS. The scope is therefore restricted to mechanical ventilation.

14.1 Types of Fans

Fans are broadly categorised as:

a) Axial fan; and

b) Centrifugal.

In axial fans, the direction of air flow is parallel to the fan's axis of rotation and in centrifugal fans, this direction is perpendicular. Each category encompasses further designs for example in centrifugal – forward curved, backward curved/inclined, aerofoil fans, plug/plenum fans and in axial – tube axial, vane axial and propellers. Fans have also been classified in terms of their application and special design for example roof ventilator, inline fan, jet fan, spark resistant fan, fume extract fan to name a few. These types may be available in both centrifugal and axial designs.

Recent advances in fan technology have led to the development of mixed-flow fans. These fans combine the high-pressure capability of centrifugal fans with the high flow rate of axial fans.

14.1.1 *Application*

Table 34 provides a general guideline on selecting the type of a fan for a given application, for example for kitchen exhaust, a backward curved centrifugal fan, for basement smoke ventilation, a high temperature rated fan and for laboratory ventilation, a fume extract fan.

Table 34 General Guideline for Fan Type and its Application

(*Clause* 14.1.1)

Sl No.	General Fan Selection Guide	Double Inlet Centrifugal			Single Inlet Centrifugal			Plenum	Tube Axial	Vane Axial	Propeller	Mixed Flow	Tubular Centrifugal	Roof Ventilator	Spark Resistant Construction	Fume Extract Fan	Jet Fan	Powerless Roof Ventilator	High Volume Low Speed (HVLS)
	Application	FC	BC/ BI	AF	FC	BC/ BI	AF												
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
i)	Air handling units - static less than 70 mm	X	X	X				X											
ii)	Air handling unit - static above 70 mm		X	X				X											
iii)	Fan filter units	X	X	X				X											
iv)	Cabinet fans	X	X	X				X											
v)	Basement ventilation-supply fans	X	X	X				X	X	X									
vi)	Basement ventilation-exhaust fans		X			X			X	X		X							
vii)	Ductless basement ventilation																X		
viii)	Kitchen exhaust					X	X	X	X										
ix)	Smoke extraction		X			X		X	X	X		X		X					
x)	Chemical fume extraction								X	X						X			
xi)	Wall mounted exhaust								X	X	X								
xii)	Roof exhaust													X				X	

Table 34 (*Concluded*)

Sl No.	**General Fan Selection Guide**	**Double Inlet Centrifugal**			**Single Inlet Centrifugal**			**Plenum**	**Tube Axial**	**Vane Axial**	**Propeller**	**Mixed Flow**	**Tubular Centrifugal**	**Roof Ventilator**	**Spark Resistant Construction**	**Fume Extract Fan**	**Jet Fan**	**Powerless Roof Ventilator**	**High Volume Low Speed (HVLS)**
	Application	FC	BC/ BI	AF	FC	BC/ BI	AF												
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
xiii)	Toilet exhaust (Ducted)											X	X						
xiv)	Toilet exhaust (Unducted)										X			X					
xv)	Ventilation of explosive environment														X				
xvi)	Ventilation of nuclear facilities		X	X				X	X										
xvii)	Ventilation of dusty environment		X			X		X	X										
xviii)	Tunnel ventilation								X	X							X		
xix)	Large volume recirculation																		X

14.1.2 Selection and Operation

A fan consumes most of the energy in a mechanical ventilation system. To meet a given requirement of air flow rate and system pressure drop, the primary fan selection criterion shall be the overall fan system power consumption and efficiency, that is by the fan, the drive train, the motor and any electric controller such as a variable frequency drive (VFD). This is shown schematically in Fig. 9.

The fan energy index (FEI) is a measure of the overall fan system efficiency and relates the electric power input to the fan motor (or to the motor drive) with the aerodynamic power imparted to the air by the fan (for additional information special publication may be referred). FEI is an index (ratio) that compares the overall energy performance of the selected fan to that of a reference fan. The reference fan is a conceptual fan capable of producing the required airflow and fan pressure at a specified shaft input power using a V-belt drive and a 4-pole IE3 efficiency classification electric motor. The reference fan does not include speed control. FEI of a selected fan at a desired duty point is defined as:

FEI = (Reference Fan Electrical Input Power)/(Selected Fan Electrical Input Power)

NOTE — Special publication maybe ISO12759-6 : 2024 ‘Efficiency Classification for Fans, Part 6 – Calculation of the Fan Energy Index’.

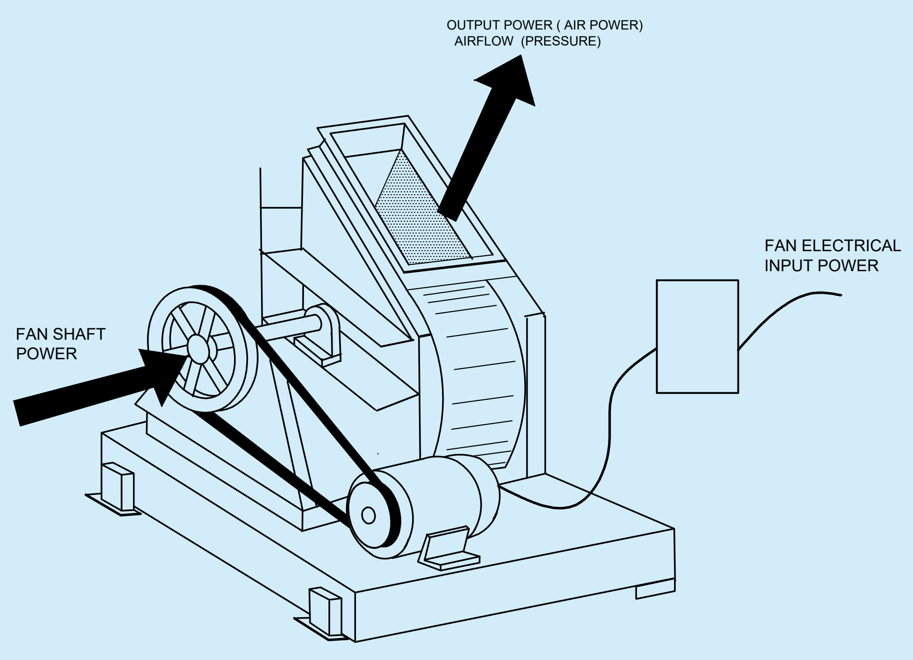


FIG. 9 FAN INPUT (ELECTRIC) POWER TO FAN OUTPUT (AIR) POWER

14.1.2.1 *Reference fan*

The Reference fan is a conceptual fan whose input power and efficiency values for a given duty point (flow rate Q and pressure P) are predefined and are used as a reference to calculate the FEI of any fan. The same reference fan is used to calculate FEI of various types of fans for a given duty point (Q, P).

Reference fan shaft power ($H_{\mathrm{i,ref}}$) at a given duty point of flow rate Q and Pressure P is defined as:

For Ducted Outlet Fans $H_{\mathrm{i,ref}} = (Q + 0.118) \times (P_t + 100)/660$ kW

For Free Outlet Fans $H_{\mathrm{i,ref}} = (Q + 0.118) \times (P_s + 100)/600$ kW

where Q is in m^3/s and P_t is total pressure, P_s is static pressure, both in Pascals.

Reference transmission efficiency ($\eta_{\mathrm{t,ref}}$) is defined as a function of reference fan shaft power $H_{\mathrm{i,ref}}$ as:

$$\eta_{\mathrm{t,ref}} = \frac{0.96}{[H_{\mathrm{i,ref}}/(H_{\mathrm{i,ref}} + 1.64)]^{0.05}}$$

Combining fan shaft power with transmission efficiency, the Reference motor output power shall be calculated as:

$$= H_{i,ref}/\eta_{t,ref}$$

Basline motor efficiency ($\eta_{m,ref}$) shall be calculated from the Reference motor output power from the graph in Fig. 10.

By reading the value of Reference motor efficiency corresponding to the reference motor output power, the reference motor input power (or Reference fan electric power input) shall be calculated as under:

$$= H_{i,ref}/(\eta_{t,ref} \times \eta_{m,ref})$$

The reference electric power input at a given duty point is the same irrespective of fan type and shall be used to calculate the FEI for any fan selected for the given duty point.

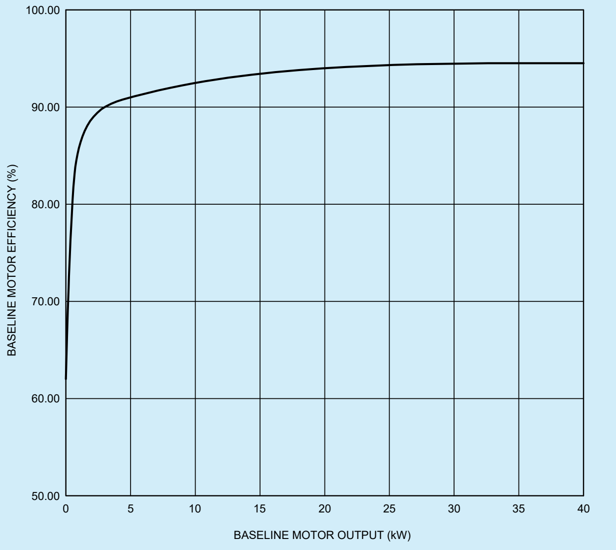


FIG. 10 MECHANICAL AND MOTOR EFFICIENCY REQUIREMENTS (MINIMUM) FOR FANS IN ECSBC BUILDINGS

14.1.2.2 *Fan selection criteria*

The following selection criterion shall be used to select fan for various type of mechanical ventilation applications for a new building:

a) For axial fans requiring a shaft power of 2.0 kW or more, its FEI shall be 1.00 or more;

b) For centrifugal fans and mixed flow fan requiring a shaft power of 2.0 kW or more, its FEI shall be 1.10 or more; and

c) The above prescribed minimum FEI values shall be applicable for all the duty points the fan is selected to operate at.

The choice of a fan type and its drive arrangement also depends on the nature of air to be handled and the type of application. If the fan has to handle dust laden or contaminated air, for example, industrial exhaust or kitchen exhaust, the fan drive arrangement (motor, pulleys, bearing and belts) shall be kept outside the air stream. The same applies to the temperature of air to be handled. For higher-than-normal air temperatures, for example in smoke ventilation, the fan shall be rated for high temperature application.

If fan noise is a concern, it shall be addressed by specifying acceptable limits of certified fan sound power ratings and not by arbitrary limits on fan speed or fan outlet velocity. Specifying fan noise in terms of fan sound pressure levels shall be discouraged.

14.2 Industrial Ventilation

In Industrial buildings, ventilation is needed not only to provide oxygen rich fresh air normally required for health and hygiene and to mitigate against thermal loads due to equipment, people and building heat gains, but also to remove and maintain the hazardous industrial pollutants within safe limits.

14.2.1 *Ventilation for Heat Control*

The required ventilation flow rate shall be calculated both for the sensible and latent heat load. In majority of cases the sensible heat load far exceeds the latent heat load, so the design rate usually shall be calculated on the basis of sensible heat alone. The sensible heat load includes solar heat gain, occupancy, lighting load, equipment load as well as other particular sources, if any.

The ventilation flow rate shall be calculated using the following equation:

$$Q_s = 3.462 \times \frac{H_s}{\Delta T}$$

where

Q_s = air volume flow rate, in m^3/h;

H_s = sensible heat load, in kcal/h; and

ΔT = allowable temperature rise, in °C.

Ventilation system shall be designed for air to flow through the hot environment in a manner that will effectively control the excess heat.

14.2.2 *General (Dilution) Ventilation Versus Local Exhaust Ventilation*

General exhaust ventilation (dilution ventilation) is appropriate when,

a) emission sources contain materials of relatively low hazard (*see* note);

b) emission sources are primarily vapours or gases, or small, respirable size aerosols (those not likely to settle);

c) emissions occur uniformly;

d) emissions are widely dispersed;

e) moderate climatic conditions prevail;

f) heat is to be removed from the space by flushing it with outside air;

g) concentrations of vapours are to be reduced in an enclosure; and

h) portable or mobile emission sources are to be controlled.

NOTE — The degree of hazard is related to toxicity, dose rate, and individual susceptibility.

Local exhaust ventilation is appropriate when:

1) emission sources contain materials of relatively high hazard;

2) emitted materials are primarily larger diameter particulates (likely to settle);

3) emissions vary over time;

4) emission sources consist of point sources;

5) employees work in the immediate vicinity of the emission source;

6) the plant is located in a severe climate; and

7) minimizing air turnover is necessary.

Local exhaust ventilation normally requires lower air flows than general (dilution) ventilation.

Dilution ventilation is used to reduce the concentration of vapours from a given liquid solvent in the air to a safe level known as the threshold limit value (TLV) of the solvent expressed in ppm (parts per million). For a given solvent, the volume of air required to dilute its vapour concentration to below TLV shall be calculated by the following equation:

$$\text{Air volume in m}^3\text{ per kg of evaporation} = \frac{(24 \times 10^6 \times k)}{M \times TLV}$$

where

k = constant varying from 3 to 10 depending on the solvent, uniformity of air distribution, dilution of vapours in air and location of exhaust hood; and

M = molecular weight of the solvent.

A local exhaust ventilation system normally consists of a hood, a duct system, air cleaner, a fan and an exhaust stack. Such a system captures the contaminants at the point of generation through a properly mounted exhaust hood. The exhaust flow rate is determined from the area of the hood opening and capture velocity sufficient to prevent outward escapement of the contaminant. Table 35 lists the recommended range of capture velocity for various types of industrial contaminants.

Table 35 Recommended Capture Velocities for Industrial Contaminants

(*Clause* 14.2.2)

Sl No. (1)	**Condition of Dispersion of Contaminant** (2)	**Process Example** (3)	**Recommended Capture Velocity** m/s (4)
i)	Released with practically zero velocity into still air	Evaporation from pickling tank, degreasing tank	0.25 to 0.5
ii)	Released at low velocity into moderately still air	Spray booth, intermittent container filling, welding, plating, low speed conveyor transfer	0.5 to 1.0
iii)	Active generation into zone of rapid air motion	Spray painting in shallow booth, barrel filling, conveyor loading, crushers	1.0 to 2.5
iv)	Released at high initial velocities into zone of very rapid air motion	Grinding, abrasive blasting, tumbling	2.5 to 10

The sizing of the ducts shall be determined considering the volume of air required and recommended duct velocity necessary to convey the contaminants with minimum possible pressure drop keeping in mind economics of installation and operation. Recommended duct velocity for exhaust ventilation system is given in Table 36.

Table 36 Recommended Duct Velocity for Exhaust Ventilation Systems

(*Clause* 14.2.2)

Sl No.	Nature of Contaminants	Examples	Recommended Duct Velocity m/s
(1)	(2)	(3)	(4)
i)	Vapours, gases, smoke	All vapours, gases and smoke	5 to 10
ii)	Fumes	Welding	10 to 12.5
iii)	Air laden with very fine dusts	Litho powder, wood flour, cotton lint	12.5 to 15
iv)	Dry dust and powders	Fine rubber dust, moulding powder dust, cotton dust, jute lint, soap dust, leather shaving	15 to 20
v)	Average industrial dusts	Grinding dust, general material handling, clay dust, brick cutting, lime stone dust, asbestos dust in textile industry, dry buffing lint, granite dust, silica flour, shoe dust	17.5 to 20
vi)	Heavy dusts	Metal turnings, saw dust, sand blast dust, C.I. boring dust, lead dust, foundry tumbling barrels and shakeout	20 to 22.5
vii)	Heavy and moist dusts	Lead dust with small clips, moist cement dust, sticky buffing lint, quick lime dust	22.5 and above

The selection, installation and operation of fan shall be in accordance with the nature of contaminants. For dust and other industrial contaminant laden air, the drive arrangement (motor, belts and pulleys) shall be kept outside the air stream.

14.3 Underground Car Park Ventilation

14.3.1 *Requirement*

Ventilation in enclosed car parking areas to dilute the level of toxic gases such as carbon monoxide (CO), oxides of nitrogen (NOx), presence of petrol/diesel fumes and smoke from engine exhaust. The ventilation rate will be such so as to ensure that the CO level is maintained within 40 mg/m^3 (35 ppm) for 1 h exposure, with a maximum of 29 mg/m^3 (25 ppm) for an 8 h exposure (as per best practices of special publication).

NOTE — Special publication may be ISO 10121-2.

14.3.2 *Ventilation Rate Requirement of Mechanically Ventilated Underground Car Parks*

For enclosed underground car parks without provision for natural ventilation, a minimum ventilation rate of 6 air changes per hour (ACH) shall be provided to keep contaminants within acceptable hygiene limits. In large basements, each compartment shall be independently ventilated at the minimum rate of 6 ACH.

14.3.3 *System Requirement*

The underground car park ventilation system shall be classified as supply-only, exhaust-only or a combination of the two. A system of ducts or impulse/induction fans (jet fans) may also be used for proper distribution of air in the car park.

For underground car parking, the fans and the ventilation system used for normal CO level ventilation are also used for smoke ventilation during a fire. The extraction fans, ancillaries and the system should therefore be rated for high temperature operation including air changes per hour requirement, as specified in Part F 'Fire and Life Safety' of this NBCS.

14.3.4 *Demand Control Ventilation Based on CO Level*

The ventilation air flow rate shall be varied according to CO level in order to conserve energy during off peak hours when vehicular movements is much lower than during peak hours. In multilevel basements as well as in large single level structures, independent fan system with individual control is required to take care of fire compartmentation requirements (*see* also Part F 'Fire and Life Safety' of this NBCS).

14.3.5 *Location of Sensors*

The sensors for car park ventilation shall be placed in the following manner:

a) Maximum distance of any corner in the car park to the nearest sensor should be less than 25 m;

b) Sensors should be grouped according to the zone covered by the exhaust fan. The coverage area of each sensor should typically be 400 m^2; and

c) Sensors should ideally be located between 0.9 m and 1.8 m above floor level. However, for practical reasons (in order to avoid vandalism), the sensors may be installed at just above 1.8 m height from floor.

14.4 Commercial Kitchen Ventilation

The basic purpose of a kitchen ventilation system (KVS) is to provide a comfortable environment in the kitchen and to ensure the safety of the people working in the kitchen and other building occupants, by effective removal of effluents which may include gaseous, liquid and solid contaminants produced by the cooking process and products of fuel and food combustion.

Heat and grease are the primary ingredient of kitchen effluents. 50 percent to 90 percent of the appliance energy input is released in the form of a rising convective thermal plume above the cooking surface; balance is released into the surrounding space through radiation. The exhaust hood shall be of sufficient size and placed at proper height to capture the whole plume. The hood exhaust flow rate shall be slightly higher than the plume flow rate. Extra exhaust capacity may be required to resist cross drafts.

14.4.1 *Hood Exhaust Flow Rate*

Kitchen hoods have been classified as two types, Type I and Type II. Type I hoods are used to collect and remove grease, smoke, steam and heat. Type II hoods only remove steam and heat. Thus, Type I hoods are fitted with some kind of grease collection device such as grease filters, baffles and a fire suppression system but a Type II hood typically does not have these devices. Appliances such as cooking ranges, fryers, broilers and griddles require Type I hoods whereas ovens, steamers and dishwashers shall work with Type II hoods.

Hood exhaust flow rates for different types of cooking equipment and exhaust hoods per linear meter of hood length shall be calculated as per Table 37. If more than one duty category appliance is placed under one hood, the hood exhaust flow shall be calculated on the basis of the heaviest duty appliance.

For Type II hoods, the prescribed exhaust flow rates are from 150 liters per second per linear meter of hood length to 460 liters per second per linear meter of hood length for oven hoods, and 460 liters per second to 770 liters per second for condensate hood.

Table 37 Hood Exhaust Flow Rates by Appliance Category

(*Clause* 14.4.1)

Sl No.	Appliance Category Surface Temperature °C	Light	Medium	Heavy	Extra Heavy
		200 °C	200 °C	315 °C	370 °C
(1)	(2)	(3)	(4)	(5)	(6)
i)	Cooking equipment	a) Electric/gas ovens	a) Hot top/element	a) Open burner ranges	Appliances using solid fuels for example, wood, charcoal briquettes
		b) Electric/gas steamers	Ranges	b) Broilers	
		c) Cheese melters	b) Griddles	c) Wok ranges	
		d) Pizza ovens	c) Fryers		
		e) Food warmers	d) Pasta cookers		
			e) Conveyor ovens		
			f) Grill		
			g) Rotisseries		
ii)	Plume velocity (m/s)	0.25	0.43	0.75	0.93
iii)	Hood type	Hood exhaust flow rates per linear meter of hood length (litres per second)			
	a) Wall mounted canopy	309	463	618	850
	b) Single island	618	772	927	1080
	c) Double island (per side)	386	463	618	850
	d) Back shelf	463	463	618	–

14.4.2 *Good Hood Design and Installation Practices*

Wherever feasible, the following good hood design and installation practices shall be adhered to:

a) Increasing hood overhang increases capture volume which aids capture and prevents spillage. A minimum overhang of 150 mm on all open sides for all canopy hoods is prescribed. Increasing front overhang and use of inclined side panels (instead of side overhang) significantly reduces capture flow rates;

b) Deployment of side panels improves hood performance significantly. Side panels prevent the plume from spilling at the side, prevent cross drafts and increase velocity at the hood front;

c) Under a wall canopy hood, pushing the appliance towards the back wall significantly improves hood performance in two ways, increased front overhang and reduction in gap between the appliance and the back wall;

d) When using multiple duty category appliances in line under a single hood, the lowest capture rates are achieved when light duty appliance are at the end of the line. Therefore, hood performance is best when heavy duty appliances are placed in the middle of the line; and

e) Hood shall be mounted at as low a height as practical above the appliance surface.

14.4.3 *Oil/Grease Removal*

The removal of oil/grease from the exhaust airflow is a very important part of commercial kitchen operation. Collection of grease in the duct system, in the fan, in roof top equipment and its emission in the environment poses not only pollution problems but is also a serious fire hazard. Grease shall be effectively removed in the hood exhaust system through the use of proper filtration device. The design and selection of proper filtration device shall ensure that the exhaust air is clean and in accordance with the applicable pollution control norms.

14.4.4 *Exhaust Duct Design, Installation and Maintenance Practices*

Kitchen exhaust ductwork carries hot grease laden air. The following general guidelines shall be followed in their design, installation and maintenance:

a) Ducts should be round or rectangular;

b) Ducts shall be grease tight and should be free of traps that shall hold grease;

c) Minimum sheet gauge should be (16 gauge) mild steel or 18 gauge stainless steel;

d) All joints and seams shall be fully welded and made grease tight;

e) Ductwork shall lead directly to building exterior and should not be interconnected with any other type of building ductwork;

f) Horizontal duct runs should be minimized and pitch towards the hood or an approved reservoir for continuous drainage of liquid grease and condensate. The slope should be 2 percent for runs under 23 m. For horizontal runs greater than 23 m, 8 percent slope should be provided. A grease drain outlet shall be provided in form of a leg under a vertical riser;

g) Maximum velocities are limited by pressure drop and noise and should normally not exceed 12.5 m/s;

h) The minimum air velocity for exhaust ducts should be 2.5 m/s;

j) For new single speed fan system, a design duct velocity of 7.5 m/s to 9 m/s is appropriate;

k) Ducts should be as per the requirements given in Part F ‘Fire and Life Safety’ of this NBCS;

m) Access doors duly nut bolted with lead/fire rated gasket shall be provided for scavenging/grease removal during maintenance. This should be marked/provided in drawings as well as in actual duct work, so that nothing is built to block access to them; and

n) It is recommended that duct cleaning at regular intervals be carried out so that the grease film thickness inside ducts (measured with a wet film thickness gauge or equivalent device) does not exceed 180 microns. This will avoid accidental grease sparks and fire.

14.4.5 *Fan for Kitchen Exhaust*

Kitchen exhaust consists of hot, grease laden air with some solid particulate matter also. Fan shall be capable of handling this air and the motor and the drive train (shaft, bearings, belts, etc) shall be kept outside the air stream. The kitchen exhaust fan shall consist of a backward centrifugal impeller or backward SISW centrifugal impeller to capture grease particles.

14.4.6 *Terminations of Kitchen Exhaust System*

Kitchen exhaust systems shall be terminated so that:

a) Discharge direction shall be such as to minimize re-entry into fresh air intake. This not only requires a minimum separation between exhaust and fresh air intake but also knowledge of prevailing winds;

b) Grease shall be collected and drained into a closed container (a fire safety precaution);

c) Rainwater shall be kept out of the grease container;

d) Grease shall not be allowed to drain down the side of the building;

e) Discharge shall not be directed downward or towards pedestrian areas;

f) Roof top discharge shall de released a minimum 4 m above the roof surface; and

g) For discharge from building sides, it shall be ensured that the discharge air is clean, free from odours and in accordance with the applicable pollution control norms.

14.4.7 *Replacement* (*Make-up*) *Air Considerations*

The air exhausted through a kitchen hood shall be replaced 100 percent with clean outside air. Kitchen room pressure shall be maintained slightly lower than the adjoining building space (for example, dining room) to allow conditioned air to transfer into the kitchen and to contain heat and odours within the kitchen. For kitchens adjacent to a building exterior wall, the kitchen pressure shall be slightly higher than outside to prevent ingress of dust, heat and insects.

14.4.8 *Energy Management Considerations*

Significant energy savings are possible with demand control ventilation (DCV) because the power consumed by a fan is proportional to the third power of its speed. Exhaust and supply air flow rates shall be controlled to cater to peak and off-peak periods by installing variable frequency drives (VFD) on the fan motors.

14.5 Laboratory Ventilation

Most laboratories are the source of chemical and biological contaminations which may be very harmful for the occupants. Effective ventilation shall be provided to control the air quality and remove contaminants to protect the health and safety of laboratory personnel and surrounding environment.

14.5.1 *Ventilation of Chemical Laboratories*

a) The laboratory rooms shall have mechanically operated supply and exhaust air system. Exhaust air shall not be recirculated or short cycled through make up air;

b) Chemical laboratories shall have a minimum of 6 air changes per hour (as per best practices of special publication);

c) Fume hoods (*see* Fig. 11) and/or local extractors shall be deployed for effective exhaust from localized processes. Face velocity at fume hood sash shall be sufficient to maintain the maximum allowable escape of contaminants at 0.01 ppm. This shall be verified by tracer gas tests post commissioning;

d) Laboratories shall be maintained at negative pressure with respect to surrounding corridors or less hazardous areas;

e) Ventilation system shall be capable of shutting down in case of fire;

f) Exhaust duct air velocity shall be maintained at 5 m/s to 10 m/s to prevent condensation of fumes or accumulation of solid contaminants;

g) Eddies and cross drafts in the vicinity of fume hoods shall be minimized;

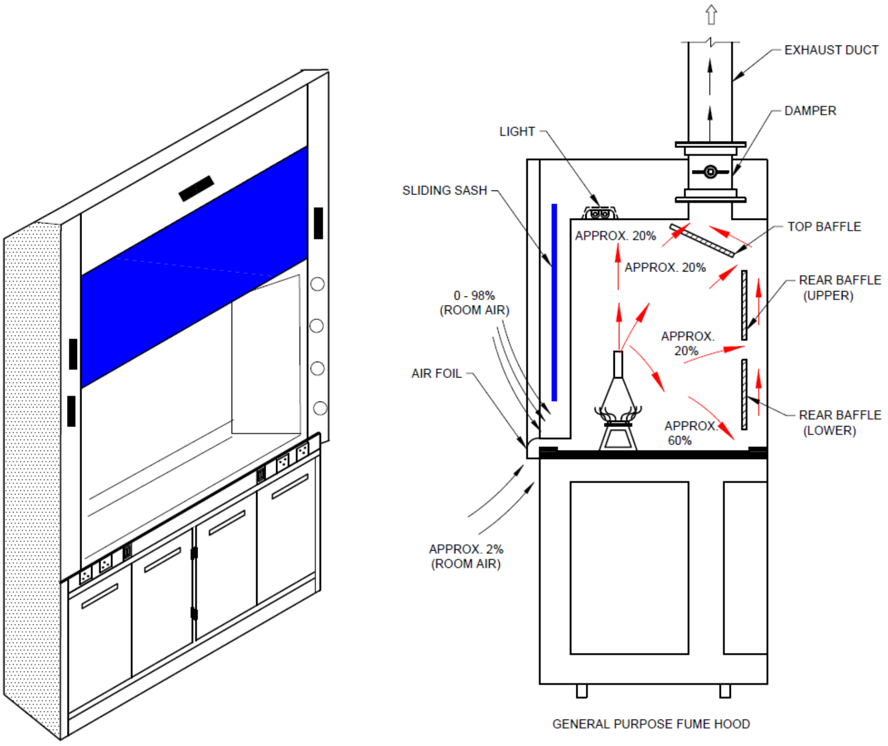


FIG. 11 GENERAL PURPOSE LABORATORY FUME HOOD

h) Certain minimum level of ventilation shall be provided even when the laboratories are not functional to evacuate the vapours generated from the chemicals in the laboratory;

j) Openable windows shall be prohibited to maintain containment and negative pressure in laboratory rooms;

k) Exhaust duct shall not be internally insulated for thermal or acoustic purpose. Sound attenuators or external insulation should provide adequate sound transmission class (STC) and weighted sound reduction index (R_w) ratings to ensure better isolation. Sound attenuators or external insulation may have STC and $R_w \geq 50$ dB for better isolation;

m) Fume hood using heated perchloric acid shall be designed to have the entire exhaust path in spark and corrosion resistant construction as well as with a washing system to avoid explosion hazard;

n) Adequate makeup air shall be provided to compensate the air exhausted by the hoods or other exhaust system; and

p) Air flow direction shall be from low hazard to high hazard areas.

NOTE — Special publication may be ISO 10121-2.

14.5.2 *Ventilation of Biological Laboratories*

Depending upon level of hazard and requirement of protection, biological labs are generally classified into four bio-safety levels (BSL), further categorized into BSL1, BSL2, BSL3 or BSL4 based on combination laboratories practices and techniques, safety equipment and laboratory facilities. General ventilation requirements of BSL3 labs are as prescribed below:

a) Minimum rate of 6 air changes per hour shall be maintained at all times;

b) Laboratories shall be maintained at negative pressure of 12.5 Pa or lower with respect to adjoining corridors, areas, other containment or pressure zones. Monitoring and control devices shall be installed to ensure that pressure differential is maintained at all time;

c) Ventilation system shall effectively remove heat, contaminants and odour from all equipment and laboratory spaces;

d) Visual readout devices and alarm should be provided at entry to containment space, in ante rooms and at entry to other individual rooms within the containment area;

e) Dedicated exhaust air system shall be provided. This system may not be connected to a common system or any other system serving the spaces outside the biocontainment space;

f) Exhaust system shall be provided with variable frequency drive with necessary airflow sensors and a standby fan for redundancy;

g) All duct work shall be with welded joints and in stainless steel construction;

h) It is highly recommended to provide the exhaust system for a BSL3 lab with high efficiency particulate air (HEPA) filters {accepted standard [D-3(19)], [D-3(35)], [D-3(36)], [D-3(37)] and [D-3(38)]}. This filtration shall be provided as close as possible to the biocontainment area. The filtration system shall include bag-in/bag-out type filter replacement system so as to replace the filters without shutting down the exhaust system. Necessary arrangement shall be provided for full face scanning of HEPA filter integrity;

j) Necessary equipment such as laminar flow units, bio safety cabinets of required class, glove box etc. shall be used to ensure the protection of biologically delicate material or to contain bio hazard material during the experiment; and

k) The airflow direction shall be from the clean area to the biocontainment spaces.

14.5.3 *Ventilation of Animal Research Labs*

Properly designed ventilation system provides an adequate amount of oxygen to the lab personnel and animals, removes thermal load generated by animals, removes biological contaminants including allergens and airborne pathogens, controls the humidity of animal housing systems, dilutes the gaseous contaminations, maintains pressure differential between adjoining spaces, maintains micro environment in primary enclosure (housing cage) and maintains animal health.

Animal research facility shall be classified as under with respect to housing system:

a) Conventional animal facility with open type pan; and

b) Modern animal facility with individually ventilated animal housing system.

14.5.3.1 *Animal lab with conventional system*:

a) Shall be provided with minimum of 10 to 15 outside air changes per hour for animal biosafety level (ABSL) 1 and ABSL 2 labs and higher for ABSL 3 facility. System should be once through. Recirculation of air is generally not permitted;

b) Both, supply and exhaust air system shall be provided with HEPA filter to protect the animal from outside contamination and also to protect the environment from biological contamination;

c) System shall be designed to maintain required hygroscopic conditions as per animal requirement; and

d) High velocity draft shall be avoided near animal housing pans to protect animals from wind chill effect.

14.5.3.2 *Animal lab with individually ventilated housing system*:

a) Shall be provided with fresh air supply depending upon the total cage volume and number of air changes required by the system;

b) Necessary adjustment factor shall be considered while designing the HVAC system as the relative humidity in close cage will be 8 percent to 10 percent higher than in the room;

c) Shall ensure no air movement from contaminated area to clean area; and

d) Ventilated caging system shall be selected and pressure gradients shall be adjusted in system itself according to different ABSL level requirements.

14.5.3.3 *In addition*:

a) The direction of air flow shall be from clean corridor to animal room to the service corridor. Necessary pressure gradient shall be maintained to ensure this all the time;

b) Both, supply and exhaust systems shall be designed for redundancy and shall be in operation all the time;

c) Animal experiment room shall be maintained under negative pressure with respect to clean area. Animal quarantine room and healthy animal rooms shall be maintained under positive pressure;

d) Use necessary isolation equipment to protect surrounding environment from infected animal or to protect immune compromised animals from surrounding environment.

14.6 Tunnel Ventilation

14.6.1 *General*

The tunnel ventilation system (TVS) for underground metro network is intended to provide:

a) An acceptable environment in the tunnel and station trackway for the operation of trains;

b) Pressure relief produced by the piston effect of train movement during normal operation;

c) Heat removal during congested/maintenance operation; and

d) An effective means of controlling smoke flows during emergency conditions for safe evacuation of passengers

14.6.2 *Operation Philosophies*

There are three design operating conditions for the tunnel ventilation system that is normal operation, congested operation and emergency operation.

During normal operation, that is when trains are running as per scheduled headway the main source of ventilation for the tunnel is airflow generated due to piston effect produced by moving train. Tunnel ventilation fans are not operated during train movement in tunnel. The trackway exhaust system (TES) at the station extract the heat from train air-conditioning or braking equipment when train is dwelling at the stations. The air extracted from the TES is either exhausted to the atmosphere or shall be used to recirculate to the station air-conditioning system as per the requirement. The trackway exhaust fans are generally provided with variable frequency drives to operate the fan at optimal speed to save energy.

In congested operation, the tunnel ventilation fans (TVFs) are activated for preventing the accumulation of warm tunnel air around idling train in the affected tunnel section. The tunnel ventilation design condition for congested train operation is maximum stratified tunnel air temperature (approximately 50 °C) as per the design of the rolling stock.

In emergency operation, the TVS is set to operate to control the movement of smoke and provide a smoke-free path for safe evacuation of the passengers and for firefighting purposes. The ventilation system is operated in a ‘push-pull’ supply and exhaust mode with tube axial flow fans/nozzles. This enables driving tunnel air flows such that the smoke is forced to move in one direction, enabling evacuation to take place in the opposite direction. A typical ventilation system in tunnel during fire on a train is shown in Fig. 12.

One of the most important factors in selection of the system is to generate the minimum critical velocities of air flow in the tunnel to prevent back-layering of smoke laden air in the tunnel.

14.6.3 *System Description*

The tunnel ventilation system (TVS) consists of tunnel ventilation fans (TVFs), trackway exhaust fans (TEFs), tunnel booster fans (TBFs), tunnel ventilation dampers (TVDs), tunnel ventilation nozzles and sound attenuators provided in the tunnel ventilation plant rooms at each end of the station and connected to both trackways and to outdoors through ventilation shafts.

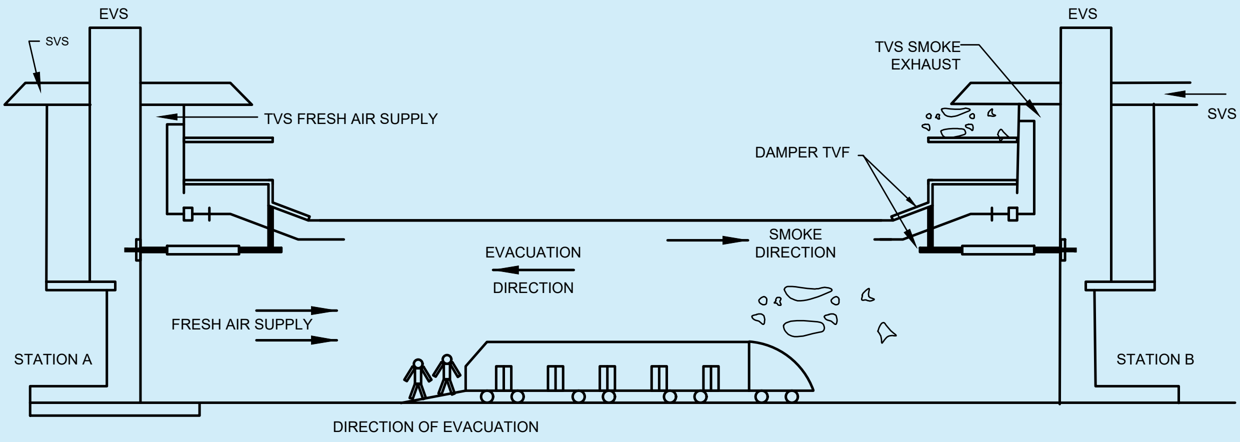


FIG. 12 VENTILATION IN TUNNEL DURING FIRE ON A TRAIN

Each tunnel ventilation installation has two fully reversible tunnel ventilation fans with fan isolation dampers. These dampers are closed when the fan is not in operation. In addition, there is a bypass duct with isolation dampers around the fan room, which acts as a pressure relief shaft when open during normal conditions and enables the flow of air to bypass the TVFs, allowing air exchange between tunnel and outdoor with flows generated by train movement.

The tunnel booster fans are installed at the crossover locations/at portals that is, where the train moves from underground to overground to provide thrust and to direct the flow in desired direction during congestion and emergency scenarios.

The trackway exhaust fans are located in separate plant rooms at each end of the station and connected to station trackway through under platform exhaust and over track exhaust ducts and to the outdoors through exhaust ventilation shafts, to enable heat removal from train AC system and braking system. The TEFs shall also be utilized for smoke extraction from the concourse/platform public areas with the help of dampers connecting the ducting system.

All the components of the tunnel ventilation system are rated minimum for 250 °C for one hour. The fire rating of the system shall be increased based on the requirements.

The specialized software tools such as subway environment simulation (SES), IDA tunnel software, computational fluid dynamics (CFD) analysis are used to evaluate the requirement and efficacy of the tunnel ventilation system.

A typical schematic of the TVS system installed at platform level is shown in Fig. 13.

14.6.4 *Control and Monitoring of TVS*

The TVS system shall be equipped with provisions for automatic, manual, local and remote controls so that the fans and damper motors shall be operated from a station control room (SCR) or from the operations control centre (OCC). At OCC, an integrated supervisory control and data acquisition system (SCADA), should be employed to control and monitor the TVS plant in each station, as the same are generally not attended locally.

The operation of the tunnel ventilation fans during congestion are integrated with the signalling system to identify the affected tunnel section or the ventilation zone. The fans shall be operated automatically or semi-automatic as per the requirements.

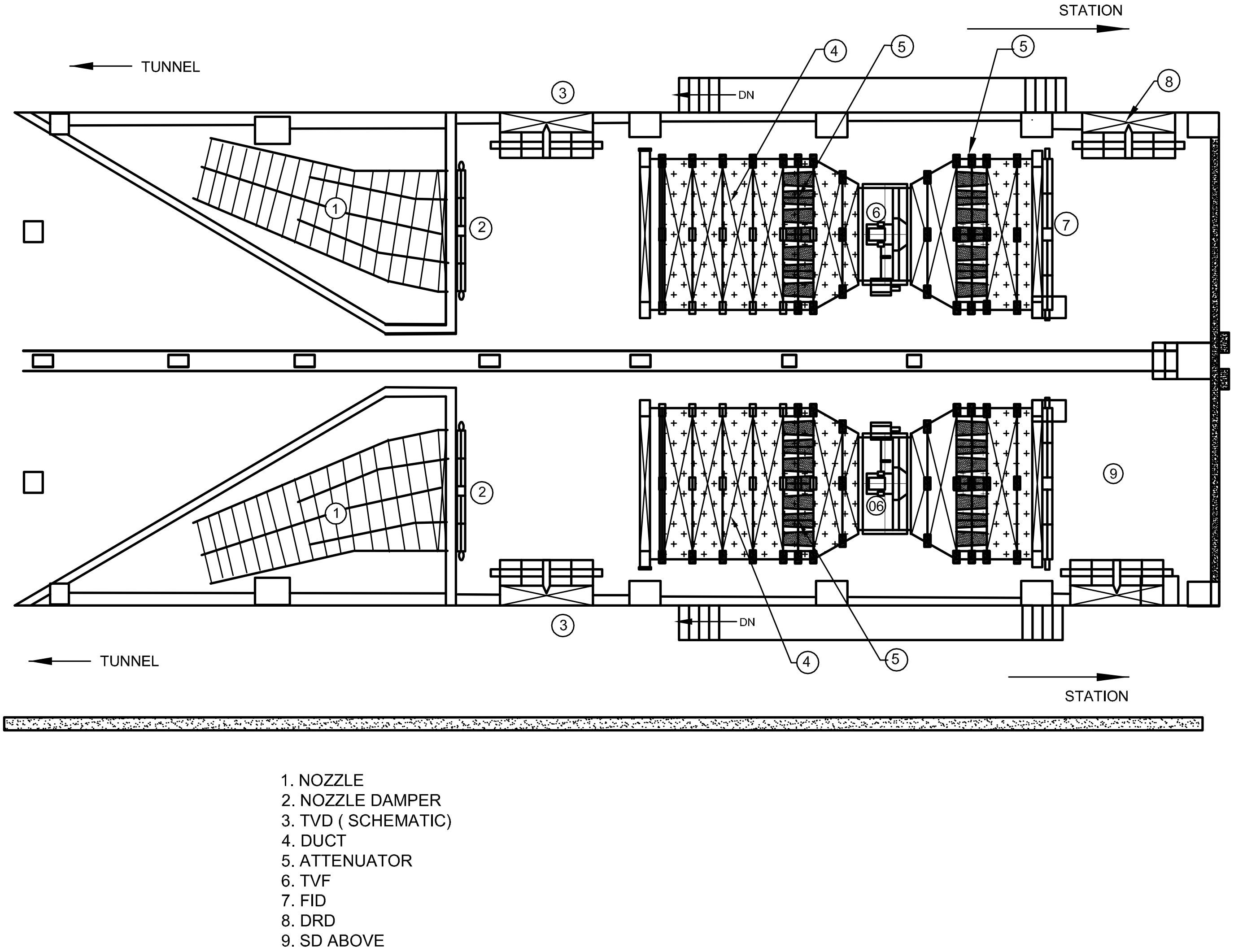


FIG. 13 TYPICAL SCHEMATIC OF THE TVS PLANT ROOM AT PLATFORM LEVEL

In case of unattended train operation, suitable means shall be provided to locate the fire on train for deciding the direction of operation of the ventilation system.

The SCADA for TVS shall be designed with a minimum safety integrity level that is SIL-2. The redundancy shall be provided for communication, processor and power supply.

14.7 General Ventilation Rates for Non-Air-Conditioned Areas

In non-air-conditioned areas, ventilation may be provided through natural or mechanical means to maintain acceptable indoor air quality and thermal comfort. The design may consider climatic conditions, building orientation, effective opening area, and occupancy pattern to ensure adequate air movement and dilution of indoor pollutants. For more details, refer to **5** of Part C ‘Structural Design, Section 1 Loads and Load Effects’ of this NBCS.

15 AUTOMATION AND CONTROLS

In commercial buildings, there are various equipment and systems that consume a lot of energy in applications while delivering occupant comfort and achieving their functionalities. There are multiple aspects for operating these systems to deliver design conditions due to which automation and controls become inevitable. Systems are supposed to function at the set parameters throughout the year whereas ambient conditions vary throughout the operating hours of the building. Systems and equipment normally get designed for peak loads and demands but they operate at part load conditions for a majority of their operating hours. This aspect of operations under various outside as well as inside conditions impacts the operating efficiencies of these systems. To maintain various functionalities within the design conditions, systems should have proper controls incorporated in design as well as in operations. Nowadays equipment come with a lot of built in intelligence and it becomes very necessary to integrate them to a higher level of BMS to ensure owners and end users shall monitor and control the various systems to achieve operating efficiencies, safety, comfort and health of the building and its occupants. In addition to these aspects, the speed with which the digital technology is moving forward, internet of things (IoT) is becoming an integral part of equipment. Buildings shall incorporate futuristic design aspects of BMS in building design. The various aspects of automation and control elements in a building for the various systems are addressed below.

15.1 Roles and Requirements of Automation and Controls in a Building for Various Systems

Given below are the required roles for automation and control in building for various system:

15.1.1 *Heating, Ventilation and Air Conditioning Systems (HVAC)*

Automation and Controls should be designed for:

a) *Monitoring* — Should monitor air quality and thermal comfort parameters as specified in section;

b) *Control* — Controls shall switch on/off of the various equipment based on demand, and open/close or modulate valve actuators and HVAC dampers based on time schedule, occupancy or control parameters like temperature or RH or pressure or flow based on the application;

c) *Energy data management* — Should Provide energy consumption data to monitor and help create energy saving strategies;

d) *Alarm management* — Should Provide better monitoring, control and early notification for predictive and preventive maintenance, optimize operational efforts and reduce downtime of the system; and

e) *Building parameter data management* — Should provide historical data for analysis of system performance.

15.1.2 *Fire and Life Safety*

There is a lot of data exchange required between the fire alarm system and HVAC system for monitoring and controlling the pressurization systems in a building from the BMS. Life safety systems are always stand-alone systems but monitoring of all these systems from the BMS should be deployed critical for proper operation and monitoring of the buildings:

a) Automation for fire and life safety in commercial buildings, residential communities, public places and FAS and BMS should be seamlessly integrated:

    1) *Monitoring* — Shall monitor status of various equipment - water tank levels, primary pumps, diesel pumps, jockey pumps, fire sensors, smoke sensors, pressure across the system, leakages, fire-panel alerts and diesel fuel tank level, fire extinguishers;

2) *Control* — It should have controls for automatic filling of water in fire tanks independently and proactive steps for managing alerts from the fire panel. should include predictive and preventive maintenance scheduling via automation for various components; and

3) The Wired or wireless technology for automation should be deployed based on the overall implementation of that project and budget.

b) Automation for life safety systems and monitoring of systems with interlinked logics and sharing of information with fire responders.

Application in buildings, communities, cities and towns, public places, industries, data centres, hospitality and hospitals, etc.

1) *Monitoring of fire alarm panels* – status monitoring – ON/OFF, alarm status/normal status this should be covered over IoT (Via Wi-Fi/4G/3G or wired). - Intend of this application – To have status monitoring locally and remote capability via IOT which shall be seen by fire responders;

2) *Monitoring of hydrant system* – Pressure in hydrant pipes should be continuously monitored and remotely displayed, Change of Pump switch from auto/manual or vice versa, change in ON/OFF status of pumps. Calls and SMS/Or mail alerts at all levels with escalation matrix defined; and

3) The Wired or wireless technology for automation should be deployed based on the overall implementation of that project and budget.

For real life saving impact, we need to look at early detection methods. Wired and wireless technology shall be employed. Wireless IoT sensors and applications should be programmed to provide 'Notifications' of critical events in small and medium sized buildings that do not have a complete BMS system.

15.1.3 *Electrical*

The following sub systems should be connected with the BMS for monitoring purposes. BMS should monitor:

a) critical parameters of diesel generator (DG);

b) fuel levels of day fuel tank;

c) electrical breakers for risk free operation of the system;

d) various parameters from energy meters to ensure that energy consumption levels are trended and logged for proper analysis of the usage of energy and taking corrective action at the appropriate time to save the energy consumption levels in buildings; and

e) vertical and horizontal transportation (VHTs) from a single platform.

The integrated building management system (IBMS) should create necessary dashboards for easy access to the operating personnel.

Medium size buildings should use independent wireless IoT based energy monitoring device to monitor and control energy usage of VRF and ducted split units.

15.1.6 *Controls Requirement for Significant Components of Building*

Based on the above details of requirements of various systems for control and monitoring functionalities, following Table 38 defines compliance requirements for significant components of BMS at equipment level and system level.

Table 38 Controls Compliance Requirement for Significant Components of Building

(*Clauses* 15.1.6, 15.2.1(1) *and* 15.2.3)

Sl No.	Discipline	Control and Monitoring Level	Equipment/System	Control/Monitoring Base Level	Control/Monitoring Energy Intensive Buildings	Control/Monitoring for Critical Buildings
(1)	(2)	(3)	(4)	(5)	(6)	(7)
	HVAC					
i)	HVAC	Equipment level	DX IDU/ODU	Stand alone	Stand alone	Stand alone
ii)	HVAC	Equipment level	DX VRF	Stand alone	Stand alone	Provide networked controllers
iii)	HVAC	Equipment level	CHW FCU	Stand alone	Individual time clock control using controller	Provide networked controllers
iv)	HVAC	Equipment level	CHW AHU	Stand alone	Individual time clock control using programmable controller	Provide networked controllers
v)	HVAC	Equipment level	CHW Pumping	Stand alone	Provide group controls for all the pumps	Provide networked controllers
vi)	HVAC	Equipment level	Cooling tower fan	Stand alone	Stand Alone - as per ECSBC	Provide networked controllers
vii)	HVAC	Equipment level	Extract fan	Stand alone	Stand alone	Provide networked controllers
viii)	HVAC	Equipment level	Pressure Control (Air side)	Stand alone	Stand Alone	Provide networked controllers
ix)	HVAC	Equipment level	CT Level Control	Stand alone	Stand alone	Provide networked controllers
x)	HVAC	Equipment level	Basement ventilation	Stand Alone - as per ECSBC	Stand Alone - as per ECSBC	Provide networked controllers with all monitoring points in the dashboard screens
xi)	HVAC	Equipment level	Energy recovery (Airside)	Stand Alone - as per ECSBC	Stand Alone - as per ECSBC	Provide networked controllers
xii)	HVAC	System level	CHW pumping	Stand alone	Stand alone	Provide networked controllers
xiii)	HVAC	System level	Variable air volume	Stand alone	Stand alone	Provide networked controllers

Table 38 (*Continued*)

Sl No.	Discipline	Control and Monitoring Level	Equipment/System	Control/Monitoring Base Level	Control/Monitoring Energy Intensive Buildings	Control/Monitoring for Critical Buildings
(1)	(2)	(3)	(4)	(5)	(6)	(7)
xiv)	HVAC	System level	Pressure control	Stand alone	Stand-alone	Provide networked controllers
xv)	HVAC	System level	Demand control ventilation	Stand alone as detailed in ECSBC	Stand alone as detailed in ECSBC	Provide networked controllers
xvi)	HVAC	System level	Economizer	Provide controls as per ECSBC	Provide controls as per ECSBC	Provide networked controllers
xvii)	HVAC	System level	Chillers and chiller plant control	Chiller plant control as per ECSBC details	Chiller plant control as per ECSBC details	Provide networked controllers with data for analysis
	LIGHTING					
xviii)	Lighting	Equipment level	Lux level control	as per details given in ECSBC	as per details given in ECSBC	as per details given in ECSBC
xix)	Lighting	System level	Lighting Management System (LMS)	-	-	Integrate LMS with BMS; share occupancy/unoccupancy mode data; based on based on which, VAVs to switch to occupied/unoccupied modes
	ELECTRICAL AND VERTICAL TRANSPORTATION					
xx)	Electrical and vertical transportation	Equipment level	Transformers, breakers, VHT	-	-	Monitor healthy status of the equipment
xxi)	Electrical and vertical transportation	Equipment level	Energy meters	Record energy value at all meters for monitoring purposes for all utilities	Digitally connect all utility energy meters; track energy consumption for analysis	Digitally connect all utility energy meters; track power and energy consumption data for analysis

Table 38 (*Concluded*)

Sl No.	Discipline	Control and Monitoring Level	Equipment/System	Control/Monitoring Base Level	Control/Monitoring Energy Intensive Buildings	Control/Monitoring for Critical Buildings
(1)	(2)	(3)	(4)	(5)	(6)	(7)
xxii)	Electrical and vertical transportation	System level	Building level	-	Comply as per ECSBC	Comply as per ECSBC
	WATER MANAGEMENT					
xxiii)	Water management	Unit/equipment level	PHE Equipment	Provide stand-alone control for equipment functioning	Provide stand-alone control for equipment functioning	Track parameters at the dashboards
xxiv)	Water management	Equipment level	STP System	Stand-alone control	Stand-alone control	Track parameters at the dashboards
xxv)	Water management	Equipment level	Water Meters	Recording of Water Consumption data;	Recording of Water Consumption data;	Recording and trending of water consumption data

NOTE — Details of for abbreviations mentioned in column under equipment/system are provided below - this matrix is part of Chapter 13 of ECSBC and shall be referred also from ECSBC.

DX IDU/ODU	DX Split Unit
DX VRF	DX Variable Refrigerant Flow Unit
CHW FCU	Chilled water Fan Coil Unit
CHW AHU	Chilled Water Air Handling Unit
CHW Pumping	Chilled water Pumping
CT Level Control	Cooling Tower Level Control
PHE equipment	Public Health and Engineering equipment
VHT	Vertical and Horizontal Transportation

15.2 Building Management System (BMS) and Internet of Things (IoT)

The following points outline the various components and functionalities associated with BMS and IoT in modern buildings

15.2.1 *BMS System Architecture*:

a) Control Systems in a building shall have a system architecture that ensures control and monitoring of various operating parameters at the following levels:

   1) Unit/equipment Level for equipment performance, monitoring, control and energy optimization as per the control logic developed to achieve the design objective. Necessary and appropriate field devices shall be used at this level to capture various parameters that need to be controlled and monitored (*see* Table 38);

   2) System and automation level shall ensure coordinated and integrated control logic between the various sub systems as per the design intents; and

   3) Management Level shall contain necessary workstations with software and dashboard screens provide macro level parameters of various high-level systems to monitor trend and analyse the various data.

b) System shall bring in all mechanical, electrical and public health engineering (MEP) equipment and systems under its architecture;

c) Control system shall be constructed to achieve energy optimization based on the level of intelligence and functionalities in-built in the equipment;

d) A matrix of equipment and parameters that shall be controlled and monitored shall be drawn (*see* Table 38 for various building systems). In addition to Table 38, critical parameters namely, temperature, pressure, voltage, current, energy, and others shall be recorded and monitored and shall be made available for the operations team for corrective action either through stand-alone controls or networked controls;

e) Based on point (d) above, detailed Input/output point summary (IOP Summary) shall be developed;

f) Control schematics and sequence of operation shall be developed for various control loops based on the respective design philosophy and intent of the building by the concerned design team; and

g) The controls system architecture shall be developed to effectively integrate and manage various building systems and technologies. The key requirements shall include:

   1) Scalability and flexibility – Allowing for future expansion and adaptation;

   2) Interoperability;

   3) Real-time data acquisition and analysis;

   4) Security and privacy;

   5) Redundancy and fault tolerance;

   6) Energy efficiency and sustainability; and

   7) Centralized management for control and monitoring.

15.2.2 *Protocols*

All unit level and system level controls shall have industry standard open protocols adopted for connecting various equipment/controllers/third party devices that have built-in intelligence in their controllers and factory installed field devices/equipment like chillers, diesel generating sets, energy meters, and variable speed drives. Other industry standard open and accepted protocols such as open platform communications (OPC), message queuing telemetry transport (MQTT), zigbee, Wi-Fi, modbus, meter-bus (M-Bus), global system for mobile communication/general packet radio services (GSM/GPRS), Z-wave, device language message specification (DLMS) shall be used for connecting devices.

15.2.3 *Controllers*

For various applications, controllers with built-in logic or programmable control logic shall be used to achieve the desired design intents.

Depending upon the building application and criticality, networked controls shall be used.

a) All networked controller systems shall comply with **15.2.2** for protocols used; and

b) Critical parameters namely, temperature, pressure, voltage, current, energy, and others shall be made available for effective monitoring and control of the system through networked centralized control system. (Table 38 shall be referred for various parameters to be considered based on the application.)

15.2.4 *Internet of Things* (*IoT*)

IoT devices and automation optimize building performance by providing data on core building operational systems and enabling automatic control of the building's main operating functions. IoT devices, when implemented, shall be able to connect via standard building and industry protocols as mentioned in **15.2.2**.

For IoT devices to be accessed and configured on the field and/or remotely shall have hardware interface and software or wireless interface for remote configuration.

Integrating IoT with BMS represents a significant advancement in building management, offering improved efficiency and enhanced user experiences. While implementing systems with IoT enabled controls, following aspects have to be taken care of in the design:

a) *Interoperability* — This is to ensure different IoT devices and systems work together seamlessly. For medium sized buildings, all applications for devices should be accessible from the same screen. Use of higher-level local servers running continuously are to be considered to achieve interoperability when stated in OPR;

b) *Data privacy* — Safeguarding the personal data collected by loT devices is important. Use of VLAN and Privacy Levels to be as per requirement detailed in OPR. For medium sized buildings WPA/WPA2 will otherwise be the minimum level;

c) *Scalability* — Ensure the system is scalable and adaptable to changing needs within the same platform; and

d) *Security* — Protect the system from cyber threats by ensuring that remote access to all IP and other applicable devices have USER configured usernames. Default usernames and passwords shall not be retained and device shall not be accessed by use of default username and password. Security levels to be as per requirement detailed in OPR. For medium sized buildings WPA/WPA2 otherwise accepted as the minimum level.

15.2.5 *Cyber Security*

Vulnerabilities in the IT based systems are diverse. Due to their physical location across all parts of a facility and connectivity with open protocols, systems are prone to technical and physical attacks at all architectural levels. System shall take care of all aspects of cyber security.

15.2.6 *Software*

The BMS workstation software that brings in all the data and the graphics including all the functionalities and sequence of operation and logic to the operator workstation shall have the following options depending upon the criticality and application of the building and also based on owner's project requirements (OPR).

a) Computer workstation software or server based software depending upon the number of data points for monitoring and control.

b) Optional server based on premise or remote depending upon the scale and application of the building.

c) IoT and cloud based system as per OPR.

15.2.7 *Integrators/Gateways*:

a) High level integrators/gateways shall be used to ensure conversion of various protocols mentioned under **15.2.7 (c)**.

b) Protocol conversion for 3rd party devices integration of various equipment in a building shall happen when various equipment is connected through soft link to bring in the various parameters residing at the equipment to the BMS platform without installing any additional field devices.

c) Conversion from one protocol to another protocol:

   1) BACnet MSTP to BACnet/IP;

   2) MODBus RTU– BACnet/IP;

   3) MODBus TCP/IP - BACnet/IP;

   4) M-Bus to BACnet-IP; and

   5) MODBus – GSM/GPRS.

   NOTE — The above are not exhaustive and other conversions may also be required as per the equipment and protocols installed.

15.2.8 *Dashboard*

High level parameters of various sub systems shall be captured on the dashboard screen and customized based on the OPR.

a) HVAC;

b) Electrical;

c) Energy management – consumption, generation;

d) Water management – levels, volume, consumption;

e) Sewage treatment plant;

f) Lighting management – power consumption, circuits status, luminaire fused status circuits status, luminaire fused status;

g) Fire – status of alarms/alerts;

h) IEQ/IAQ;

j) Waste management;

k) Occupancy status; and

m) UPS/battery management.

15.3 Instrumentation and Field Devices

Instrumentation in automation and controls shall be provided to measure various parameters and communicate the same to the next level in the system architecture:

a) *Monitoring* — Status monitoring of multiple aspects of buildings like,

   Utilities (water, lighting, energy, gas), water quality (WTP, STP, ETP), air quality, ventilation (HVAC, mechanical), VHT (lifts, elevators, escalators, travellators), fire and life safety, UPS (power consumption, battery management), DG set, parking, security (cameras, boom barriers, access control, intrusion detection), plumbing etc;

b) Control of critical/non-critical areas as defined in OPR;

c) *Instrumentation considerations* — These devices range from field devices, loggers, aggregators, controllers - sensors, PLCs, controllers (PID, IoT), mechanical (actuators, valves, dampers etc.), internal and external communication devices and any special purpose instruments. These shall be of analogue or digital type. Communication protocols like analogue (V, A), digital, serial, TCP/IP etc. based on the application shall be considered; and

d) *Technology* — A combination of wired and wireless field devices shall be used based on the overall application of the project and OPR.

15.4 Sequence of Operation and Control Logic

Sequence of operation and the control logic of any control loop shall be developed in the BMS based on the design logic of that particular discipline and application. This is to be developed by the concerned design team and the same will be used in developing the Input/output point summary as well as for determination of necessary field devices to be installed for capturing the parameters to be controlled and/or monitored.

15.5 Data Gathering for Analysis and Performance Improvements

This is a very important part of the BMS where all the data that are gathered through the field devices as well as those processed at the controllers, data stored through various trending and logging from the various equipment and system shall be stored in a PC workstation or a server depending upon the number of data points.

This data shall be made available for analysis by the facilities and operations team for making performance improvements in the system as well as comparing through a range of time spans to understand the behaviour of the building. These data will also be useful in making informed decisions like the life of the equipment, for drawing up replacement schedules, comparing performances for various buildings etc.

15.6 Energy Savings — Optimization for Decarbonization

To effectively use the data from the BMS for measuring the sustainable level of operations of a building, following dashboard screens, at the minimum shall be made in addition to those listed under **15.2.6**. These will not only help the facilities and operations team for trending and analysis but also for measuring the carbon footprint of the building and the decarbonisation levels of the building. These will help the owner in understanding the carbon emissions and help in migrating towards net zero goals.

Dashboard screens shall be developed for the following:

a) Energy;

b) Environment;

c) HVAC system;

d) Lighting control system;

e) Water management system; and

f) Electrical and VHT systems.

For example, energy consumption data to monitor and help create energy saving strategies, energy dashboards shall provide energy data to building and asset management team in graphical form for easy understanding and implementation.

15.7 Installation and Commissioning of Control Systems

15.7.1 *Field Devices*

Field Devices like temperature sensors, RH Sensors, pressure transmitters, flow meters and transducers, level sensors and switches, IAQ Sensors shall be installed as per manufacturers installation manual and recommendations. Necessary precautions shall be taken during installation of the field device for measuring the parameter that is detailed in the input/output point summary and the sequence of operation and control logic diagrams.

15.7.2 *Enclosure Panels*

The controllers, integrators and other components of BMS shall be housed in an enclosure panel that is appropriately rated (electrically) for the ambient conditions at which they are surrounded by so that the control components are neither damaged nor communicate incorrect data to the system. Since most of the controllers and field devices operate with 240V a.c./24V a.c./24V d.c. (as per manufacturers data sheets and installation manuals), necessary transformers have to be installed in the enclosure panel to supply the voltage as per the requirements. The transformers shall be rated to take care of the necessary VA ratings of the field devices and the relays being operated by the controller. Proper earthing etc, shall be provided as per the relevant sections of the accepted standard [D-3(39)] and Part D ‘Building Services, Section 2 Electrical and Allied Installations’ of this NBCS. These enclosure panels shall be suitably IP rated depending on their installation environment.

Relevant sections concerning electrical components in NBCS shall be followed for proper compliance.

15.7.3 *UPS Power Supply*

Necessary uninterrupted power supply shall be provided to the controllers and other control components of the BMS through proper electrical distribution system. Necessary earthing etc, shall be provided as per the relevant sections of the accepted standard [D-3(39)].

Relevant sections concerning electrical components in accepted standard [D-3(39)] shall be followed for proper compliance.

15.7.4 *Field Cabling and Containment*

Field cabling shall be provided between the various control components like the field devices, sensors, transducers, controllers, starter panels, 3rd party equipment for integration as per the relevant sections of this NBCS and as per the recommendations of the manufacturer of the control system. Control cables, integration cables and field cables shall be screened, twisted, shielded and the sizing shall be as per the recommendations of the controls’ contractor and OEM. There shall be a detailed cable schedule drawn up based on the input/ output point summary before carrying out this work. Necessary earthing etc, shall be provided as per the relevant sections of the accepted standard [D-3(39)]. Containment of cabling shall be carried out as per the relevant sections of the accepted standard [D-3(39)] and as per the details of the projects approved documents. Necessary drawings have to be made for the entire system and approvals taken from concerned Engineer-in-charge

15.7.5 *BMS PC Workstation/Server*

The PC Workstations or servers, depending upon the number of data points and based on the application of the building and OPR, shall be installed in an air-conditioned room. These along with either the monitoring station or display units shall be accessible by the facilities and operations team. UPS power supply shall be provided for these components since these will have to handle data from the entire BMS online and have to store data as well for use.

Necessary network components like network switches and accessories shall be installed based on the control manufacturers recommendations and drawings.

15.7.6 *Programming and Commissioning of BMS*

The entire BMS system shall be properly installed, field cabling all checked for continuity prior to the commissioning of the system.

Based on the control logic and the applications, necessary programming shall be developed by the controls contractor and the same shall be downloaded to the various controllers or configured based on the type of control system (wireless or wired).

Various control parameters that are measured through the field devices are to be mapped onto the controllers and checked for consistency. Various set points need to be determined based on the applications and the programs have to be test run and observed for proper operations and necessary fine tuning needs to be done on various control parameters like – PID gains, range etc, for trouble free and accurate operation of the programs.

With all the above completed and as-built drawings, the BMS system needs to be handed over to the end user with as-built drawings and all IOMs for the entire system.

16 HYDRONIC PIPING SYSTEMS

This NBCS establishes uniform standards for the design, installation and maintenance of hydronic and refrigerant piping used in heating, ventilation and air conditioning (HVAC) systems. By adhering to these standards, practitioners shall enhance system performance, reduce operational risks and meet regulatory compliance.

The provisions for material selection, sizing criteria, installation practices, testing procedures and maintenance guidelines for HVAC and refrigerant piping are specified.

16.1 General Hydronic Piping Systems

In HVAC systems, piping systems play a crucial role in transporting fluids such as water and refrigerants throughout the building. Some general type of hydronic systems commonly found in HVAC system are:

a) *Chilled Water Piping System* — Network of pipes designed to distribute chilled water from a central plant to various points of use within a building or facility. Primarily used for air conditioning, refrigeration, and industrial cooling applications;

b) *Hot Water Piping System* — Network of pipes designed to distribute heated water from a central heating source to various points of use within a building or facility. Primarily used for space heating, domestic hot water supply, industrial processes, and other applications requiring heated water;

c) *Condenser Water Piping System* — Network of pipes designed to circulate water between a chiller's condenser and a cooling tower or other heat rejection equipment. It's a crucial part of a water-cooled HVAC system, commonly used in large commercial buildings for air conditioning and refrigeration; and

d) *Condensate Drain Piping System* — Network of pipes designed to collect and remove condensate water generated by cooling equipment, such as air conditioners, refrigerators, and dehumidifiers. Condensate forms when warm, moisture-laden air comes into contact with a cold surface, causing the water vapor in the air to condense into liquid water.

16.1.1 *Open and Closed HVAC Piping Systems*

a) *Open and closed system* — An open system is one in which the water enters a reservoir that is exposed to the atmosphere such as collecting tanks, air washers, and cooling towers. A closed system is one in which the water flow is never exposed to the outside environment except at expansion tank part; and

b) *Once – thru and recirculating* — Piping system shall be once through that is, when water is released from system, it only goes through the machinery once. Water circulates in a recirculating system by going through the refrigeration equipment, the heat exchanger, and back again instead of being discharged.

16.1.2 *Selection of Pipe and Fitting Materials*

Selection of right HVAC pipe material shall be done considering fluid type, pressure and temperature range, system layouts, space constraints and special requirements if any (flexibility/corrosion resistance):

a) *Material options for HVAC pipe*:

   1) *Steel pipe* — Carbon steel or stainless-steel pipes should be used in HVAC systems for their strength, durability, and resistance to corrosion. They are suitable for high-pressure applications such as chilled water, hot water, and steam distribution;

   2) *Copper pipe* — Copper pipes have excellent thermal conductivity, corrosion resistance, and ease of installation. They should be used for refrigerant lines, domestic water supply, and hydronic heating systems;

   3) *Polyvinyl chloride (PVC) pipe* — PVC pipes are lightweight, cost-effective, and resistant to corrosion. They may be used for low-pressure applications such as drainage, venting, and condensate lines in HVAC systems;

   4) *Cross-linked polyethylene (PEX) pipe* — PEX pipes are flexible, durable, and resistant to corrosion and scale buildup. They may be used for radiant heating systems, and hydronic piping systems in HVAC; and

   5) *High-density polyethylene (HDPE) pipe* — HDPE pipes are highly resistant to corrosion, abrasion, and chemical damage, making them suitable for outdoor or underground applications in HVAC systems, such as geothermal heat pump systems and chilled water distribution.

b) *Pipe fittings terminology*:

   1) *Elbows* — Elbows are used to change the direction of flow in a piping system. They are available in various angles (for example, 45°, 90°) to accommodate different piping layouts;

   2) *Tees* — Tees create branch connections in a piping system, allowing fluid to flow in multiple directions;

   3) *Reducers* — Reducers connect pipes of different sizes, allowing for a smooth transition between different sections of the piping system;

   4) *Couplings* — Couplings join two pipes together end-to-end, providing a leak-tight connection;

   5) *Flanges* — Flanges connect pipes to valves, fittings, or equipment. They provide a secure and leak-proof connection and allow for easy disassembly when required; and

   6) *Unions* — Unions are similar to couplings but allow for easy disassembly of pipe joints for maintenance or repairs.

   A significant portion of the pressure drop in the piping system is caused by elbows. Elbows with a longer radius shall be provided wherever feasible. Whenever possible, 45° elbows shall be provided over 90° elbows when arranging offsets.

c) *Piping connection methods*:

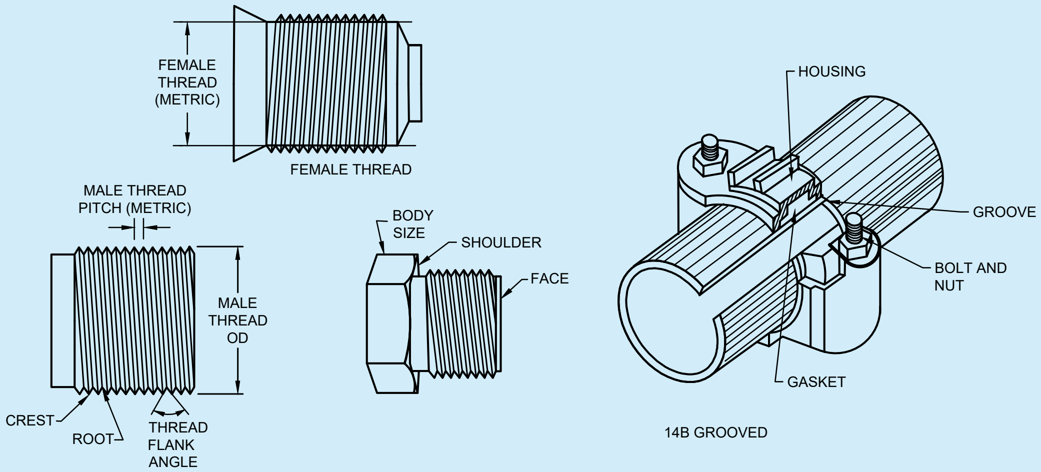
   1) *Soldering/brazing* — Soldering or brazing is commonly used to join copper pipes and fittings together in HVAC systems. It involves heating the joint and applying solder or brazing material to create a strong and leak-free connection;

   2) *Threaded connections* — Threaded connections are used with threaded pipes and fittings, allowing for easy assembly and disassembly without the need for soldering or welding. This is usually recommended for low pressure system up to 6.9 kPa. (*see* Fig. 14);

3) *Grooved connections* — Grooved connections use grooved pipes and fittings with rubber gaskets to create a tight seal. They are quick and easy to install and are commonly used with steel pipes in HVAC systems. (*see* Fig. 14);

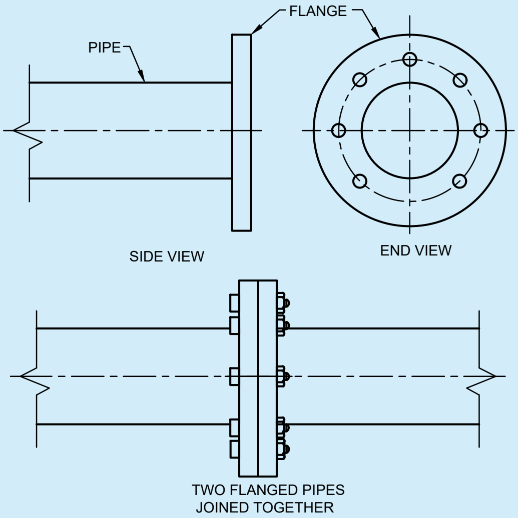
4) *Flanged connections* — Flanged connections use flanges to connect pipes to valves, fittings, or equipment. They provide a secure and leak-proof connection and allow for easy disassembly when required. (*see* Fig. 14); and

5) *Welding* — Welding is used to create permanent connections between pipes and fittings in HVAC systems. It involves melting the edges of the pipe and fitting and fusing them together with heat. This type of fitting is recommended on high pressure system and larger diameter pipes.


FEMALE THREAD (METRIC)
FEMALE THREAD
MALE THREAD PITCH (METRIC)
MALE THREAD OD
CREST
ROOT
THREAD FLANK ANGLE
BODY SIZE
SHOULDER
FACE
HOUSING
GROOVE
BOLT AND NUT
GASKET

14A THREADED

14B GROOVED


FLANGE
PIPE
SIDE VIEW
END VIEW
TWO FLANGED PIPES JOINED TOGETHER

14C FLANGED

FIG. 14 PIPING CONNECTION METHODS

16.1.3 *Piping Supports*:

a) Pipe supports shall be selected to ensure strong anchoring, absorbing vibrations, providing flexibility and reducing noise transmission;

b) Rigid supports/spring hangers and supports/neoprene pads and inserts/ vibration isolators shall be selected based on load capacity to bear the combined weight of the insulation, pipe, fittings, valves, and fluid in the pipe accounting for static and dynamic loads;

c) Manufacturer's guidelines and specifications should be referred for recommended support type based on pipe material, size and system dynamics; and

d) Consultation with HVAC engineers, vibration specialists or manufacturers to tailor support selection is recommended for specific project requirements.

16.1.4 *Expansion Loops*:

a) Expansion loops should be installed in straight runs of pipe or at points where significant temperature changes occur, such as near equipment or in outdoor installations. They prevent damage to piping, equipment, and surrounding structures caused by thermal expansion; and

b) Expansion loops shall be fabricated from standard piping fittings such as elbows and tees, or they shall be custom-designed to meet specific project requirements.

16.1.5 *Valves – Types and Applications*:

a) *Gate valve* — Gate valves control flow by raising or lowering a gate (wedge-shaped disk) to allow or restrict fluid passage. When fully open, the gate is lifted entirely out of the flow path, minimizing flow restriction. Gate valves may be used for ON/OFF control in HVAC systems where full flow or shut-off is required. They may also be provided for isolating equipment/piping sections for maintenance;

b) *Globe valve* — Globe valves feature a globe-shaped body with a movable plug (the 'disc') that regulates flow by moving up and down. As the disc moves, it alters the size of the flow opening, allowing for precise flow control. Globe valves may be used for pressure balancing, throttling or regulating flow in HVAC systems, such as controlling the flow of water or steam in heating and cooling applications. They may also be used for isolation of equipment/piping sections;

c) *Ball valve* — Ball valves feature a spherical disc (the 'ball') with a hole through the center that controls flow. The ball rotates within the valve body to open or close the flow path. Ball valves may be used for on/off control, isolation, and emergency shut-off;

d) *Butterfly Valve* — Butterfly valves use a circular disc (the 'butterfly') mounted on a shaft to control flow. The disc rotates perpendicular to the flow direction to open or close the valve. Butterfly valves should be used for large-diameter pipes in HVAC systems for ON/OFF control;

e) *Check Valve* – Check valves allow fluid to flow in one direction only, preventing backflow or reverse flow. They typically consist of a movable disc or flap that opens to allow forward flow and closes to prevent reverse flow. Check valves should be used in HVAC systems to prevent damage to equipment, maintain system efficiency, and ensure proper flow direction in piping systems;

f) *Balancing Valve* — Balancing valves should be used in hydronic systems to achieve proper flow distribution and maintain system balance;

g) *Control Valve* — Control valves regulate fluid flow based on signals from a control system, such as a thermostat or building automation system. They modulate the flow by adjusting the position of a valve plug, disc, or ball in response to changing system conditions. Control valves should be used in HVAC systems for precise temperature control, flow modulation, and energy management in heating, cooling, and air distribution systems;

h) *Pressure Independent Control Valve (PICV)* — A PICV is an advanced type of control valve used in HVAC (Heating, Ventilation, and Air Conditioning) systems for precise flow control and temperature regulation. It combines the functions of a control valve, differential pressure regulator, and flow limiter into a single device. This is recommended to be used to replace balancing and control valve in the system. (*see* Fig. 15); and

j) *Triple Duty Valve* — A triple duty valve is a multifunctional valve and combines the functions of a check valve, balancing valve and an isolation valve into a single unit. Use of these valves simplify installation, save space and improve system efficiency. These are recommended to be used in hydronic chilled water and hot water systems (*see* Fig. 16).

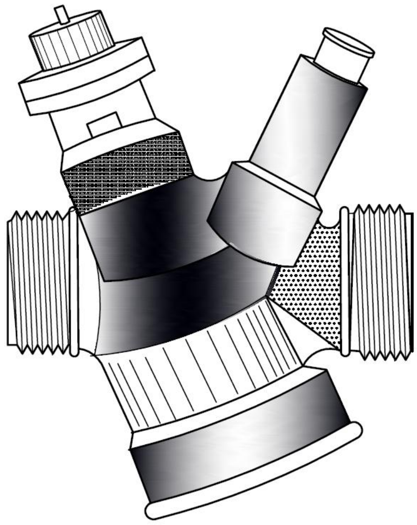


FIG. 15 PICV VALVE

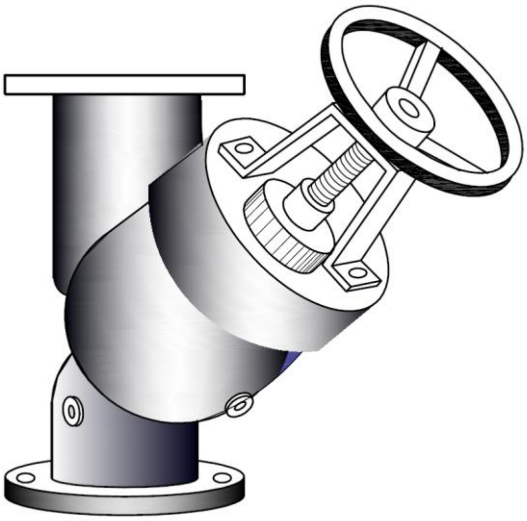


FIG. 16 TRIPLE DUTY VALVE

16.1.6 *Buried Piping Systems*

The following points cover the key aspects of buried piping systems:

a) *Design considerations* — Thermal expansion, corrosion protection and accessibility should be considered in buried piping design. Corrosion-resistant materials like HDPE, steel with protective coatings, ductile iron, or PVC should be selected. These materials shall withstand corrosive environments and prolong the service life of the piping system. Access points like valve boxes, manholes, or cleanouts should be planned along the pipeline route for maintenance;

b) *Material options* — These are material options recommended to be used:

   1) *High-Density Polyethylene* (*HDPE*) — HDPE pipes may be used for buried piping due to their lightweight nature, flexibility, and excellent resistance to corrosion, abrasion, and chemical damage;

    2) *Steel* — Steel pipes with corrosion-resistant coatings like epoxy or polyethylene may enhance their longevity in buried applications; and

    3) *Polyvinyl Chloride* (*PVC*) — PVC pipes are lightweight, cost-effective, and resistant to corrosion, making them ideal for low-pressure applications in buried piping systems.

c) *Installation considerations* — Proper installation is crucial to ensure the efficiency, safety, and longevity of systems and equipment. The following points highlight key considerations for installation:

    1) *Trenching* — Excavation of trenches shall be carried out to the required depth and width to accommodate the piping system. Trench dimensions should be determined based on factors such as pipe size, soil conditions, and local building codes;

    2) *Bedding and backfilling* — A layer of bedding material such as sand or gravel should be placed at the bottom of the trench to provide support and stability for the pipes. After installation, the pipes to be backfilled with soil, compacted in layers to prevent settling, and ensure proper support;

    3) *Protection* — Buried pipes may be wrapped with protective materials such as geotextile fabric or insulation to shield them from damage due to abrasion, soil movement, or external forces. This protective layer helps preserve the integrity of the piping system over time; and

    4) *Marking and identification* — Buried piping systems shall be marked and identified with durable markers or tape along the pipeline route to indicate the location, type of pipe, and purpose of the system. This facilitates future reference, maintenance, and repair activities.

16.1.7 *HVAC Piping in High Rise Buildings- Design Considerations*

Designing of HVAC Piping systems for high rise buildings should consider efficiency, reliability and safety aspects. Material selection shall be suitable for building's structural and environmental conditions. Factors such as corrosion resistance, thermal expansion and fire safety ratings should be considered. HVAC piping in high rise buildings should be designed to handle the required pressure ratings. Accounting for pressure drops due to friction losses, fittings and changes in elevations. Design should facilitate ease of maintenance and future expansion. Few recommendations are:

a) Ensure valve controls and access points are easily available for servicing and repair;

b) Implement measures to mitigate noise and vibration transmission through HVAC piping; and

c) Comply with fire safety regulations by using fire rated materials and design pipe routes to minimize fire spread and maximize compartmentation.

16.1.8 *HVAC Piping in Radiant Cooling Systems-Design Considerations*

Designing piping systems for radiant cooling involves several critical considerations:

a) *Pipe material selection and sizing* — Piping with high thermal conductivity such as cross-linked polyethylene, copper or specialized composite pipes should be used. Select pipe sizes based on flow rates required to meet cooling/ heating demands. Zoning strategies should be implemented to allow different areas to be heated or cooled independently based on occupancy and usage patterns;

b) *Floor construction and thermal mass* — The type of floor construction should be assessed (for example, concrete/wood) to determine its conductivity for efficiency of radiant system. Ensure proper insulation beneath the radiant pipes to minimize heat loss downward;

c) *Integration with building design* — Radiant piping layout to be coordinated with other services like electrical, plumbing and structural components; and

d) *Maintenance and accessibility* — Access to manifold stations and control valves should be planned for maintenance and repair.

16.1.9 *HVAC Piping Testing, Commissioning and Maintenance Guidelines*

Testing, commissioning, and regular maintenance of HVAC piping systems to ensure proper functioning and long-term reliability. The following points outline the guidelines for these processes:

a) *Testing procedures* — The periodic testing procedures recommended to ensure efficiency, longevity and reliability of HVAC piping system shall include pressure testing to check integrity of piping joints and connections; leak detection tests to identify and repair any leaks; flow tests to measure flow rates to check they meet design specifications and adjust as necessary.

b) *Balancing and commissioning process* — The piping system shall be balanced for even distribution of flow and pressure across all the branches. Verify system performance against design criteria and operational requirements. The commissioning procedure shall involve flushing, purging and filling the system with appropriate fluids.

c) *Regular inspection and maintenance* — A regular maintenance schedule should be established based on manufacturers recommendations and operational demands:

   1) This shall include but not limited to visual inspection for signs of corrosion, damage or leaks. Periodic cleaning of pipes should be done to remove any debris or build up to maintain optimal flow and efficiency; and

   2) Valves operation shall be tested to ensure proper functioning and prevent sticking or seizing. Inspect and adjust pipe supports and hangers for any sagging or stress in joints.

d) *Documentation* — Maintain comprehensive documentation of testing, balancing, commissioning activities including test results.

16.2 Refrigerant Piping

The following points outline key considerations for the design, installation, material, and maintenance of refrigerant piping

16.2.1 *Considerations in Refrigerant Piping*

The refrigerant when flowing through these pipes, imposes friction with the inner piping wall due to the velocities. The friction reduces the system efficiencies and as such shall be maintained as low as possible. The norm is to maintain the pressure drops in these pipes, not exceeding an equivalent of 1.10°C which for most of the commonly used refrigerant works out to 1.3 kPa to 1.9 kPa for suction line and 4.0 kPa to 6.0 kPa for hot gas and liquid lines. This shall however be verified with the refrigerant pressure-temperature charts.

The second consideration is oil migration during operation. When refrigerant flows out of the compressor in vapor form, some amount of compressor lubrication oil escapes along with the refrigerant. The piping system shall be designed to ensure that the escaped oil is made to return back to the compressor after travelling through the system to ensure that the oil levels in the compressor is maintained. Following practices should be followed to achieve this objective:

a) The refrigerant velocities in suction line as well as hot gas line be maintained high enough so that it impels oil to move along the direction of the flow. The velocities in horizontal pipes should be minimum 3.8 m/s and that in vertical lines be maintained at a minimum of 7.6 m/s;

b) The suction line and hot gas line in horizontal traverse should be pitched downwards in the direction of the flow to ensure that the oil does not flow back. The recommended gradient is 1 : 200;

c) When the suction line and hot gas line traverse in vertical direction, the U-shaped trap shall be provided at the bottom and inverse U-shaped trap shall be provided at the top. The bottom trap provides holding space for the oil in vertical pipe and not allowing it to travel backward. The top trap prevents the oil that has reached the top from traversing back;

d) In the event of vertical pipe for suction line or hot gas line travelling upwards exceeds 3.5 m, a U-shaped oil trap should be installed at every 3.5 m;

e) In the event the compressor has part load operation capabilities, the piping velocities in vertical risers may not be possible at the lowest capacity operations. In such events, a double suction riser should be installed in vertically upward pipes. One riser should be sized for the minimum capacity and the second riser should be sized for the balance capacity; and

f) Since liquid refrigerant is perfectly miscible with the oil, the refrigerant velocity is not needed for transportation of oil. However, sudden closing of refrigerant flow shall result in liquid hammer effect. To minimize this impact and consequent damage to the piping system, the refrigerant velocities in liquid line should not exceed 1.5 m/s.

16.2.1.1 The third consideration is migration of liquid refrigerant during the system off cycle. When the system is not operational, the piping layout shall ensure that the liquid does not migrate either to the evaporator or the compressor.

a) When the relative position of compressor is at lower elevation than the condenser, the inverted U-shaped riser should be provided at an elevation higher than the condenser;

b) When the evaporator is at the lower elevation than the condenser, once again a similar inverted U-shapes riser should be employed. It is also a good practice to employ controls such that the system is switched on only after a time delay after the evaporator pump/fan is switched on; and

c) Pump down control may be employed, particularly on the larger systems to shut off the flow of refrigerant by installation of solenoid valve so that when the system is off cycle, the most of the liquid refrigerant is stored in condenser or receiver.

16.2.2 *Piping Material*

Since the refrigerant in the system operate at high pressures, the piping material and thicknesses should be complaint with the subjected pressures. Following materials could be used for refrigerant piping.

a) Steel tubes and pipes;

b) Copper tubes and pipes;

c) Aluminium tubes; and

d) Copper alloy tubes.

NOTE — For copper tubes and pipes, When the pipes are laid in an environment where pipes may be subjected to damage, soft annealed copper tubes should be avoided.

Any other proprietary material may be used provided they are rated for the subjected pressures as well as the verified data of pressure drops is well documented.

Post installation of piping the entire piping system should be pressure tested at 1.5 times the operating high pressure and joints tested for leaks. Post the pressure testing the system should be vacuumized to a pressure of 500 microns with holding of vacuum for the period of 4 h to 6 h to ensure that all non-condensable vapours are removed from the system and any trace of remaining moisture is removed.

The suction line pipes shall be adequately insulated. The insulation thickness should be calculated minimize the heat loss as well as to avoid condensation over the surface. Hot gas line insulation may not be deployed unless the pipes are laid in an environment where the hot gas temperatures may cause burns to occupants. Liquid lines may not be insulated. However, if the equipment is with reversible cycle such as heat and cool mode, all pipes need to be insulated. The insulated pipes should be protected from possible damages as well as the ultra violet exposures.

The piping system should be adequately supported. The supporting system should not damage or compress the insulation system integrity. Alternatively, the piping may be rested on well supported continuous trays.

16.2.3 *Refrigerant Piping Accessories*

The piping system should incorporate accessories which will either aid in proper operation of the system or may assist in trouble shooting:

a) *Oil separators* — Oil separators may be mounted in the hot gas line at the outlet of the compressor when piping lengths are excessively high or when the refrigerant velocities are on the border line. The refrigerant piping velocities however, should not be compromised;

b) *Receivers* — Receivers should be installed where the condenser volume is not adequate to store the entire refrigerant charge of the system. Receivers should be properly designed so that no flash vapor shall enter the liquid line;

c) *Filter dryers* — Filter dryers should be installed in the liquid line to ensure that all solid impurities are arrested prior to the entry of refrigerant in the expansion device. These devices also aid in removing minor amount of water vapor from the piping system that may have been left behind;

d) *Sight glass* — Sight glass may be installed in the liquid line to visualize the adequate flow of refrigerant as well as for to view adequate system dryness; and

e) *Isolation valves* — Isolation valves either in form of hand shut-off valve or solenoid valve may be installed upstream and downstream locations of filter dryer for maintenance works.

17 INSTALLATION AND COMMISSIONING OF HVAC SYSTEMS/EQUIPMENT

The installation and commissioning of HVAC systems are critical to ensuring the system operates efficiently, safely, and in compliance with design specifications. The following points outline the objectives and planning considerations for the installation and commissioning process.

17.1 Objectives

The objectives for the installation and commissioning of HVAC systems and equipment shall be to fully meet the owner's project requirements. The installation process must prioritize optimal energy efficiency, ensuring the systems operate reliably and maintain high-quality standards. Safety is a top priority, with all installations executed to the highest safety standards. Timeliness to meet project deadlines, while also ensuring the optimum life cycle cost is achieved. In addition, the systems should be designed and commissioned to minimize noise and vibration, providing a comfortable and efficient environment.

a) Shall fully meet owner's project requirements;

b) Optimal energy efficiency;

c) Reliability/Quality;

d) Safety;

e) Speed/Timeliness;

f) Optimum life cycle cost; and

g) Minimum noise and vibration.

17.2 Planning the Installation

Meticulous planning results in a trouble-free installation at optimum time and cost with little chance of wastage and rework. Planning ensures safety during installation and commissioning.

Following factors are common across all types of equipment/systems:

17.2.1 Location of installation shall be selected with care. Location shall be such that there is adequate space to mount the equipment as well as to operate, service and maintain it. It shall be as close to the area to be served as possible. Good ventilation and natural lighting are important.

Where the installation is large, a separate utility block should be considered along with a service tunnel to house chilled and condenser water piping, electrical and control cabling and communication systems.

Equipment room floor shall be light coloured and finished smooth but non-slippery with epoxy paint coating. Where required, water proofing of plant/equipment room floor shall be done.

17.2.2 Noise generated by the equipment shall not be objectionable to surrounding spaces and any vibration generated shall not be transmitted to the building structure. Noise levels to be as per CPCB norms.

17.2.3 Equipment rejecting heat to surroundings shall be mounted in such a way that there is no obstruction to heat rejection and good ventilation and adequate top and side clearances are provided.

17.2.4 Location shall be such that proper access to material handling equipment such as crane, forklift etc is available not only during installation but also for its removal and replacement at a later date. When equipment has to be located in the basement of the building, service ramps or removable hatches shall be provided for this purpose.

17.2.5 Structure should be able to take the static and dynamic load of the equipment and transfer it to the ground.

17.2.6 Location shall be dust free and clean.

17.2.7 Equipment which needs drainage shall have the facility. For basement installations, provision shall be kept to pump out excess water from sumps provided. These sumps shall be coupled to alarms in case water level rises beyond set point. In no case shall the condensate water be left out in the open. It shall either be connected to the building drainage and if the installation is large, options for condensate recovery and re use shall be explored.

17.2.8 Locations of shafts, wall openings etc shall be planned in advance so that breakage/rework shall be avoided. Pipes may be supported from floor or ceiling slab as specified by designer. All floor and ceiling support for pipes, cable trays, ducts etc shall be suitably isolated from building structure to prevent transmission of vibration. The openings around service shafts shall be closed as specified. Openings in structural elements (beam, slab etc) shall not be made without the approval of structural engineer.

17.2.9 Equipment foundations shall be structurally designed and concrete foundation blocks shall be protected by epoxy coated angle nosing. Inertia blocks and seismic restraints shall be used where specified. Floor finish/slope shall be such that any water spillage does not stagnate around equipment foundations.

17.2.10 Fresh air intakes shall be planned taking into consideration required distance from exhaust outlets as well as other sources of contamination. All such intakes and exhausts which open outside the building shall be provided with wire mesh and bird screen on inside and louvres with rain protection or cowl piece on the outside. Where specified, intake air filters shall be used. When any duct is terminated on the roof, it shall have a swan's neck to prevent rain ingress.

17.2.11 Access to equipment rooms shall be through double leaf doors or rolling shutters of adequate width and height and fan room doors shall be airtight. Doors shall open outside and a sill provided to prevent water ingress.

17.2.12 It shall be possible to isolate equipment rooms in case of fire or distress. For provisions for compartmentation in case of fire, *see* **19**. Escape routes shall be planned and clearly marked on site.

17.2.13 All equipment/materials delivered to site shall be compared with the documented and approved specifications and found correct. Test certificates shall be sought and verified for physical properties such as thickness, malleability, test pressure etc. Where independent testing is specified, third party test reports from labs [D-3(40)] accredited shall be produced. Agreed lot sizes shall be inspected at site before use. Where factory inspection is specified, same shall be carried out as provided in contract. Agreed quality assurance plan (QAP) shall be specified and test results recorded suitably. All instruments and gauges shall be calibrated, and valid calibration certificates shall be available.

17.2.14 All equipment's, materials and sub systems shall be cleaned prior to use. Installed sub systems such as duct and pipe work shall be cleaned as per an approved Standard operating procedure and shall be kept with all open ends suitably closed. All equipment shall be kept covered with tarpaulin /canvas cloth till they are ready to be commissioned. Shafts of electric motors and other rotating equipment, if stored for a long time, shall be rotated by hand once a fortnight so that grease applied on them do not solidify.

17.2.15 Testing of sub systems shall be carried out in sections as per an approved schematic drawing. Applicable standards and test pressures/duration of test shall be approved by the owner. Testing schedules shall be prior intimated to owner and tests shall be witnessed by owner's representative or by commissioning authority (CxA). Owner shall have the right to approve contractor's testing personnel regarding qualification and experience.

17.2.16 Number of test points for duct and pipe work shall be pre agreed between owner/CxA and the contractor. Once testing of individual sections are completed (with suitable isolation), the entire system shall be tested as a whole. Power and control cabling shall be tested as one single unit.

17.2.17 Receiving of equipment at site, its unloading, shifting to place of installation or interim storage shall be done with care and by using suitable tools and tackle. This requires advance planning and providing adequate lifting and shifting equipment at site. This is of special significance in case of heavy and bulky equipment such as chillers, fans etc to be installed in basement or building terrace. To the extent possible, heavy equipment shall be received at site only after its location of installation is fully ready and at the first instance the equipment should be located at the right place of installation. Multiple shifting of heavy equipment shall be avoided.

17.2.18 Source of power and water shall be provided as close to point of use as possible and shall be terminated with an isolator/valve. All electrical systems shall be properly grounded and electrical protections such as surge protectors/circuit breakers installed as required. When remote start/stop or control is specified, adequate provisions shall be made.

17.3 Specific Requirements for Equipment/Systems

17.3.1 *Room* (*Window*) *Air Conditioner*

There shall be an opening of adequate size in the outer wall of the room (can be a window) and a wooden frame of suitable size shall be fitted therein. The air conditioner unit shall be placed inside the frame with its outer casing firmly fitted inside the wooden frame with metal screws keeping a slope of 6 mm to 10 mm for drainage of condensate. Drain line of adequate size shall be fitted to the back of the unit. Unit shall be properly levelled and any gap between the frame and wall/window shall be sealed off. Adequately rated electric power socket with on/off switch shall be provided close to the unit. Before fixing the front grill on the unit, it shall be ensured that supply and return air openings are properly isolated and short cycling of air does not happen (*see* Fig. 17, Fig. 18 and Fig. 19).

In addition, the installation shall be as per the manufacturer specified installation requirements and instructions. In absence of manufacturer's installation instruction and requirement.

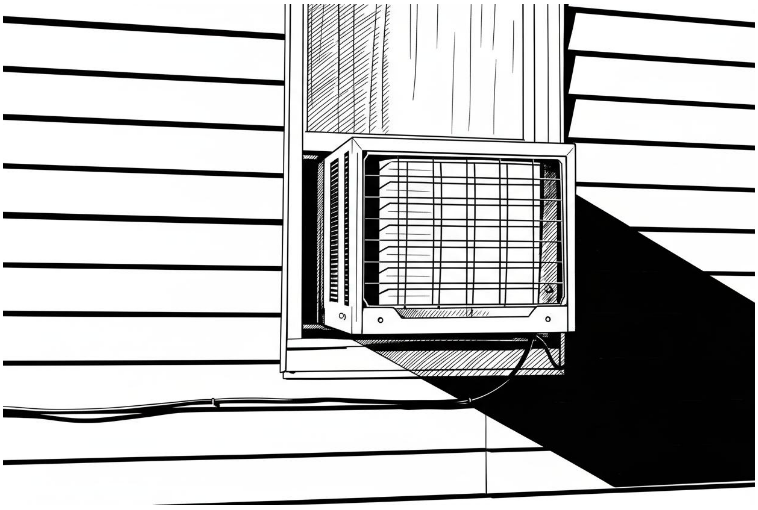


FIG. 17 ROOM AC INSTALLATION – WALL MOUNTED

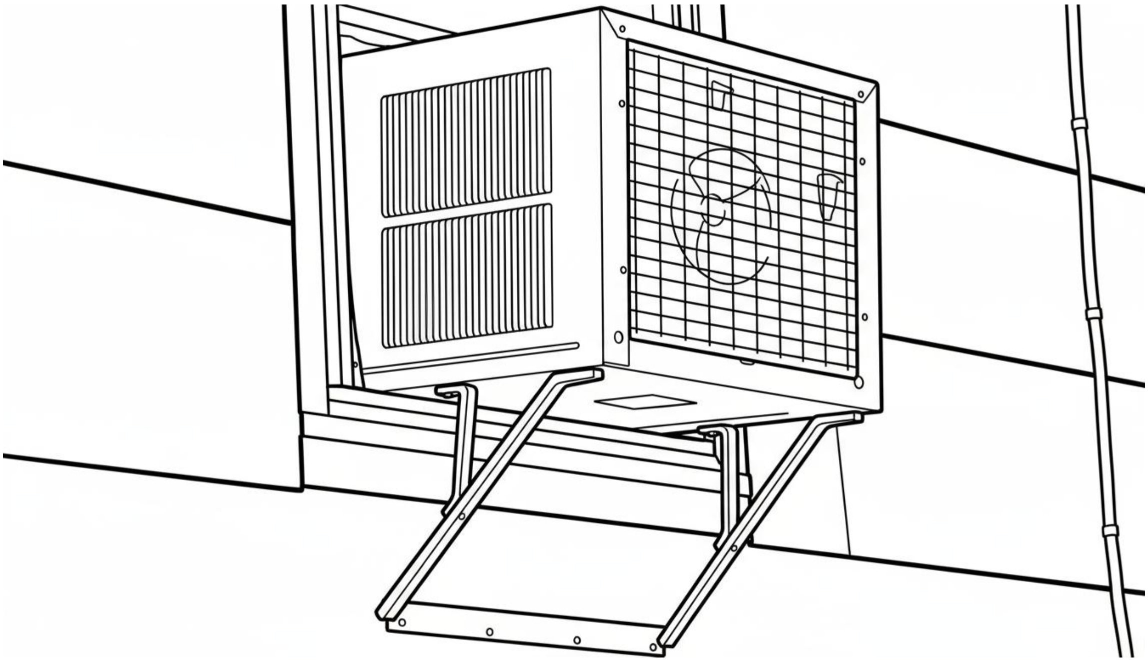


FIG. 18 ROOM AC INSTALLATION – SUPPORTED ON BRACKETS

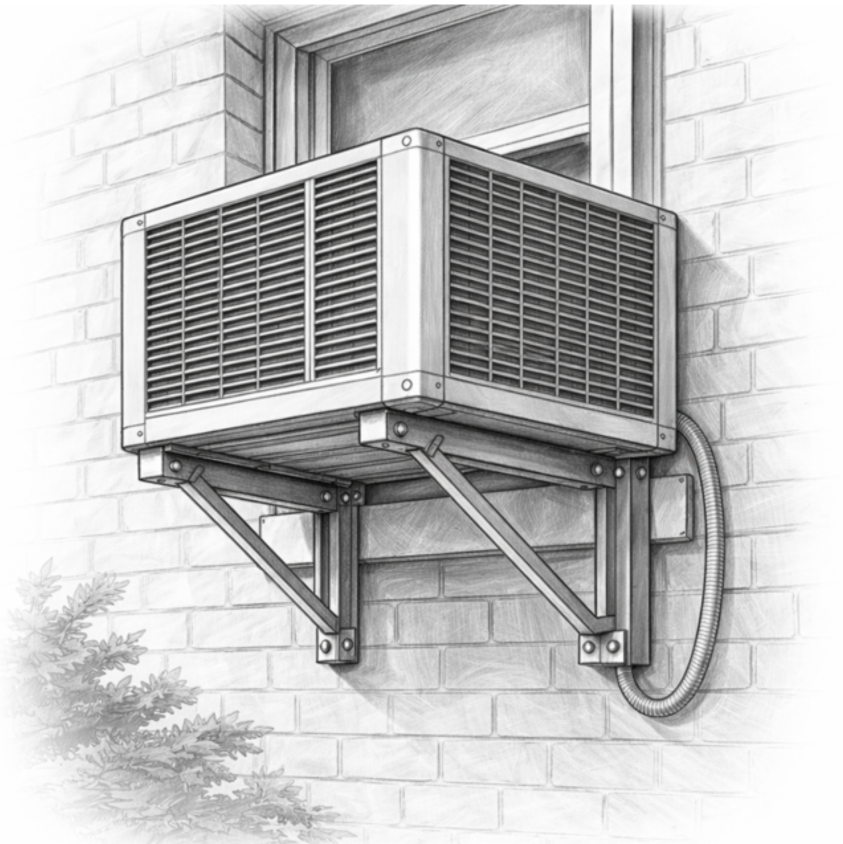


FIG. 19 WINDOW AIR CONDIONING UNIT INSTALLATION

17.3.2 *Split Air Conditioner*

The indoor unit (IDU) shall be located in the conditioned space at a suitable location away from any obstacles to airflow. IDU shall be accessible for regular filter cleaning and maintenance. Drilled holes in the wall to locate the IDU are best located with a template and a spirit level. A hole of adequate diameter shall be drilled in the wall close to the unit (adjacent to the refrigerant pipe connection side of the unit) through which supply and return refrigerant piping (both insulated), drain pipe to remove condensate water and power cabling to the outdoor unit (ODU) shall be carried. A PVC sleeve may be used to carry the lines and the annular space between the wall and the sleeve shall be filled with caulking material or sealant (*see* Fig. 20 and Fig. 21).

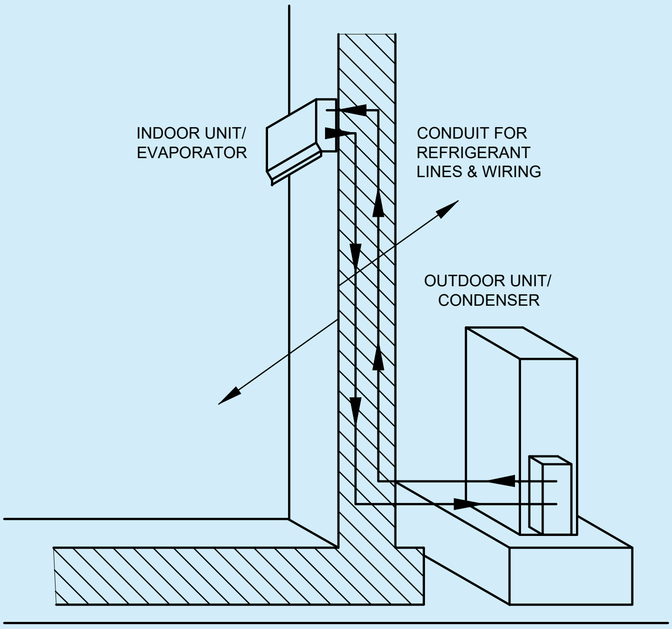


FIG. 20 TYPICAL SPLIT AC UNIT PIPING

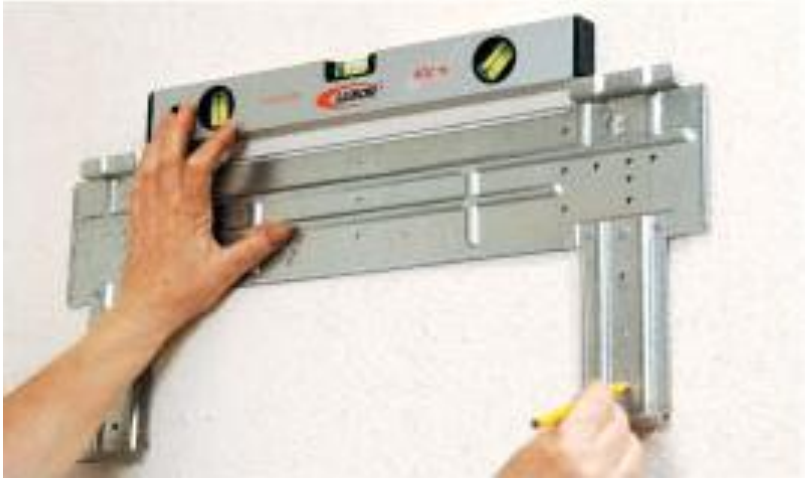


FIG. 21 TEMPLATE FOR LOCATING SPLIT INDOOR UNIT (IDU)

Refrigerant piping between the IDU and ODU shall be of copper with minimum number of bends and the minimum radius of each bend shall be 10 mm. Maximum piping length between IDU and ODU, difference in height between IDU and ODU and any additional refrigerant charge/lubricating oil charge that may be required shall all be specified by the equipment supplier. In cases where the IDU is located at the same level or above the ODU level, the suction line shall rise to the top of the IDU. This prevents the refrigerant liquid from migrating to the compressor during off cycle. Horizontal suction lines shall be either straight or slightly sloped towards the ODU. A refrigerant trap shall be installed at the bottom of the vertical riser (*see* Fig. 22 and Fig. 23).

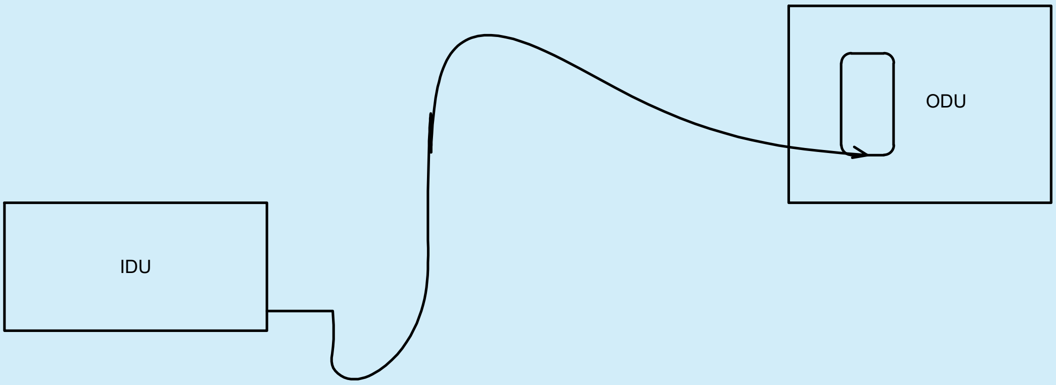


FIG. 22 SUCTION PIPE WITH U TRAP

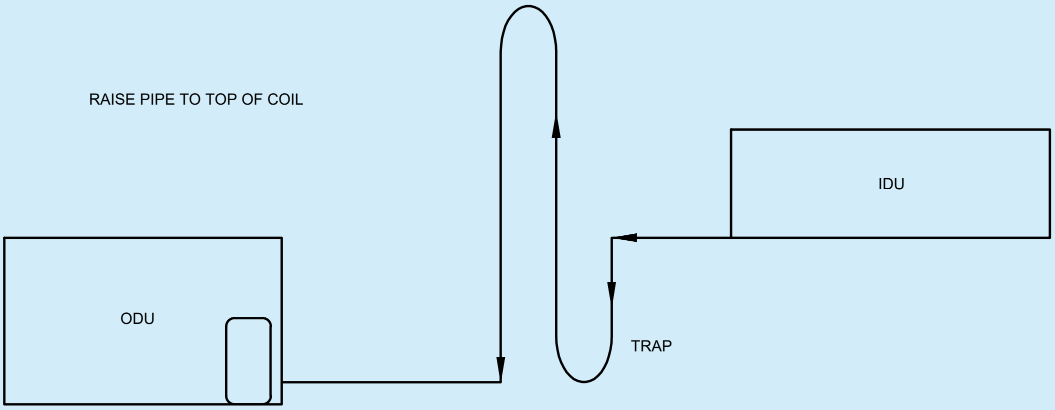


FIG. 23 SUCTION PIPE WHEN ODU IS BELOW IDU LEVEL

Where the ODU is located above the level of the IDU, a trap shall be installed at the bottom of the suction riser immediately after the IDU.

Pipes shall not be in direct contact with the building structure to prevent vibration transmission. Pipes shall be clamped to walls at suitable intervals and separation may be kept between pipe and clamp to prevent bi-metallic erosion.

ODU shall be placed on a flat firm surface which shall take the load of the unit. Vibration isolators or serrated rubber pads shall be placed below the unit. The ODU shall be located where air for cooling shall flow freely through the condenser coil. As far as possible, ODU shall not be exposed directly to sunlight. ODU shall be easily accessible for servicing. Where multiple ODUs are located, they should not face one another, and an adequate arrangement shall be made to prevent short cycling.

Once the piping between the ODU and IDU is completed, it shall be pressure tested at 21 × 10^4 Kg/m^2 on the high side and 10 × 10^4 Kg/m^2 (or 1.5 times the maximum operating pressure) on low side for minimum 6 h. Thereafter, the system shall be evacuated and a vacuum of 500 microns of Hg shall be maintained for 6 h before refrigerant is charged. Refrigerant charge/oil charge shall be as recommended by the manufacturer.

Condensate drain from the indoor unit tray shall be planned, routed and connected to the designated drain point (*see* Fig. 24).

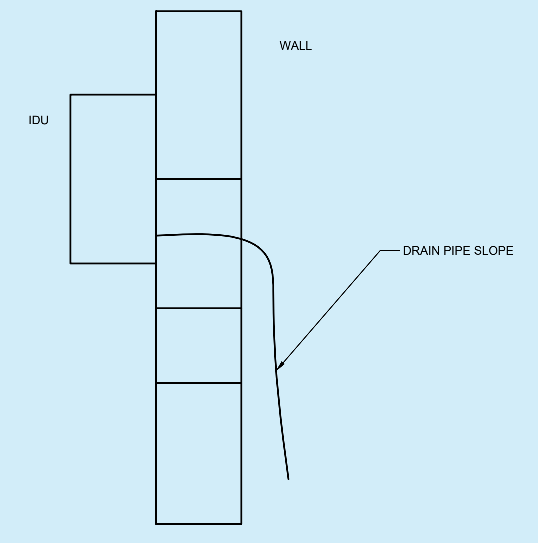

WALL
IDU
DRAIN PIPE SLOPE

FIG. 24 TYPICAL DRAIN CONNECTION FOR IDU

Unit shall be started only by the supplier's authorised service personnel. All installation and start up checks shall be as per the manufacturer's/supplier's documented SOP.

In addition, the installation shall be as per the manufacturer specified installation requirements and instructions. In absence of manufacturer's installation instruction and requirement.

17.3.3 *Variable Refrigerant Flow* (*VRF*) *Systems or Multi Split Units*

All requirements detailed in **17.3.2** shall apply (*see* Fig. 25).

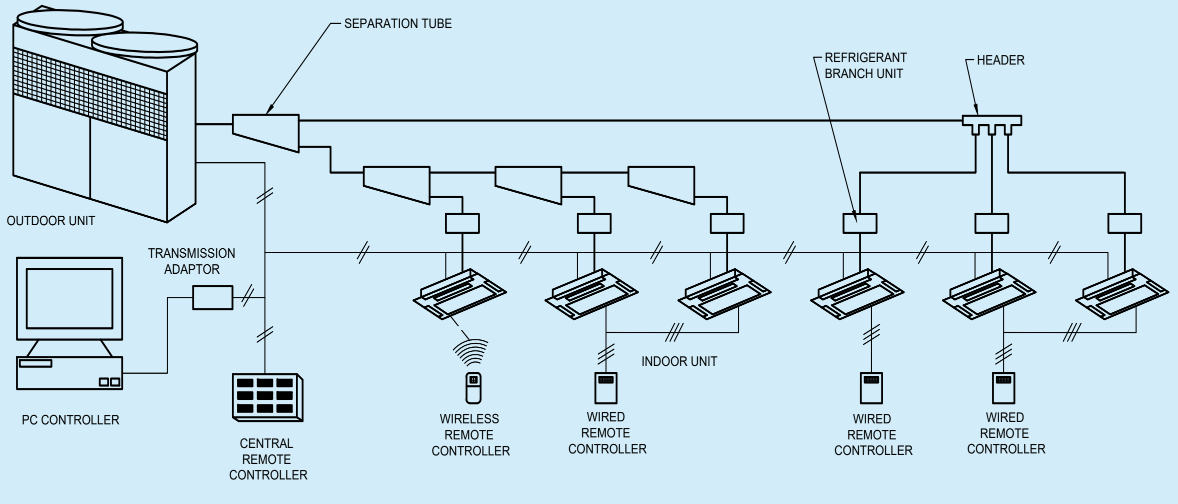

SEPARATION TUBE
REFRIGERANT BRANCH UNIT
HEADER
OUTDOOR UNIT
TRANSMISSION ADAPTOR
INDOOR UNIT
PC CONTROLLER
CENTRAL REMOTE CONTROLLER
WIRELESS REMOTE CONTROLLER
WIRED REMOTE CONTROLLER
WIRED REMOTE CONTROLLER
WIRED REMOTE CONTROLLER

FIG. 25 TYPICAL VRF CONFIGURATION.

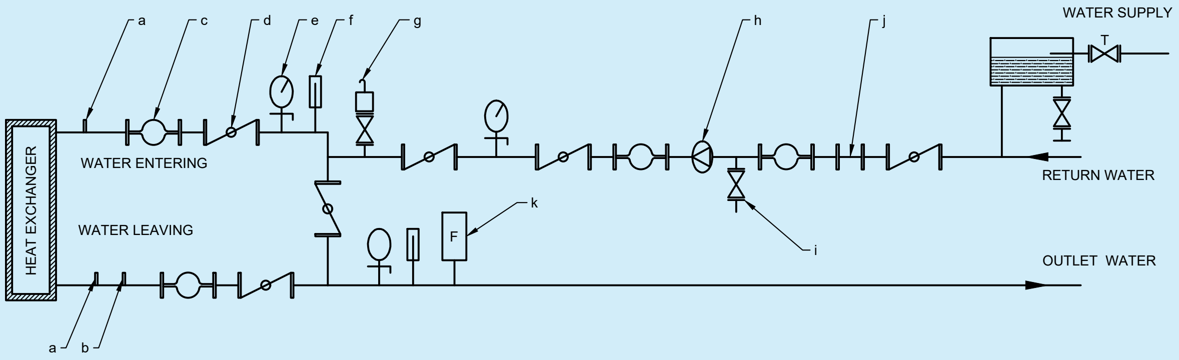
Since the same (set of) outdoor units serves multiple indoor units with varying lengths of piping, charging the correct amount of refrigerant and lubricating oil is important and manufacturer's instruction shall be followed. Communication wiring between all indoor units and the corresponding ODU shall be connected as per the manufacturer's instructions and communication cable shall be away at a distance minimum 300 mm to avoid interference.

Allowable length of refrigerant piping and height between various IDUs and between IDU and ODU shall follow manufacturer's specification. Ball valves shall be installed for zoned refrigerant isolation. Evacuation shall be possible at each IDU and ODU. Start up by manufacturer/installer's authorised personnel shall include configuring and setting up of all control devices.

17.3.4 *Chiller* (*Air Cooled and Water Cooled*)

Chillers are heavy and built with either rotating or reciprocating equipment. adequate foundation system shall be provided to transfer the load to ground thru beams/columns and this shall be done in consultation with structural specialist. Dynamic loading shall be considered while designing the structure and shall be as per the accepted standard [D-3(41)]. Vibration isolation mounts or serrated rubber pads (as recommended by manufacturer) shall be placed between the chiller frame and the foundation. Where open type compressors are used, the alignment of the compressor with its motor shall be checked with a dial gauge (*see* Fig. 26).

Piping connections to the chiller shall be made only after the chiller is finally located in place and levelled. Piping ends shall have offsets for flexibility and piping shall be supported independent of the chiller. Coolers and condensers shall be connected through victaulic/equivalent couplings and suitable flexible connections as recommended by the manufacturer. Provision for fixing temperature sensor and pressure gauges shall be made immediately after the condenser and cooler at a distance of minimum 150 mm from the outlet.



a	TEMP. SENSOR	b	THERMO SWITCH	c	SHOCKPROOF JOINT
d	BUTTERFLY VALVE	e	PRESSURE GAUGE	f	THERMOMETER
g	AUTOMATIC AIR RELIEF	h	WATER PUMP	i	DRAIN VALVE
j	Y - SHAPE FILTER	k	WATER FLOW SWITCH		

FIG. 26 TYPICAL CHILLER PIPE CONNECTIONS.

Temperature at the location where chiller is installed shall be within the limits specified by the manufacturer. Where air-cooled chillers are installed open to atmosphere, a suitable cover over the roof panels is recommended. All electrical enclosures in case of open installations shall be IP 55 or higher as per accepted standard [D-3(42)]. Space for air circulation, people movement and maintenance shall be provided on all four sides.

Where the chiller is mounted above grade, a structural steel platform, capable of supporting the dynamic load of the chiller, shall be provided. A maintenance platform providing access to all parts requiring maintenance/ attention shall also be provided. Service space shall include space for tube cleaning or for attaching the tube cleaning device.

Electrical isolation shall be provided not more than 2 m away from the chiller. Floor drain and water supply point near to the chiller shall be planned. Where accessories to chiller such as expansion tank, air separator unit etc are to be located in the plant room, adequate space for installing and servicing them shall be planned.

Where chillers are located inside the building, floor to floor height of the plant room shall be adequate to house the piping, valves, strainers etc. Height ranging from 3.6 m to 4.5 m is recommended depending on chiller type. A guide rail arrangement is recommended over the chiller for easy removal of components in case of failure. The chiller concrete foundation base should be 150 mm to 200 mm above floor level.

17.3.4.1 Quality of water used for condenser circulation and chilled water make up greatly influences chiller performance as well as chiller life. Make up supply of soft water may be provided at a suitable height above the chiller allowing flow by gravity. Manufacturer's recommendation in this regard shall be strictly followed even for the water used for pressure testing and commissioning. The Table 39 should be referred for the water quality requirements.

Table 39 Water Quality Requirements

(*Clause* 17.3.4.1)

Sl No. (1)	**Properties** (2)	**Limit** (3)	**Circulating Chilled Water** (4)	**Make up Water (Chiller)** (5)	**Condenser Water** (6)
i)	Total hardness as CaCo3	*Max*	80	50	200
ii)	Total alkalinity as CaCo3	*Max*	100	80	100
iii)	Chloride ion, ppm	*Max*	50	50	200
iv)	Iron as Fe, ppm	*Max*	0.3	0.3	1.0
v)	Silica as SiO2, ppm	*Max*	30	30	50
vi)	Ammonia, ppm	*Max*	0.2	0.2	1.0
vii)	*p*H	*Min* to *Max*	7.2 to 8.5	6 to 8	7.2 to 8.5

17.3.5 *Packaged Air Conditioner (Air Cooled and Water Cooled)*

Installation of water-cooled packaged air conditioners (PAC) shall be similar to installation of water-cooled chiller whereas installation of air-cooled chiller shall generally follow the installation guidelines for split air conditioners as detailed in **17.3.2**. Following additional points are specific to PAC installation

a) While lifting and hoisting the unit with a sling, spreader bars shall be used to prevent damage to sides and top;

b) In respect of air-cooled PAC where piping length is more than 7 m, additional refrigerant/oil may require to be charged;

c) Unit connections shall be through reinforced flexible connector;

d) Condensate drain with a water trap shall be installed next to the access panel of the unit; and

e) Pre-filters shall be anti-bacteria and shall be washable. Unit shall not be operated without filter in place.

17.3.6 *Pumps*

17.3.6.1 Pump base frame shall be mounted on an adequately sized concrete block and there shall be cork or serrated rubber pads or anti-vibration mounts between the concrete block and plant room floor and shall be as per the accepted standard [D-3(41)]. Load shall be transmitted to beam or column as per advice of structural engineer.

17.3.6.2 More than one pump shall not be installed on a single base frame or concrete block. Factory supplied pumping systems mounted on common base frame is an exemption to this.

17.3.6.3 Foundation bolts where required shall be embedded correctly. Before grouting the bolts, the level of the base frame shall be checked.

17.3.6.4 Pump motor shall be mounted on the base frame, alignment checked and then only coupled with the pump shaft. Pump shall not run without its coupling guard. Pump alignment shall be checked once again after completing the suction and discharge piping in order to ensure that alignment is not disturbed after connecting the piping.

17.3.6.5 Before being test run, the pump shall be lubricated as per manufacturer's instructions.

17.3.6.6 Suction and discharge lines shall be supported independent of the pump and shall be connected to the pump through flexible connectors. Isolation valves shall be provided on both sides (suction and discharge). Provision for pressure gauge connections at the inlet and outlet of the pump shall be made (*see* Fig. 27).

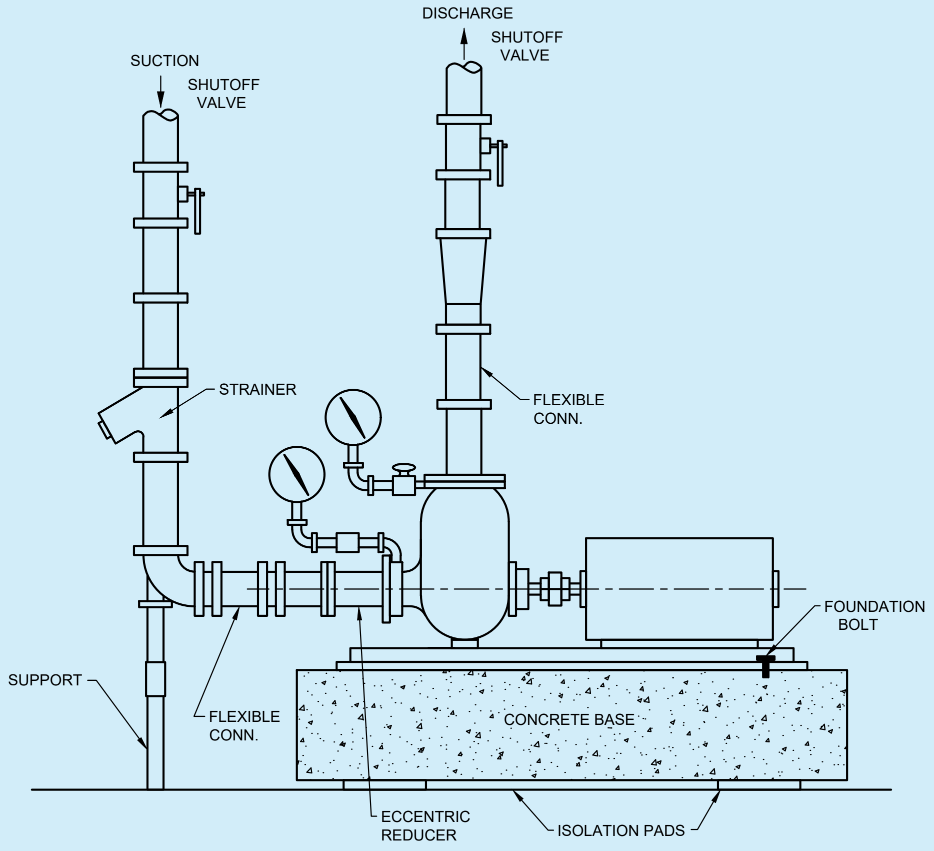


FIG. 27 TYPICAL PUMP INSTALLATION DETAILS.

17.3.6.7 In-line pumps may be installed directly in the piping with pipe hangars adequately sized to handle the load of the pump and piping. For larger size in -line pumps, a flange support or floor support with saddles shall be used. All supports to floor and ceiling shall be vibration isolated.

17.3.6.8 Correct direction of rotation of the pump (which shall be indicated on the housing) shall be checked before start up.

17.3.6.9 A factory installed drain connection with a site fitted installation valve shall be used to drain the pump reservoir.

17.3.6.10 Where low temperatures are encountered, freeze up precautions shall be taken.

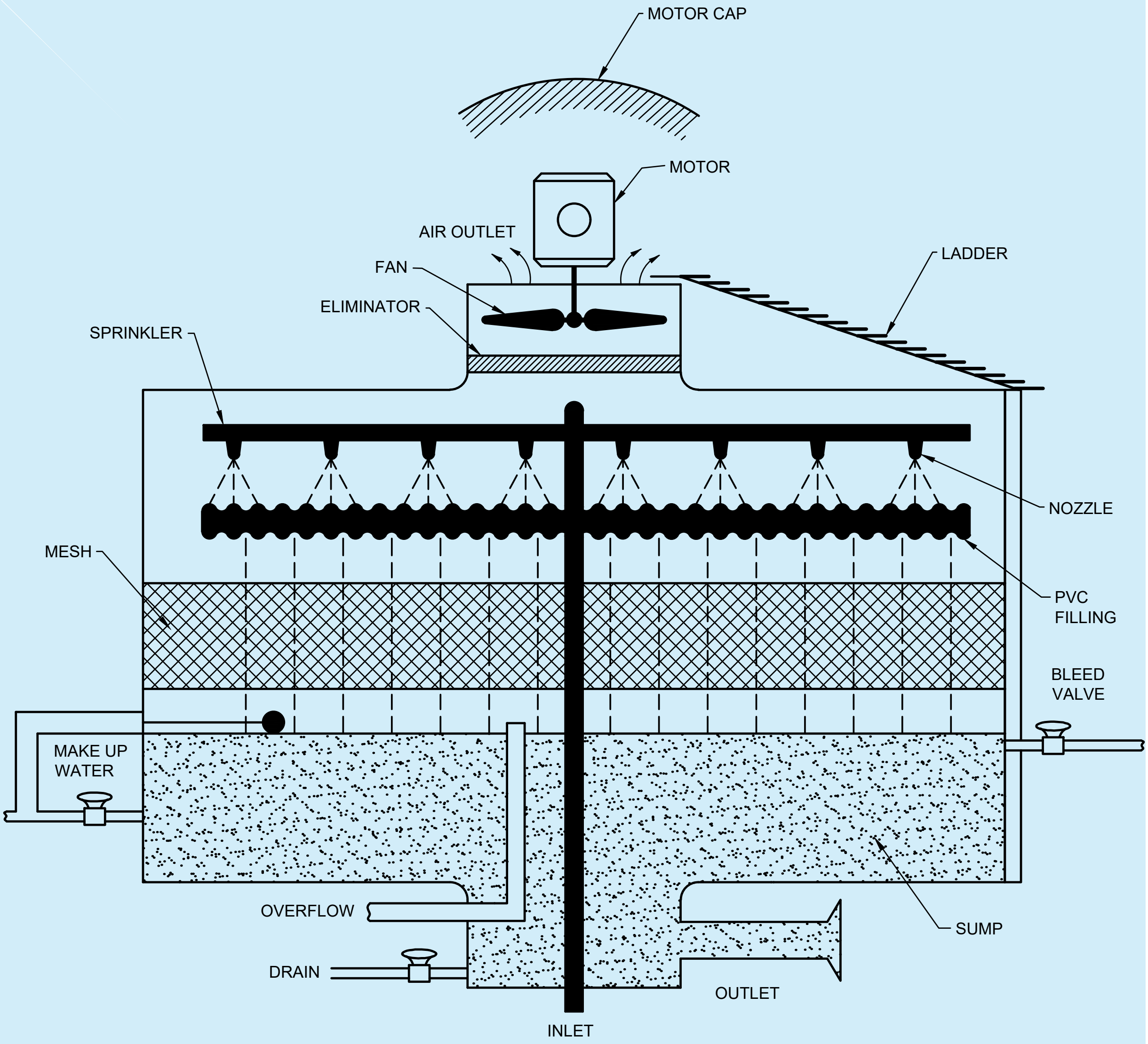
17.3.7 *Cooling Tower*

17.3.7.1 Cooling tower shall be located in such a way that noise as well as water drift are not objectionable. Tower location should not be close to leaf shedding trees.

17.3.7.2 Location shall be open and well-ventilated and manufacturer's instructions regarding side clearances for air circulation shall be meticulously followed.

17.3.7.3 If located on building terrace, the operating load shall be transferred to beams/columns as per advice of structural engineer. Cooling tower shall rest on adequately sized MS I-sections. These I-sections shall be hot dip galvanized to accepted standard [D-3(43)]. All welded joints shall be primer with corrosion resistant coated such as epoxy. Vibration isolation shall be provided between tower and the MS I-Sections.

17.3.7.4 Installation shall be such that the space below the cooling tower shall accommodate a strainer below the water level in the sump as well as a drain pipe with a valve. It shall be possible to completely drain the cooling tower sump when required (*see* Fig. 28).



MOTOR CAP
MOTOR
AIR OUTLET
LADDER
FAN
ELIMINATOR
SPRINKLER
NOZZLE
MESH
PVC
FILLING
BLEED
VALVE
MAKE UP
WATER
OVERFLOW
SUMP
DRAIN
OUTLET
INLET

FIG. 28 TYPICAL COOLING TOWER INSTALLATION

17.3.7.5 A service platform may be constructed beside the tower so that all parts requiring cleaning or maintenance are easily accessible. Slope of the floor below the tower shall be such that water does not stagnate below the tower.

17.3.7.6 Make up and quick fill connections shall be done and uninterrupted water supply shall be made available. For water quality, water treatment and bleed off, refer 7.4.

17.3.7.7 In case of multiple cooling tower installation at the same location, equaliser connections shall be provided. In case the pumps are at the same location as the cooling tower, the cooling tower sump shall be minimum 300 mm above the pump suction to ensure positive pressure while starting the pump. The cooling tower basin shall be leak tested by filling up with water and holding it for minimum two hours.

17.3.8 *Air Handling Units* (*AHU*)/ *Heat Recovery Units* (*HRU*)/ *Fan Coil Units* (*FCU*)

Air handling units shall be either floor mounted or ceiling mounted. AHUs and FCUs shall be located close to or with in the area to be air conditioned so that duct runs are minimum. Location shall take into consideration the feasibility of running ducts, taking back return air to the unit (either through return air ducts, above the false ceiling or directly into the unit as well as provision of chilled water connections, provision of humidifiers, fresh air inlet as well as drain connections.

In a multi-storied building, it is advisable to locate the AHUs on above the other on each floor so that piping shall rise through the same shaft.

From fire safety considerations, individual AHUs shall not serve more than one floor. Similarly, it is advisable to have exclusive AHU for each fire compartment. In case, these are not possible, fire and smoke dampers shall be fitted on both the supply air and return air paths where floor crossing or fire compartment crossing takes place. Provision for pressure gauge and thermometer connections shall be made at inlet and outlet piping connections.

AHU/FCU shall be mounted in such a way that both the mechanical noise as well as the air noise does not disturb the occupants. This is specially emphasised for ceiling-suspended units. Duct mounted silencers and acoustic lining of supply air duct may be provided as specified. AHU/FCU shall not be mounted above electrical or IT rooms where water leakage shall lead to serious problems.

Adequate maintenance and service space shall be provided around AHU/FCU and trap doors for convenient access shall be available. Lamps inside the unit, belt guards, sight glass and door interlocks shall be ensured (*see* Fig. 29).

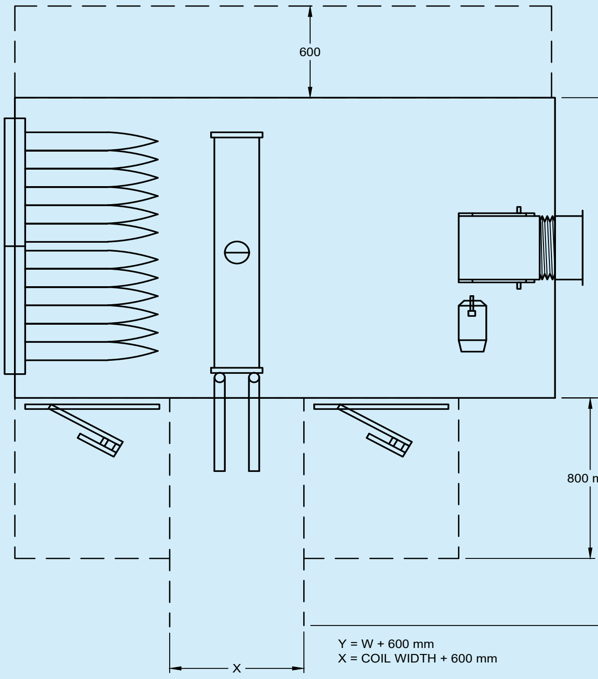


FIG. 29 TYPICAL SERVICE CLEARANCES AROUND AHU

Floor mounted AHU/heat recovery unit shall be mounted on top of pre-cast concrete block to permit easy drainage of condensate and to facilitate cleaning below the unit. Such supports shall be adequate in number and also located suitably so that transfer of dynamic load to structure safely takes place. Serrated rubber pads or other vibration isolation material shall be placed between the AHU/HRU frame and the concrete support. Insulated condensate drain connection shall be with a U- trap and the floor slope shall be towards the floor drain. Slope of the drain pan connection shall also be towards the drain pipe connection. Chilled water piping to AHU shall have a manual air vent at the top most point in the coil circuit and a drain plug at the bottom of the coil (*see* Fig. 30).

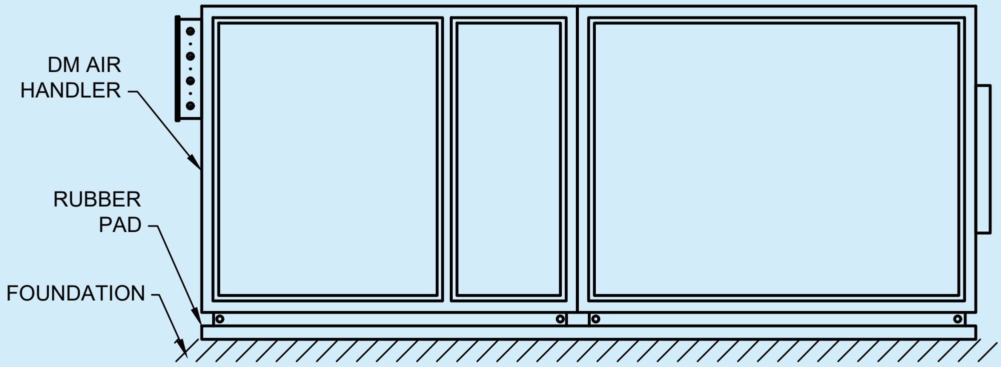


FIG. 30 AHU LOCATED ON FOUNDATION

Ducts shall be connected to the AHU/HRU with fire-proof connections to prevent transmission of vibration. Ceiling suspended AHUs/FCUs shall be hung from the ceiling with adequately sized rod and fasteners and shall be isolated from the structure by rubber or spring isolators. Illumination near the unit, drain point, water supply point and floor drain shall be provided.

17.3.9 *Air Washer Units* (*AWU*) *and Evaporative Cooling Units* (*ECU*)

Installation of AWU and ECU are similar to that of floor mounted AHU/HRU. They will have additional water connections to the spray- section with in-line recirculating pumps. Air washer units shall be preferably located on the summer wind-ward side. They shall be painted with reflective coating or thermally insulated. Large size air washers may be constructed with concrete basin. These shall have leak proof access doors as specified and basin shall be tested for water proofing integrity.

17.3.10 *Fans – Centrifugal, Axial Flow and Cabinet Type*

Fan performance is influenced by inlet and outlet conditions. 'Fan System Effect' which is the impact on fan performance due to inlet and outlet conditions as well as ways to mitigate them are described in **14**.

While rigging and hoisting heavy fans, manufacturer's instructions shall be carefully followed since the load is not uniformly distributed around the periphery.

Dynamic load of the fan, its distribution at different supporting points, vibration and noise shall be taken into account while designing the fan foundation.

Outlet connection to a duct (if provided) shall be by means of flexible fire-retardant connections.

17.3.10.1 *Centrifugal fans*

Where foundation bolts are provided, they shall be securely placed along with base plates while foundation is cast. Alternatively, fan may be mounted on suitable channel frame.

Vibration isolation base for fan and motor shall be an integral unit and shall be mounted on concrete foundation with anti-vibration mounts.

Safety screen shall be provided on fan suction side. Belt guard/coupling shall be provided and fan shall not be started without these protective devices.

17.3.10.2 *Axial flow fans*

Removable safety screens shall be provided on either side of the fan. Fans shall be properly grouted on the walls with vibration isolation material. Where the fan is suspended from the ceiling, vibration isolators shall be used.

17.3.10.3 *Cabinet fans*

A door interlock switch which shuts off the fan and switches on a bulk-head lamp mounted within the cabinet shall be provided. A water drain point shall also be provided within the cabinet. Transparent inspection windows of minimum 150 mm dia shall be provided.

17.3.10.4 For all type of fans, the sound generated is a major consideration which shall be taken care during the design/selection stage itself. Additionally, as specified by the fan manufacturer or system designer, acoustic silencers shall be mounted at inlet and outlet of the fan. Bird screen shall be provided at fresh air intake points and at exhaust outlet.

In all cases, adequate space for service and maintenance including removal and replacement of motor shall be provided.

Direction of rotation shall be verified on startup and field balancing shall be done where required. An electrical isolator or a push button switch shall be provided adjacent to the fan.

17.3.11 *Air Distribution and Ducting*

17.3.11.1 *Duct supporting/hanging systems*

Duct hanging system shall have three parts: Upper attachment to the building, the Hanger and Lower attachment to duct.

Upper attachments shall be concrete inserts which are cast into the structure, threaded concrete fasteners which are inserted into the cast slab or structural steel fasteners. Upper attachment method shall be selected with care and a safety factor of 5 is recommended. In case of steel structure, careful selection of primary and secondary supporting to be done on case-to-case basis.

Hangars shall be strips of galvanized steel or threaded round steel rods. Threaded portion of the rods shall be painted after installation.

Lower attachment is the connection between the hangar and duct section. Fasteners that penetrate the duct shall be sheet metal screws or rivets. All nuts, bolts and washers shall be zinc plated steel. Rivets shall be galvanized or made of magnesium-aluminium alloy.

Where ducts shall not be supported from the ceiling, wall brackets or other suitable support arrangements may be used.

Neoprene or other vibration isolation material of minimum 6 mm thickness shall be inserted between the ducts and the angle iron supports/brackets. Vertical ductwork shall be supported at each floor by suitable structural steel members.

Plenums where provided shall have access doors of 450 mm × 450 mm. Support details for different duct section is given in Fig. 31.

Supporting details for rectangular ducting for static pressure up to 750 Pa are given in Table 40 and for static pressure above 750 Pa are given in Table 41. Supporting details for low pressure (Up to 750 Pa) rectangular ducting system are given below:

Table 40 Supporting Details for Low Pressure (Up to 750 Pa) Rectangular Ducting System

(*Clause* 17.3.11.1)

Sl No. (1)	**Larger Side of Duct** mm (2)	**Supporting Angle** mm (3)	**Vertical Rod Diameter** mm (4)	**Maximum Spacing between Supports** mm (5)
i)	Up to 900	40 × 40 × 5	8	2 400
ii)	901 to 1 500	40 × 40 × 5	8	2 400
iii)	1 501 to 2 400	40 × 40 × 5	10	2 400
iv)	2 401 and above	65 × 65 × 5	12	2 400

Table 41 Supporting Details for High Pressure (Above 750 Pa) Rectangular Ducting System

(*Clause* 17.3.11.1)

Sl No. (1)	**Larger Side of Duct** mm (2)	**Supporting Angle** mm (3)	**Vertical Rod Diameter** mm (4)	**Maximum Spacing between Supports** mm (5)
i)	Up to 1 250	50 × 50 × 5	12	2 400
ii)	1 251 to 2 100	65 × 65 × 5	12	2 400
iii)	2 101 and above	75 × 75 × 5	15	2 400

Alternatively, slotted galvanized brackets attached to the top two bolts of the four-bolt duct connector shall be used.

For round, oval and flexible ducts, galvanized steel straps, wire or rods shall be used and support details shall be as provided by manufacturer/installer and approved by Engineer-in-Charge.

Sheet metal ducts shall be fabricated from galvanized iron sheets with minimum 180 GSM zinc coating and of lock forming quality. Fabrication of ducts shall be carried out at a factory from coil stock or at site from cut sheets. Where the overall duct area for the project exceeds 600 m^2 or where the external static pressure exceeds 250 Pa, lock forming machines shall be used for fabrication.

17.3.11.2 *Pre-insulated ducts*

Pre-Insulated duct made of polyisocyanurate sandwich panels comprising of a rigid foam board faced on both sides by stucco embossed aluminium foil shall be joined with tiger connectors or with male-female jointing system up to 500 mm. Higher sizes shall be joined by cover corners which has a holding pin which goes inside the flange. Ducts shall have suitable fixtures made of polymer plastic or extruded aluminium for jointing as well as for fixing of accessories such as grills, diffusers etc. Duct work shall be installed using supports as specified by the manufacturer.

17.3.11.3 *Fabric ducting*

Tools and accessories for installation shall be provided by the Fabric duct supplier. Fabric duct shall be connected to fan/AHU with GI duct connectors. While laying the duct, care shall be taken to prevent twisting of the fabric. A ratchet strap may be used to secure the fabric to duct connector.

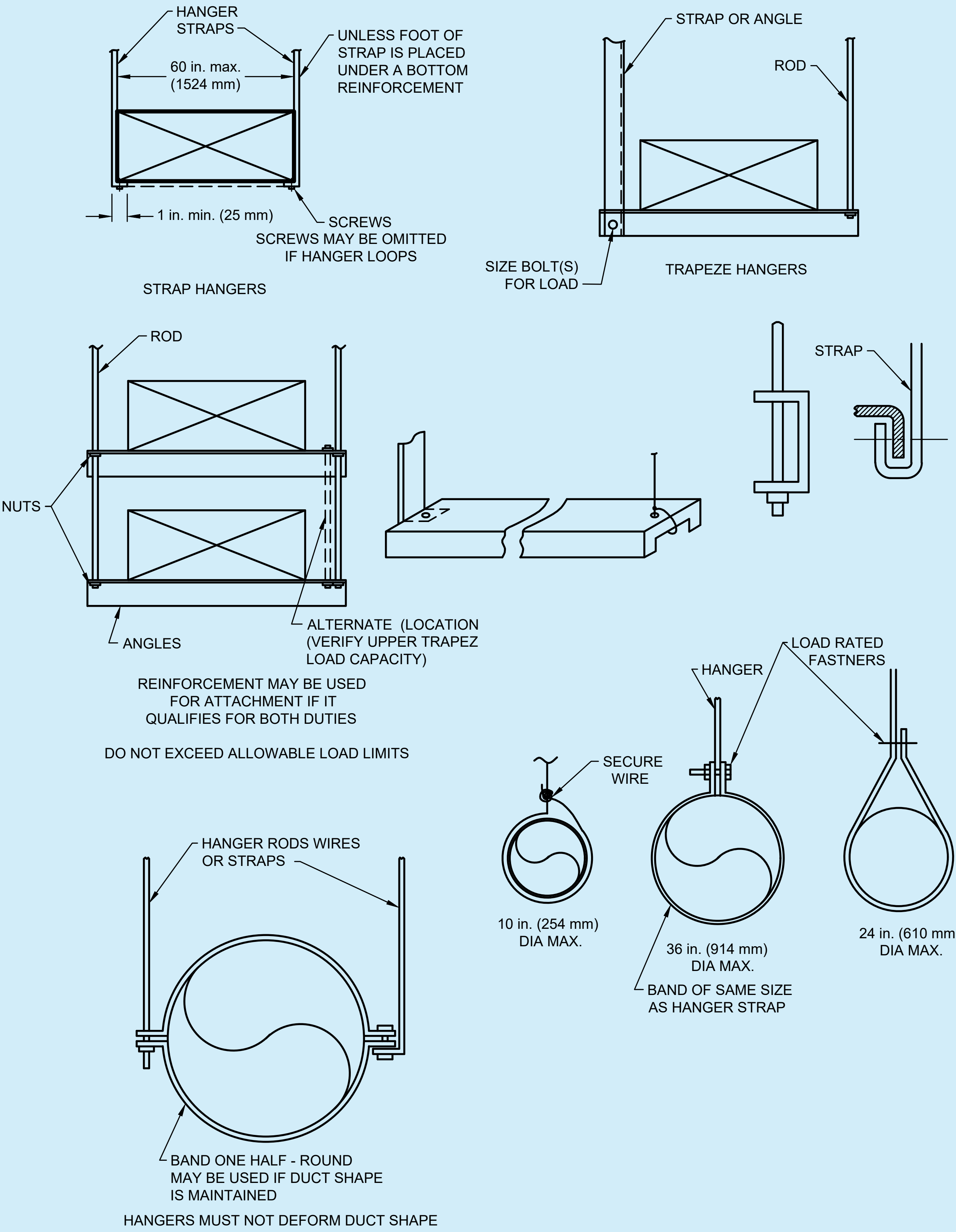

HANGER STRAPS
60 in. max. (1524 mm)
UNLESS FOOT OF STRAP IS PLACED UNDER A BOTTOM REINFORCEMENT
1 in. min. (25 mm)
SCREWS
SCREWS MAY BE OMITTED IF HANGER LOOPS
STRAP HANGERS
STRAP OR ANGLE
ROD
SIZE BOLT(S) FOR LOAD
TRAPEZE HANGERS
ROD
NUTS
ANGLES
ALTERNATE (LOCATION (VERIFY UPPER TRAPEZ LOAD CAPACITY)
REINFORCEMENT MAY BE USED FOR ATTACHMENT IF IT QUALIFIES FOR BOTH DUTIES
DO NOT EXCEED ALLOWABLE LOAD LIMITS
STRAP
LOAD RATED FASTNERS
HANGER
SECURE WIRE
10 in. (254 mm) DIA MAX.
36 in. (914 mm) DIA MAX.
BAND OF SAME SIZE AS HANGER STRAP
24 in. (610 mm) DIA MAX.
HANGER RODS WIRES OR STRAPS
BAND ONE HALF - ROUND MAY BE USED IF DUCT SHAPE IS MAINTAINED
HANGERS MUST NOT DEFORM DUCT SHAPE

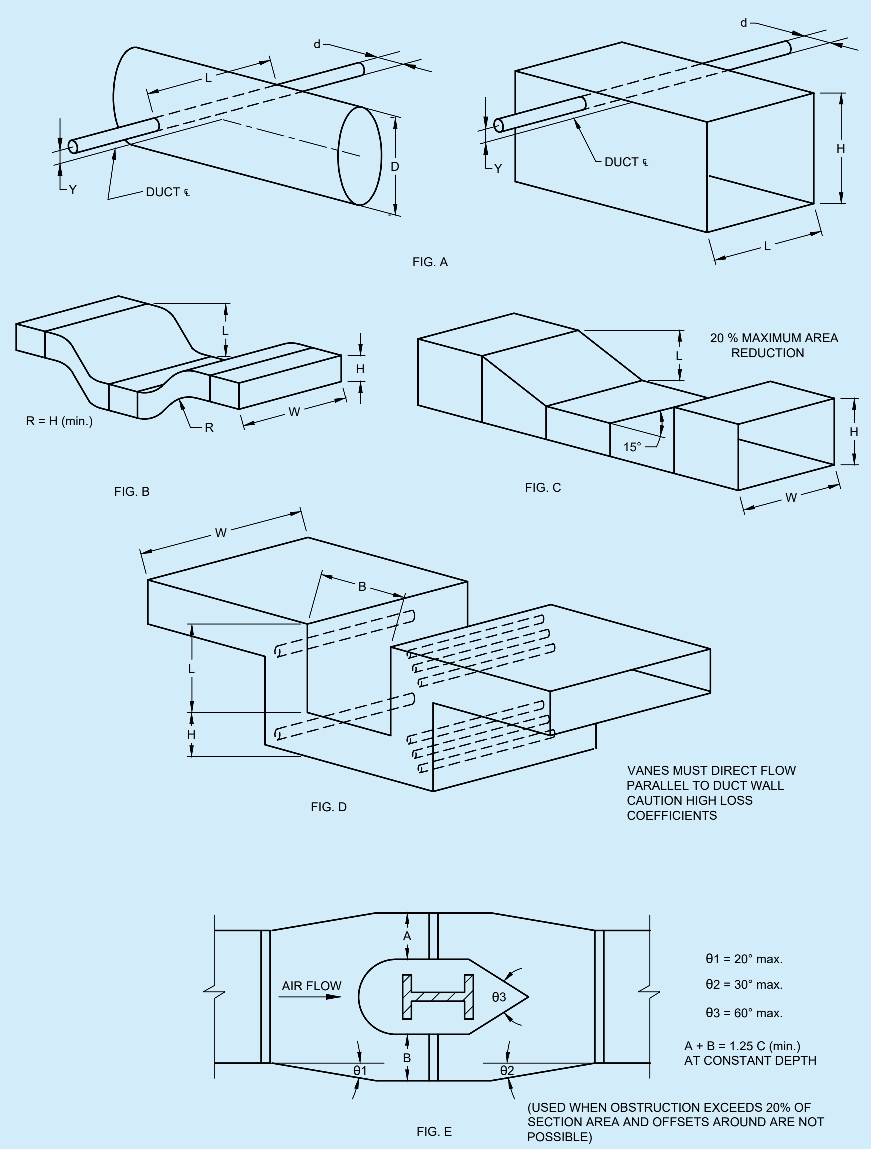
FIG. 31 SUPPORT DETAILS FOR DIFFERENT DUCT SECTIONS

17.3.11.5 Where duct penetrates brickwork or masonry openings, treated wooden framework shall be provided within the opening and the crossing duct shall be provided with heavy flanged collars on either side of the wooden frame so that the duct crossing is made leakproof. Alternatively, the duct section passing through the structure may be suitably wrapped so that vibration is not transmitted to the structure. Where duct passes through a fire compartment barrier, a fire barrier shall be created by installing a fire cum smoke damper.

17.3.11.6 When fans feed into a duct system, uniform straight flow conditions shall be ensured. Fan manufacturer's recommendation in regard to straight length of connecting duct both at inlet and outlet of the fan to obtain optimum fan performance needs to be followed. Similarly, pressure loss in a duct elbow or a volume control damper is minimum when air approaching the elbow/damper has a uniform velocity profile and positioning the elbow/damper after an adequate straight piece of duct is recommended. All elbows shall have adequate number of turning/guide vanes to ensure uniform air flow over the entire cross-section.

17.3.11.7 When duct is connected to an air handler or a fan, flexible connections made of rubberised canvas and 100 mm long shall be used between duct and AHU/fan and shall be securely bonded and bolted to the unit casing as well as the duct to prevent air leakage.

17.3.11.8 Turning vanes shall be provided at supply air outlet collars and at branch take-offs. They shall be fabricated from minimum 0.8 mm galvanized steel sheet and equally spaced on side runner and riveted or bolted to the duct (*see* Fig. 32).



d
L
Y
DUCT ℄
D
d
Y
DUCT ℄
H
L
FIG. A
L
H
W
R = H (min.)
R
FIG. B
20 % MAXIMUM AREA REDUCTION
L
15°
H
W
FIG. C
W
B
L
H
FIG. D
VANES MUST DIRECT FLOW PARALLEL TO DUCT WALL CAUTION HIGH LOSS COEFFICIENTS
A
AIR FLOW
θ3
B
θ1
θ2
θ1 = 20° max.
θ2 = 30° max.
θ3 = 60° max.
A + B = 1.25 C (min.) AT CONSTANT DEPTH
FIG. E
(USED WHEN OBSTRUCTION EXCEEDS 20% OF SECTION AREA AND OFFSETS AROUND ARE NOT POSSIBLE)

Fig. 32 Typical Turning Vanes

17.3.11.9 Take offs allow air from main duct to be diverted to branch ducts and take offs are fitted into circular or rectangular openings cut into the wall of the main duct and small metal tabs cut at the start of the take-off are bent to connect the take off to main duct. Alternatively, a snap-in attachment with an adhesive foam gasket shall be used, outlet of the take-off connects to branch duct.

17.3.11.10 Dampers shall be manually controlled or automatic. Dampers shall be rated for operation against 1.5 times the rated pressure class of ducting. Suitable links, levers and quadrants shall be provided for proper operation, control and setting of the dampers. Linkages shall be blade to blade and concealed in a jamb out of the airstream. Every damper shall have an indicating device showing the damper position and a locking device. Where Dampers are operated via an external gear train, these are to be constructed out of engineering polymers with self-lubricating properties, and, located out of the air stream. Leak resistant access doors next to the dampers shall be provided to facilitate attending to the dampers and duct cleaning.

17.3.11.11 Splitter dampers shall be installed in branches where a split takes place. They shall be made of aerofoil blades of minimum 1.6 mm thickness and hinged at downstream edge. Operation rod shall be accessible from outside with an airtight hub and locking screw. Splitter damper shall be enclosed in sheet steel ducting with flange at both ends and shall be aligned with the main ducting. Damper section shall be made of one size higher thickness than the upstream duct.

17.3.11.12 Louvre dampers shall be provided in all branches they shall be multiblade type of aerofoil construction or in triple vee grove construction, rotating in lubricated ball/roller bearings/delrin bushes. Blades shall be connected by a linkage for simultaneous operation by a rod extending outside the duct and terminating in a locking quadrant with damper position indicator. Damper shall be enclosed in sheet steel box made of one size thicker than upstream duct and shall have flanges at both ends for connecting to main duct.

17.3.11.13 Fire dampers and combination fire and smoke dampers shall be installed wherever a fire compartment barrier exists. They shall be installed in ducts, return air passages and at all floor crossings. Access door shall be provided for each fire damper. Fire dampers may be motorized (activated by an electrical impulse from the fire alarm panel or a thermal trip element) or operate on a fusible link and shall shut off airflow completely. Wiring from AHU panel to the damper (in case of electrically operated damper) shall be carried out by damper installer. Dampers shall be suitable for vertical or horizontal mounting. Damper shall be installed maintaining fire integrity of the partition and all dampers at wall/floor crossings shall have a factory fitted sleeve. In such cases, the damper shall be a free float and the annular space shall be free to allow for expansion through a smoke seal. *See also* Part F ‘Fire and Life Safety’ of this NBCS.

17.3.11.14 Any type of electrical heaters shall not be mounted inside ducts. The electrical heaters shall be allowed to be installed in locations identified and approved by competent authority.

17.3.11.15 Variable air volume (VAV) boxes shall be installed at specified locations. They may be supported from floor, wall or ceiling as specified and may be mounted in vertical or horizontal direction. Boxes shall be factory set for minimum airflow of 10 percent and maximum airflow of 110 percent of design flow. Access to the box shall be from below and shall be completely sealed but easily removable. Electrical supply point with an isolator shall be provided by others and step-down transformer wherever needed shall be part of the unit.

17.3.11.16 Grilles, diffusers and registers act as terminal units for supplying air from the duct system to the room or for collecting back air from the room either to exhaust or for return to AHU/fan. Terminal units may be fitted with air filters. Square or rectangular wall outlets shall have a flanged frame with outside edges turned and fitted with a flexible gasket between the concealed face of the flanges and the finished wall face. Core of supply air register shall have adjustable front loves parallel to the longer side capable of deflection and adjustable back louvres parallel to shorter side to achieve horizontal spread of air up to 45°. Outer framework shall be made of 1.6 mm minimum thickness of aluminium sheet and louvres shall be of aero foil design of extruded aluminium section with minimum thickness of 0.8 mm. The vane ratio (ratio of gap between the vanes and vane depth) should not be less than 1 and should not exceed 1.2.

17.3.11.17 Square and rectangular ceiling outlets /intakes shall have a flange flush with the ceiling on which it is fitted. Outlets shall have an outer ring with duct collar and removable core assembly. Inner as well as outer rings shall be minimum 1.1 mm thick and diffuser assembly shall be 0.8 mm thick extruded aluminium section. Circular ceiling outlets shall be either flush or with an outer cone. Flush cones shall have the lower edge not more than 5 mm below the finished ceiling. All outlets/inlets shall be designed to reduce dirt deposit on the ceiling adjacent to the outlet.

17.3.11.18 Linear diffusers shall have a flanged frame with the outer edge turned 3.5 mm and shall have 1 to 8 slots as specified in design. These shall be constructed out of 1.6 mm thick extruded aluminium sheet. All supply air outlets shall have volume control device made of extruded aluminium.

17.3.11.19 Locations of air outlets and intakes shall be shown in the drawing and necessary openings and the wooden framework for fixing the grilles/diffusers shall be provided by the contractor.

17.3.11.20 While installing fresh air intakes, no fixing device shall be visible from the face of the frame. Where louvres are to be fixed to brick, masonry or concrete, fixing shall be with expanding plugs or raw plugs. Where louvres are to be fixed to wood or metal, nonferrous screws or bolts shall be used. A flanged frame made of rolled steel sections shall be provided on the front face to cover the gap between the louvres and the adjoining wall face. Frame shall be structurally rigid and corners shall be welded. Where the louvre length exceeds 1 250 mm additional intermediate and equally spaced supports shall be provided to prevent sagging/vibration. Louvres shall be made of 1.6 mm thick 100 mm wide extruded aluminium sections and fitted in an extruded aluminium frame. A bird screen made of 12 mm mesh in 1.6 mm steel wire held in angle or channel frame shall be fixed to the rear face of the louvre frame. Louvres shall be fixed 45 degrees to vertical and shall provide 60 percent minimum net opening. Louver design and spacing shall ensure that there is no water ingress and the lowest louver shall be suitably overlapped to prevent water being drawn in.

17.3.11.21 Test probes which shall be installed at every fan discharge and suction duct shall be of heavy-duty zinc alloy casting. Expansion plugs shall be neoprene and capable to withstand 80 °C and 300 kPa pressure.

17.3.11.22 Kitchen exhaust ducting shall be of 16 G MS CRCA sheets and shall be of welded construction. Access doors shall be provided at 3 m intervals and the duct shall have a mild slope towards the kitchen hood. Laundry and dish washer extract ducts shall be of air and watertight construction and shall be of Aluminium sheets in accordance with accepted standard [D-3(44)]. Gasket used to be fire rated. Access doors to be provided at regular intervals and at critical points. The ducting shall be wrapped with high temperature grade EPDM, nitrile rubber or with fire wrap.

17.3.12 *Filters and Air Cleaning Devices*

The installation and commissioning of filters and air cleaning devices require strict adherence to these guidelines to ensure optimal performance and safety.

17.3.12.1 Filter elements shall be kept stored in original packing till they are ready to be installed with all upstream areas such as AHU rooms and upstream ducting is cleaned and made dust free.

17.3.12.2 Filters shall be installed with directional arrows pointing towards air flow direction. Filters shall be tightly fitted in the frames provided using gaskets with no gap between the filter and the frame.

17.3.12.3 Differential pressure gauge/switch is recommended to be installed across filters. After initial running of 48 h, if required, replace the filters (In case of pre filters only).

17.3.12.4 HEPA filters shall be handled with special care since the media is fragile and shall be installed with the gasket side of the filter facing the frame.

17.3.12.5 ESP filters shall be firmly fitted in a specially fabricated frame and wiring of the ESP filters shall be as per manufacturer’s recommendation. A clear sticker ‘Caution – High Voltage Filters’ shall be prominently displayed in front of ESP filters.

17.3.12.6 While installing ultra violet germicidal irradiation (UVGI) lamps, the layout provided by the manufacturer shall be followed. In AHUs, UVGI lamps may be installed downstream of cooling coil. Mounting frame for UVGI lamps may be at a distance of 300 mm from the cooling coil for optimum performance. After installation, the lamp surface shall be cleaned with a wick wetted with spirit.

17.3.12.7 Ballast of the lamps may be accommodated with in the UVGI electrical panel or may be tied to the UVGI mounting brackets as per manufacturer’s recommendation and IP rating of ballasts.

17.3.12.8 Follow manufacturer’s instruction for any shielding of drain pan, cable sheaths and conduits.

17.3.12.9 Safety guidelines provided by manufacturer shall be closely followed. If for any reason, AHU door needs to be opened while the lamps are 'ON' person/s in AHU room shall wear PPE kit and protective goggles. Bare eye or skin shall not be exposed.

17.3.12.10 Upper zone irradiation units may be mounted on walls or hung from ceiling well above occupied zone (minimum 2.2 m from floor level). Baffles/ louvres shall be directed in such a way that the rays are not directed towards occupied zone. In respect of upper zone irradiation units, the occupied zone UVGI shall be measured periodically to ensure that it does not exceed 1 000 UV/m^2 to 2 000 UW/m^2.

17.3.13 *Installation of Piping Works*

The following are key points for the proper installation of pipeworks, ensuring alignment, sealing, support, and compliance with safety:

17.3.13.1 It shall be verified that pipes of correct specifications such as pipe class, length, thickness, straightness and surface finish are received at the project site. Pipe routing as per 'Good for Construction' drawing shall be verified at site and pipes may be cut to required lengths.

17.3.13.2 Edges of pipes shall be bevelled by grinding to make a 'butt' joint. Welding shall be done exactly to specifications (for example, accepted standard [D-3(45)]. Fabrication of supports shall be as per site requirements and specifications. Spacing between supports shall be as specified.

17.3.13.3 Overhead piping may be supported on walls/ columns with appropriately sized brackets or may be suspended from ceiling/roof truss with MS suspension rods or hangars. Anchor fasteners of adequate sizes shall be used for pipe supports. Vertical risers shall be supported by horizontal supports mounted at regular intervals.

17.3.13.4 Vertical pipes passing through floors shall be parallel to the wall and shall be straight (as verified with a plumb line).

17.3.13.5 Where pipes pass through floor slab or walls, gaps between the pipe and floor/wall opening should be sealed as detailed in Part F 'Fire and Life Safety' of this NBCS.

17.3.13.6 Chilled water piping shall be supported on PUF or wooden gutties. Single gutties shall be used for horizontal runs and double gutties for vertical risers. While installing insulated pipes, care shall be taken that insulation is not unduly compressed.

17.3.13.7 Condenser water piping shall be placed on serrated rubber pads at each support and held in place by U-clamps.

17.3.13.8. Piping shall have expansion joints as required. Fittings, valves and instruments shall be as per approved drawings. Drain points and air vents shall be provided as required. Auto purge valves shall be provided at the highest point in each pipe loop with discharge piped out to nearest drain or sump. While T connections shall be permitted on suction side of pump, shoe connections shall be provided on the discharge side. Elbows/bends shall be minimum and reducers shall be eccentric type. Welding scale shall be removed before applying red oxide primer. Readymade fittings to specifications are recommended. Welder shall be competent and hydraulic pressure testing with 1.5 times the working pressure shall be done for 24 h (*see* Fig. 33, Fig. 34 and Fig. 35).

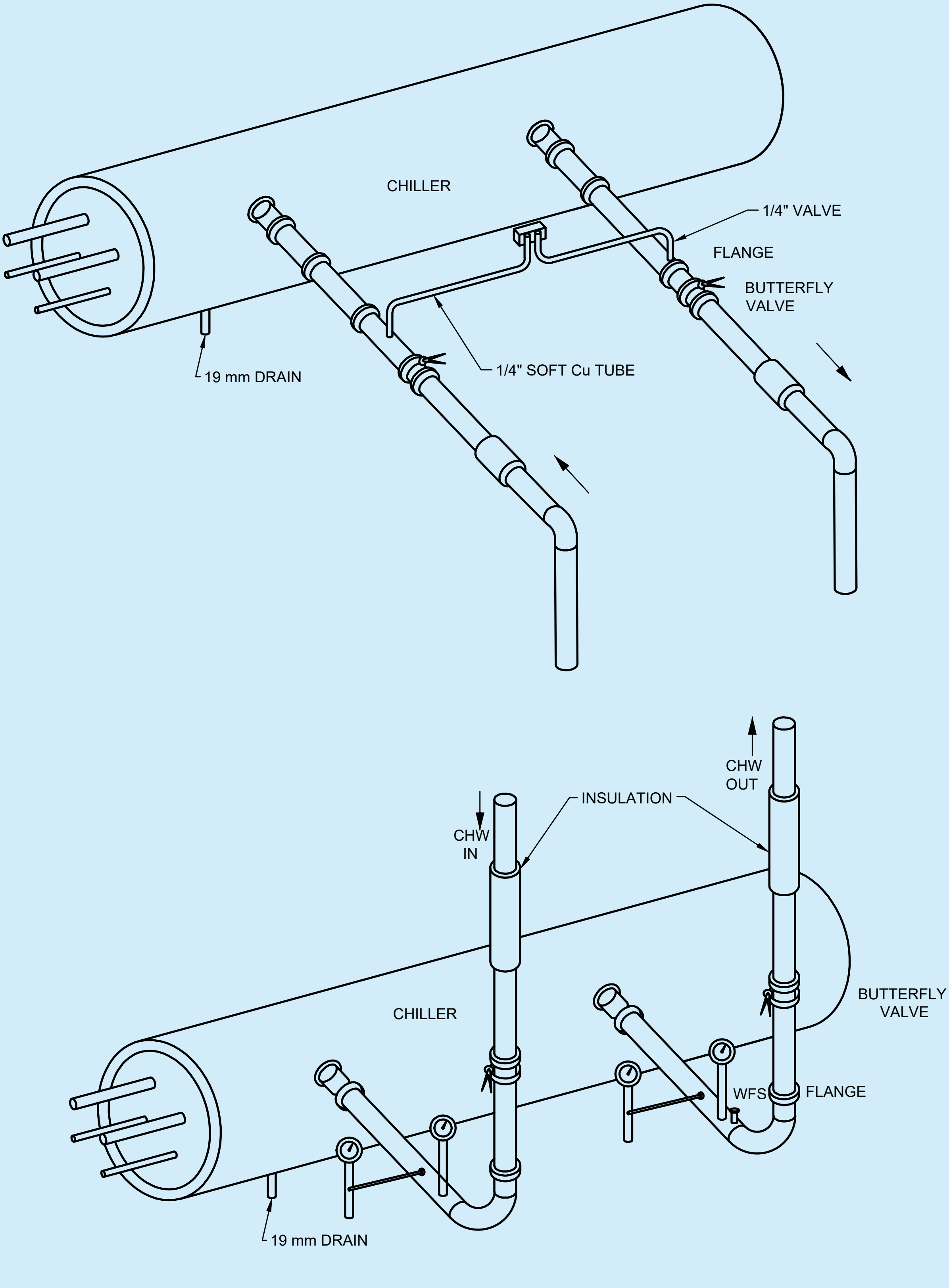

CHILLER
1/4" VALVE
FLANGE
BUTTERFLY VALVE
19 mm DRAIN
1/4" SOFT Cu TUBE
CHW OUT
INSULATION
CHW IN
CHILLER
BUTTERFLY VALVE
WFS
FLANGE
19 mm DRAIN

FIG. 33 TYPICAL CHILLER CONNECTIONS

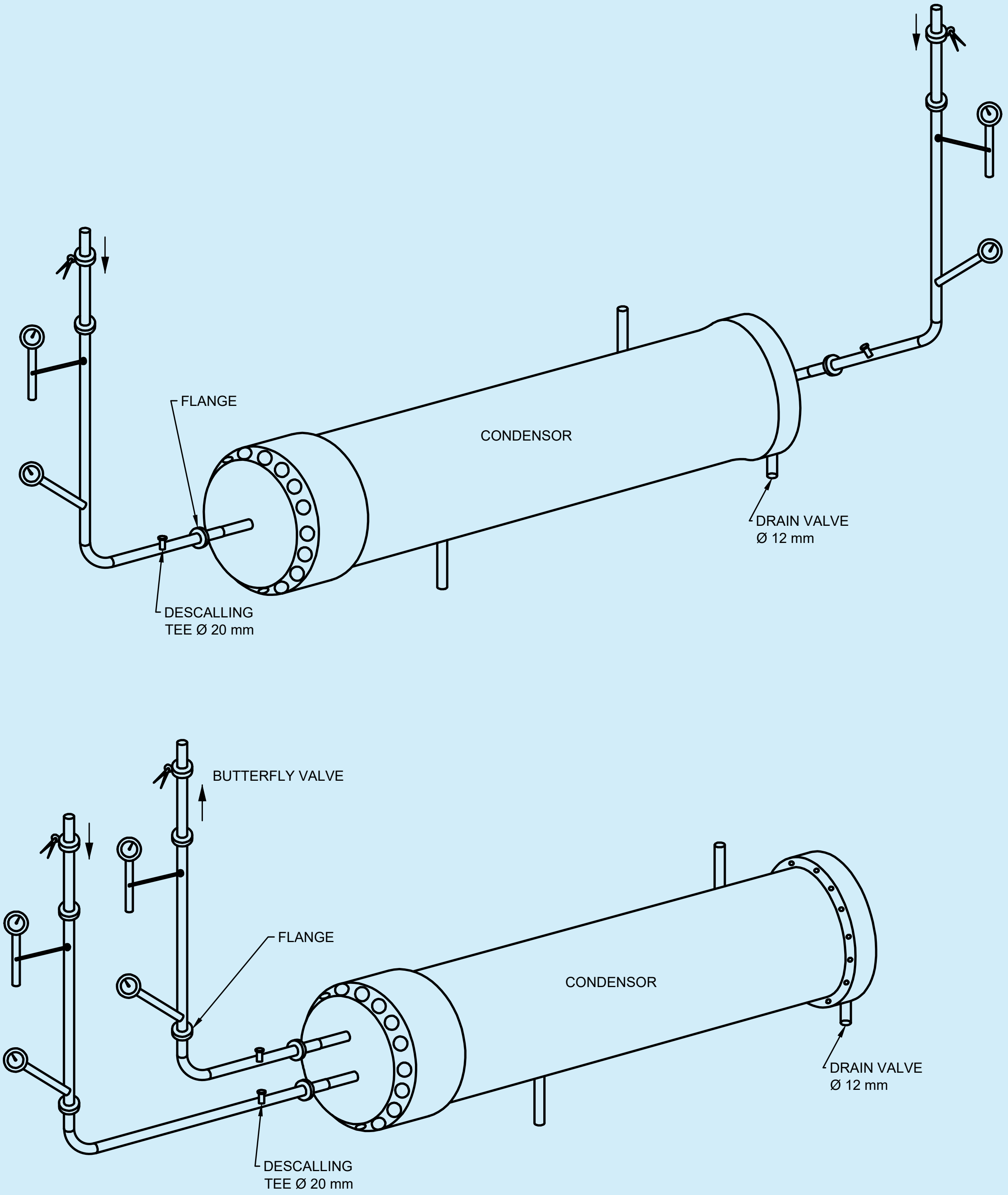

FLANGE
CONDENSOR
DRAIN VALVE
Ø 12 mm
DESCALLING
TEE Ø 20 mm
BUTTERFLY VALVE
FLANGE
CONDENSOR
DRAIN VALVE
Ø 12 mm
DESCALLING
TEE Ø 20 mm

FIG. 34 TYPICAL WATER COOLED CONDENSER CONNECTIONS

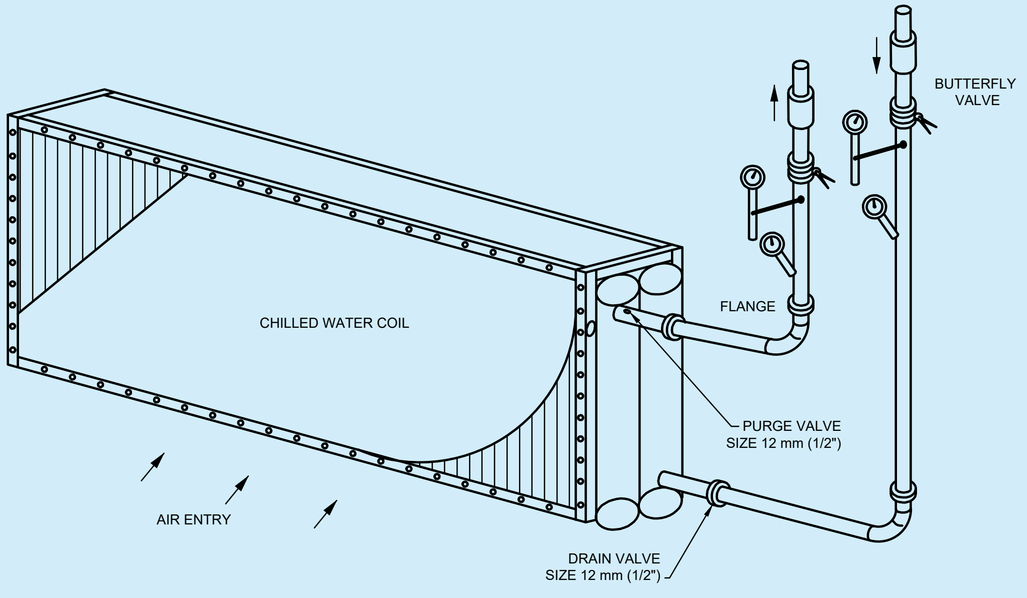


FIG. 35 TYPICAL COIL CONNECTIONS

17.3.13.9 Flanges shall be provided near each equipment connection and all flanges shall be with gaskets.

17.3.13.10 During installation process, open pipe ends shall be always kept closed.

17.3.14 *Insulation Works*

The following are key points for the proper installation of insulation works, ensuring correct material selection, proper fitting, and adherence to safety and performance.

17.3.14.1 *Thermal insulation of sheet metal ducts*

Duct surface shall be cleaned with wire brush to remove dust and grease. Two coats of cold setting fire resistant adhesive compound shall be applied over the duct surface. GI stick pins shall be used in case of glass wool/rock wool. Thermal insulation shall be wrapped around the duct with aluminium foil facing the outer side. All transverse and longitudinal joints to be sealed with aluminium tape. PVC strips shall be fixed at suitable intervals so that insulation remains in place. Insulation shall be covered with GI wire mesh (0.63 mm thick × 19 mm) netting on the outside where duct is open and exposed to weather and shall be additionally protected with tar felt or two coats of 10 mm sand cement plaster followed by two coats of water proofing chemical.

17.3.14.2 *Duct made of pre insulated boards*

Pre-insulated duct boards may be used for efficient air distribution with reduced energy loss and improved installation speed (*see* Fig. 36) providing both thermal insulation and structural stability.

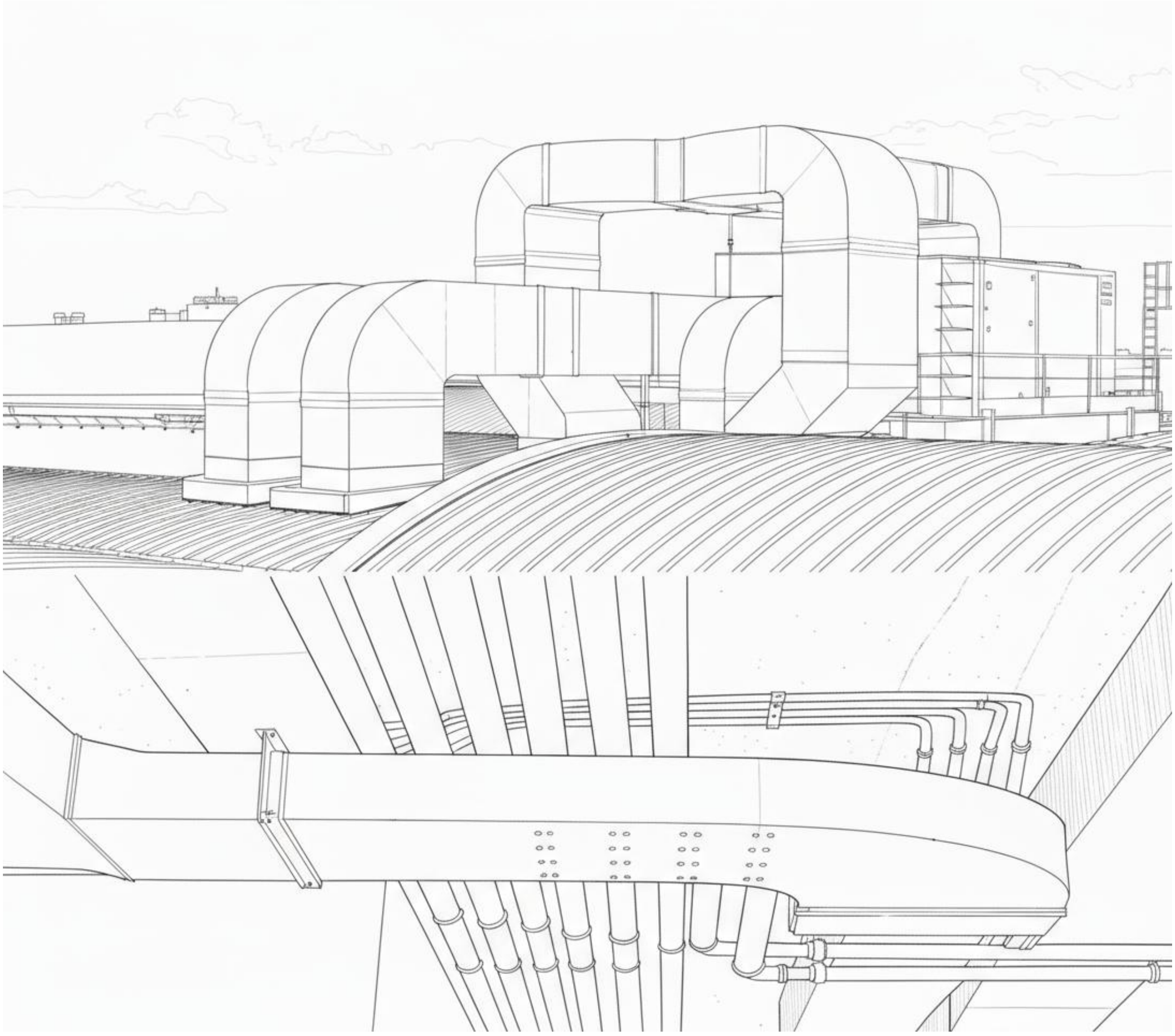


FIG. 36 PRE INSULATED DUCTS.

17.3.14.3 *Acoustic lining of duct*

Inside surface on which lining is to be provided shall be cleaned of dust and grease. Material used shall be 12 mm/25 mm thick resin bonded fibre glass/rock wool rigid board with 48 kg/m^3 density. Board shall be fixed inside duct using fire retardant adhesive and covered with tissue paper. Insulation shall be covered with 0.5 mm thick perforated Aluminium sheet having polysurlyn lamination on inner side with minimum 20 percent perforation. Insulation board and aluminium sheet shall be secured with Cadmium coated bolts, nuts, cup washers and steel screws. Ends shall be securely sealed so that no lining material is exposed. Length of lining shall be as per approved drawing.

As an alternative to the above, open cell elastomeric foams of fire-retardant type specially formulated for sound attenuation may be used. These shall be fixed inside the duct with fire retardant cold setting adhesive (*see* Fig. 37).

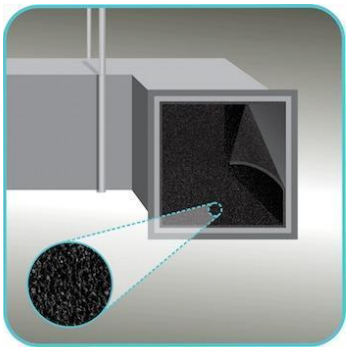


FIG. 37 ACOUSTIC INSULATION OF DUCT WITH OPEN CELL ELASTOMERIC FOAM.

17.3.14.4 *Acoustic lining of equipment rooms*

Where specified in drawings, inside walls and ceilings of equipment rooms may be lined with acoustic insulation. Surface to be cleaned with a wire brush. A frame work of U-shaped channel with height equal to proposed lining thickness made of 0.63 mm thick GI sheet shall be fixed to the walls by means of raw plugs. Similar frame work shall be fixed to ceiling by means of dash fasteners (*see* Fig. 38).

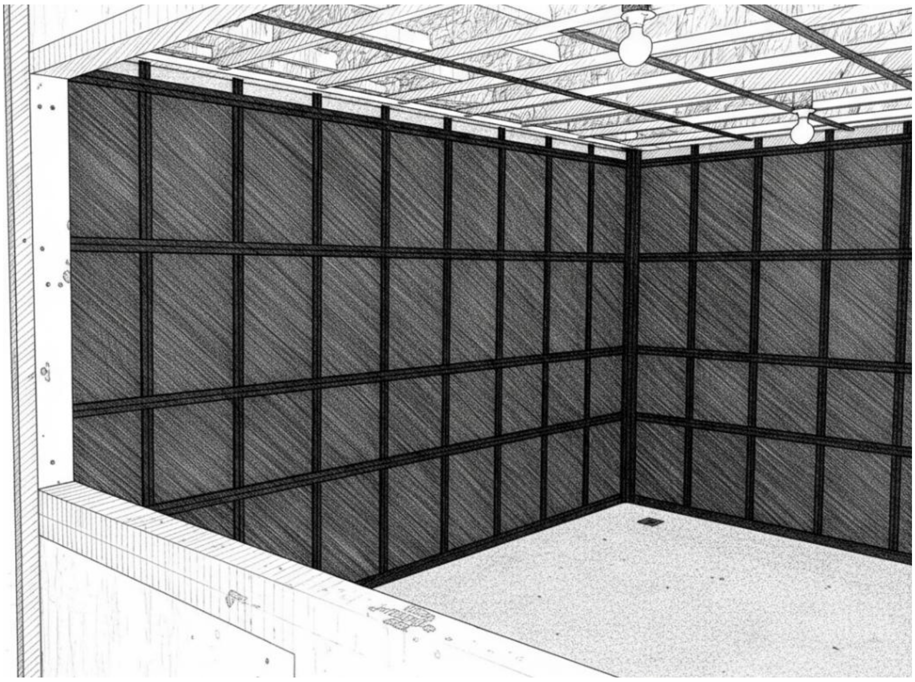


FIG. 38 PLANT/AHU ROOM ACOUSTIC INSULATION.

Resin bonded glass wool/rockwool cut to size shall be fitted in the framework and covered with tissue paper. Surface shall be covered with 0.5 mm thick perforated (minimum 20 percent perforations) aluminium sheet with polysurlyn lamination on the inside. These shall be fixed with brass screws.

17.3.14.5 *Pipe insulation*

Insulation of pipes shall be carried out with specified material. Pipe insulation material is available in pre-moulded half sections.

Pipe surface shall be cleaned of dust, rust and grease with wire brush. One coat of red oxide primer and two coats of cold setting, fire retardant adhesive compound shall be applied. After tightly fixing the insulation sections, joints shall be sealed with adhesive compound.

Piping within covered space shall be covered with aluminium cladding of specified thickness having polysurlyn lamination on the inside over a vapor barrier. Cladding shall have 50 mm overlap and shall be tied down with lacing wire.

Piping outside the building and exposed to weather shall be finished with vapor barrier and GI or Aluminium sheet cladding with polysurlyn lamination on inner side. Two layers each of 6 mm thick sand cement plaster each cured for minimum 48 h followed by two coats of water proofing chemicals or fixed with bitumen membranes with hot bitumen adhesive or cold quick setting fire resistant mastic compound.

Buried piping shall be covered with suitable gauge polythene faced hessian cloth (with polythene facing outward) with 50 mm overlap. Joints shall be sealed with bitumen. A layer of 0.5 mm × 20 mm thick sand cement plaster (1:4) shall be applied and water proofed by applying hot bitumen or cold quick setting fire resistant mastic compound with a layer of tar felt over the plaster. Final finishing shall again be with hot bitumen or cold mastic compound.

Alternatively, the insulation sections shall be protected with a 3 mm to 5 mm thick HDPE sheet cladding hot air welded and sealed at all joints.

In respect of pre insulated pipe sections, manufacturer's instructions shall be followed. For pipes inside the building, the factory provided Aluminium foil lamination shall suffice both as vapor barrier and also as finishing material. Otherwise, GI or aluminium cladding shall be provided with 1.016 mm (40 mil) polysurlyn coating on inside. After application with adhesives, all joints shall be sealed with Aluminium tape.

17.3.14.6 *Insulation of pumps, valves, expansion tank, fittings and pipe supports*

Pumps, valves, fittings and strainers in the chilled water line shall be insulated to the same thickness and using the same as the pipeline. Care shall be taken to apply the insulation in such a way that it shall be possible to dismantle the pumps and operate the valves without damaging the insulation. Moulded PUF insulation in sections may be used where access is desired. These shall be easily reset/ reinsulated after dismantling. Option is available to use pre insulated valves and flanges.

Expansion tanks shall be insulated with 50 mm thick TF quality expanded polystyrene or 40 mm thick polyurethane or poly-isocyanurate foam as specified. Surface shall be cleaned and two layers of hot bitumen or fire resistant cold adhesive compound shall be applied. Insulation slabs shall be placed abutting one another and joints sealed with same compound. Slabs shall be covered with 0.63 mm thick × 20 mm GI wire mesh netting to be fixed with brass/GI screws. Final finishing shall be with 0.5 mm thick Aluminium cladding with polysurlyn coating on inner side.

Chilled water pipe supports shall be insulated with high density (120 kg/m^3) phenolic foam of thickness equal to pipe insulation. Supports shall have same shape as the outside surface of the pipe. Shape/ dimensions of pipe supports shall be as specified.

Pipe bends shall be insulated with sections cut into bevelled lags and applied over the bends with fire retardant cold adhesive compound and all joints sealed with cut insulation pieces or factory-made shaped bends in two halves fixed with fire retardant cold adhesive compound and tied with lacing wire. Vapor barrier similar to that used for pipes shall be applied and the whole assembly may be clad with Aluminium sheet having 1.016 mm (40 mil) polysurlyn lamination on inner side. Cladding to have same thickness as pipe cladding. Joints in the cladding shall be grooved joints fixed with screws and sealed with aluminium tape or mastic compound.

17.3.14.7 *Under deck and over deck insulation*

Underdeck roof insulation shall be with phenotherm 35 kg/m^3 or polyisocynurate foam 32 kg/m^3 or resin bonded glass wool or rock wool 48 kg/m^3. Thickness shall be as specified and method of application same as that of acoustic insulation for equipment rooms (*see* **17.3.14.4**).

Overdeck insulation shall be with polyurethane foam 40 kg/m^3 to 45 kg/m^3 of specified thickness sprayed in multiple layers to form a jointless homogeneous surface. Geo – textile cloth shall cover the insulation followed by plaster and suitable water proofing system. Alternatively, extruded polystyrene slabs or polyurethane/ poly-isocynurate foam slabs shall be fixed over fully dried roof surface with fire resistant mastic and joints sealed with adhesive compound.

17.3.15 *Thermal Storage System*

Storage tanks shall be fabricated out of carbon steel of adequate thickness, hydraulically tested for 1.5 times the design pressure and shall be positioned at the location ensuring that its operating load is safely transferred. Tanks may also be fabricated on-site. Red oxide primer as per the accepted standard [D-3(46)] shall be applied to all exposed welds and edges. Tank shall be able to withstand freezing of water inside through repeated cycles without damage. Tank shall be thoroughly cleaned and flushed before use. External surface shall be insulated similar to that of expansion tank.

Where multiple tanks are installed adjacent to one another, minimum clearance of 600 mm shall be kept. Adequate height to allow for piping (minimum 1 m) shall be available above the tank. Each pair of manifold inlet/outlet connections shall include a shutoff valve to isolate the unit. Bypass circuit shall be installed with a 3-way modulating valve. Thermometer/pressure gauge shall be installed at inlet and outlet. Before start up, air shall be completely purged out from the system for which air bleed valves shall be located at the uppermost points in the piping network.

When glycol is used as the storage medium, add inhibitors as recommended by the manufacturers.

When tanks are located in the open outside the building, insulation shall be covered with a layer of 26 gauge aluminium cladding.

17.3.16 *Smoke Management Systems*

Purpose of smoke management is:

a) Inhibit smoke from entering stairwells and other means of egress, refuge spaces, elevator lobbies, elevator shafts etc;

b) Maintain tenable environment in refuge areas and egress paths during evacuation;

c) Provide conditions to enable emergency response teams to fight fire and conduct rescue operations; and

d) Protect life and property.

Smoke control systems should be as per **19** as well as Part F ‘Fire and Life Safety’ of this NBCS.

Installation aspects of smoke and fire dampers is covered in **17.3.11.13** and installation of fans and ducting is covered in **17.3.10** and **17.3.11**.

17.3.17 *Installation of Electrical Systems*

These are the key provisions for the installation of electrical systems in electrical rooms and switchboards.

17.3.17.1 All the equipment used in the electrical room shall be of sufficient current rating for its normal duty as well as during the fault current. The equipment shall be of sufficient mechanical strength to withstand the fault condition to ensure human safety.

17.3.17.2 Every switch board of medium or high voltage shall comply the following provisions:

A clear space of not less than 1 meter in width shall be provided in front of the switch board. If there is any attachment at the back of the switchboard, the space shall be either less than 20 cm or more than 750 mm in width from the farthest outstanding part of the switchgear. If the space behind the switchboard exceeds 75 cm in width, there shall be passage-way from either end of the switchboard clear to height of 1.8 meters.

All disconnect switches are to be identified and labelled stating the source of the circuit and the equipment/circuit it is feeding.

17.3.17.3 Insulation mat as per the accepted standard [D-3(47)] of proper grade to be used in front of 415 V and above electrical switchgears. All panel doors shall be locked, made vermin proof by sealing entry holes specially from cable entry points.

17.3.17.4 Bus coupler panel and its cubicle shall be handled with utmost care. Red painting of bus coupler, adaptor panel and tie feeder panel from all sides (front, top and back) for easy identification and treat Adaptor panel as a part of bus coupler.

17.3.17.5 Incoming barrier of power supply and phase barrier inside the switchgear panel to be ensured.

17.3.17.6 There should not be any loose wirings, exposed joints, distribution box or junction box in cover open condition in the workplace. No switchgear which has been kept disconnected, for period of six months or more for any maintenance job shall be energized without testing.

17.3.17.7 Over current protection to be provided to disconnect the supply automatically if the rated current of the equipment, cable or supply line is exceeded for a time which the equipment, cable or supply line is not designed to withstand. Earth fault or earth leakage protection to disconnect the supply automatically if the earth fault current exceeds the limit of current for keeping the contact potential within the reasonable value.

17.3.17.8 The operation of all electrical and mechanical interlocks on the switchgear shall be checked to ensure that they operate in a positive manner. All electrical connections shall be proved for mechanical integrity that is terminal tightness, shrouding etc. The panels, relays and control modules shall be visually inspected to ensure freedom from debris and mechanical damage.

17.3.17.9 Proper illumination in work area shall be ensured and no lone working shall be allowed inside HV/LV switch gear room

17.3.17.10 Refer to Part D 'Building Services, Section 2 Electrical and Allied Installations' of this NBCS for installation of all electrical equipment including motors and switch/control gear.

17.3.18 *Installation of Electric Motors*

These are the key provisions for the installation of electric motors

17.3.18.1 Motors shall be installed at a location compatible with its enclosure type as well as the ambient conditions.

17.3.18.2 Before installation, the insulation resistance shall be checked by applying 500 V (d.c.). If insulation resistance is low, the windings shall be dried out till the resistance increases to 5 megaohms. While doing this, the frame shall be grounded and winding discharged against frame immediately after measurement.

17.3.18.3 Foundation details and bolting arrangements shall be as specified by the manufacturer.

17.3.18.4 For belt drives, the sheave pully shall be mounted close to motor housing and clearance may be provided for end-to-end movement of motor shaft. Drive shafts shall be parallel and belt tensions may be checked periodically during the first 24 hours of operation.

17.3.18.5 Lubrication shall be done with grease recommended by the manufacturer.

17.3.18.6 Terminal housing shall be of adequate size to allow minimum terminal spacing as per article 430 of accepted standard [D-3(39)]. Adequate earthing shall be provided. Minimum earth wire permitted is No. 14 standard wire gauge (SWG).

17.3.18.7 All motor connections and protections shall comply with accepted standard [D-3(39)].

17.3.19 *Installation of Instrumentation/Controls/BMS/IOT*

These are the key provisions for the installation of Instrumentation/Controls/BMS/IOT

17.3.19.1 Field devices such as temperature and RH sensors, pressure transmitters, flow meters etc shall be installed as per manufacturer's instructions. Components of the BMS System shall be housed in an enclosure suitable for the location where they are installed in respect of temperature, RH and IP rating. Where required, suitable transformers shall be installed in the enclosure and adequate earthing shall be provided. Uninterrupted power supply shall be provided to the BMS system.

17.3.19.2 Field cabling and containment shall be as per Part D ‘Building Services, Section 2 Electrical and Allied Installations’ of this NBCS. Kept at a minimum distance of 300 mm from power cables. Field cabling shall be carried out with screened cables in conduits work stations/servers shall be installed in clean and dust free rooms.

17.3.19.3 While installing IoT – Wireless field devices, availability of repeaters to form a mesh network shall be ensured.

17.3.19.4 Method statement for installation and commissioning shall be provided by the supplier/installer and pre-approved by the Engineer-in-Charge. If energy dashboard is part of the scope of supply, all screens shall be pre-approved by the Engineer-in-Charge. Where specified, IoT interface for specified equipment shall be provided and these shall be tested as part of the commissioning process.

17.3.19.5 All back up data for restoring the system functionally, in case of any failure, shall be provided and these shall be safely stored separately.

17.3.19.6 System shall be protected from cyber threats by ensuring that all remote access is password protected. Default user names/passwords shall not be retained.

17.4 Vibration Isolation and Seismic Protection

These are the key provisions to be considered for vibration isolation and seismic protection.

17.4.1 When machinery with moving parts rests on any support or foundation, vibration gets transmitted usually accompanied by noise. Objective of vibration isolation is to minimize the effect of the dynamic forces generated by the moving parts being transmitted to surrounding structure. When a resilient material is introduced between the machine and its foundation, it deflects due to the static load and by so doing establishes the natural frequency of the isolation system. Natural frequency f_n of the machine set on resilient material is a function of the static deflection of the resilient material under the imposed load.

This shall be expressed as:

$$f_n = (946.5/V) - d$$

where

d is the static deflection in mm; and
V is the velocity in m/s.

The disturbing frequency f_d of the machine is defined by the operating characteristics of the equipment. Efficiency of isolation (percentage of vibration isolated) may be calculated as:

$$E = 100.1 - 1/(f_d/f_n)^2 - 1$$

E represents the amount of reduction in the amplitude of the transmitted mechanical vibration. Based on the graph below (Fig. 39) the static deflection required to attain the desired isolation efficiency shall be ascertained.

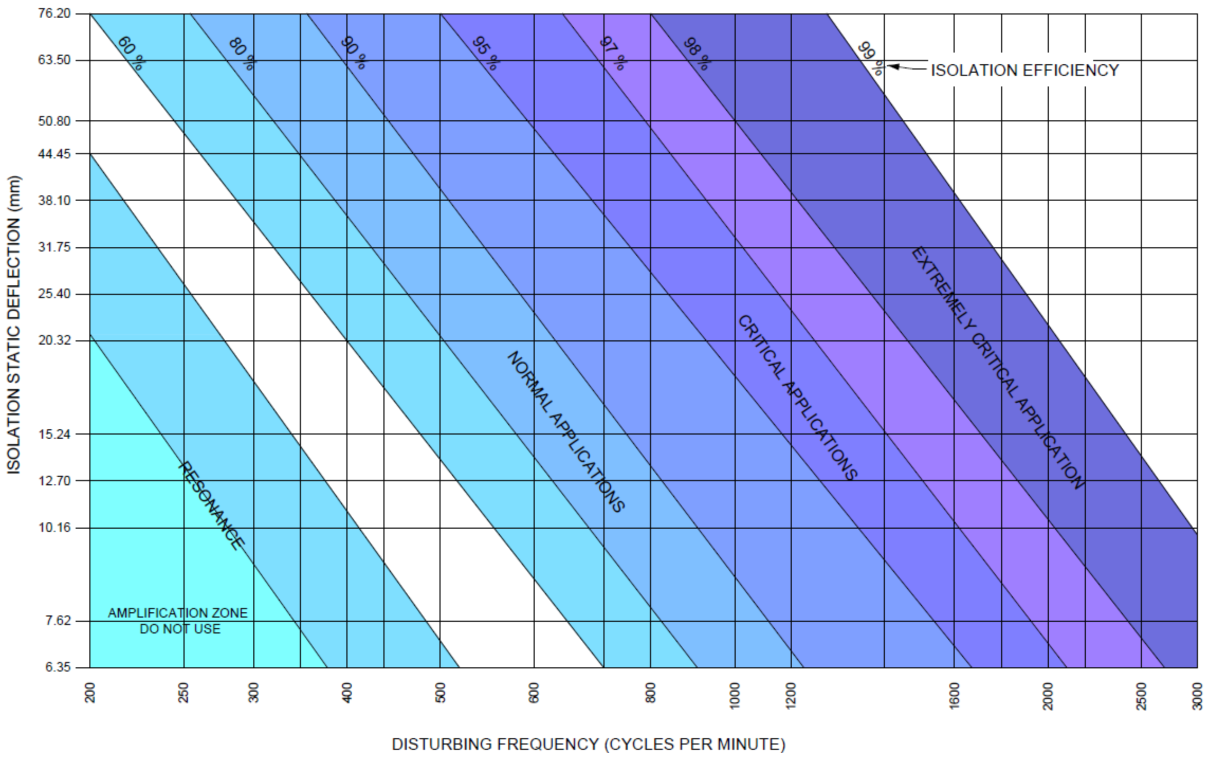


FIG. 39 STATIC DEFLECTION REQUIRED FOR DESIRED ISOLATION EFFICIENCY

17.4.2 Selection of isolator in a particular situation depends on:

a) Weight to be supported;

b) Disturbing frequency; and

c) Rigidity of supporting structure.

17.4.2.1 Anti vibration mounts (AVMs) are generally elastomer based, springs, or fluid based. These need to be selected and positioned carefully since incorrect use shall worsen the problem.

17.4.2.2 *Selection of suitable AVMs involves the following steps*:

a) Estimating the weight distribution at each support which depends on its position relative to the centre of gravity of the total mass. This is best done by a computer program. If the equipment is placed on suspended supports, same shall be factored into the selection program;

b) Selecting the appropriate AVM based on type of equipment being supported, its operating speed, nature of supporting structure, environmental conditions and space availability;

c) The load rating of the mount shall be determined based on isolation efficiency derived from charts available for that purpose; and

d) Usually, the AVM is selected for the next higher load rating than the one determined in (c) above.

17.4.3 *Seismic Isolation of Non – Structural Components*

These are the key provisions to be considered for Seismic Isolation of non- structural components

17.4.3.1 The non-structural components in the building which shall be affected by earthquake effects include:

a) Mechanical systems and components;

b) Electrical systems;

c) Fire protection systems; and

d) Plumbing systems.

17.4.3.2 Seismic protection of the above systems shall ensure

a) The components are securely attached to the supporting structure;

b) Life safety equipment such as emergency lighting and fire suppression systems continue to function; and

c) For critical applications, non-structural components continue to operate. Critical applications shall include:

    1) Health care facilities;

    2) Airports;

    3) Emergency response centres;

    4) Critical defence installations; and

    5) Data centres.

17.4.3.3 Performance objectives for seismic protection of non-structural components and how the objectives shall be met shall be as indicated below:

a) *Position retention* — Non-structural components shall retain their position under design level earthquake demands without consideration of frictional resistance produced by effects of gravity. This shall be validated by analysis of seismic calculations and such analysis shall also validate the non- structural anchorage, force resisting skeleton and attachments shall have position retention capacity equal to or greater than project specific design level demand for the installation location. Both, strength design and allowable stress design approaches shall be accepted in such calculations. This shall be done in accordance with good practice [D-3(48)].

    The use of earthquake experience data may be used to establish non-structural position retention capacity. Seismic simulation testing may be used to establish non – structural position retention capacity.

b) *System interactive avoidance* — Unwanted interaction, under design level earthquake demands, between the non-structural systems and anything else that might be located in the vicinity shall be taken into account. This is to ensure that failure of one system or contact between systems shall not cause consequential damage to system. This may also be validated through visual inspection.

c) *Active operation* — Following application of design level earthquake demands, active operational functionality of mechanical and electrical equipment and electrical distribution system shall be maintained.

17.5 Painting and Colour Codes

The following are guidelines for painting and colour coding in air conditioning installations:

17.5.1 All surfaces to be painted shall be thoroughly cleaned with a wire brush. One coat of zinc chromate primer shall be applied and after the prime coat is completely dry finish painting shall be done. Second coat of finish painting shall be done just before hand over with permission from Engineer-in-Charge. Galvanized steel ducts may be painted without a prime coat. Dry film thickness (DFT) of finished painting shall be 250 microns minimum.

17.5.2 Colour code shall be used for easy identification of various items in an air conditioning installation for correct interpretation and identification.

17.5.3 Colour band shall be 150 mm wide, superimposed on ground colour to distinguish type and condition of fluid. The spacing of band shall not exceed 4.0 m.

17.5.4 Further identification may also be carried out using lettering and marking direction of flow.

17.5.4.1 The scheme of colour code for painting of pipe work services for air conditioning installation shall be as indicated in Table 42.

17.5.4.2 In addition to the colour bands specified above, all pipe work shall be legibly marked with black or white letters to indicate the type of service and the direction of flow, as identified below:

Hot water : HW

Chilled water : CHW

Condenser water : CDW

Steam : ST

Condensate drain : CN

Table 42 Scheme of Colour Code of Pipe Work Services for Air Conditioning Installation

(*Clause* 17.5.4.1)

Sl No.	**Description**	**Ground Colour**	**Lettering Colouring**	**First Colour Band**
(1)	(2)	(3)	(4)	(5)
i)	Cooling water	Sea green	Black	French blue
ii)	Chilled water	Sky Blue	Black	Black
iii)	Central heating	Dark Blue	Black	Canary yellow
iv)	Condensate drain pipe	Black	White	
v)	Vents	White	Black	
vi)	Valves and pipe line fittings	White with black handles	Black	
vii)	Belt guard	Black yellow diagonal strips		
viii)	Machine bases, inertia bases and plinth	Charcoal grey		

17.6 Testing and Balancing

17.6.1 *Air System Balancing*

Air distribution system shall be balanced so that air quantities measured at fan discharge and at various outlets shall be within ±10 percent of the design airflows. Branch duct adjustments shall be permanently marked after the balancing is complete. Throttling losses in the system shall be minimum. Tests shall be carried out for each fan and AHU. All dampers after adjustment shall be set and locked in position. All air and static pressure measurements shall be done with probe type meters. After balancing the fan speed shall be suitably adjusted. Duct leakages shall be tested and validated as specified.

17.6.1.1 Airflow balancing shall be carried out by adjusting the flow at each diffuser to match the right percentage of total airflow in the ductwork. Balancing shall be done based on the ratio between measured and designed flow rate. Following steps may be followed for proportional balancing:

a) Ensure all VCD, VAV and fire dampers are in fully open position.

b) Adjust the damper of each diffuser proportionately to the same ratio in each branch duct.

c) Adjust each branch duct VCD in each main duct so that each branch duct has the same proportion of airflow.

d) Adjust each main duct VCD.

e) Adjust fan speed (through VFD or belt pully) or the main VCD after the AHU to ensure that each diffuser has the right airflow rate.

f) Measure and record airflow rate at each diffuser and compare it with design airflow (within ± 10 percent)

17.6.2 *Water System Balancing*

The following are guidelines for testing and balancing in air and water systems:

17.6.2.1 Water balancing (of chilled water/brine) shall be done as under:

a) Keep all balancing, control and isolating valves in fully open position;

b) Measure the water flow across each balancing valve and compare it with design flow;

c) Identify the index value (lowest flow ratio) in each branch;

d) Keep index valve fully open;

e) Throttle the farthest valve to the same ratio and after that every valve in the branch starting from the lowest ratio;

f) Monitor index valve percentage after throttling each valve gradually. By the time the last valve is completed, the flow is balanced at all valves including the index valve; and

g) Record the reading at all valves.

17.6.2.2 Where pressure independent balancing and control valves (PIBCV) are used, the proportional balancing described above is not required. Each valve may be set to correct water flow rate as per manufacturer's instructions.

17.7 Cleaning/Flushing of Duct/Pipe work

The following are guidelines for cleaning and flushing of duct and pipe work:

17.7.1 In duct work, access doors shall be provided next to dampers and these access doors shall be used to clean the duct work. Prior to commissioning of the system, entire duct shall be cleaned. Where specified, such cleaning shall be done by duct cleaning systems using robots. Otherwise, the fans shall be run with only pre-filters in place (to protect coils) and the entire dust shall be blown off. After the cleaning, pre filters shall be replaced.

17.7.2 Pipe work shall be cleaned and flushed before commissioning. Flushing of system shall be done bypassing sensitive parts such as chiller and heat exchanger tubes. Before filling up the system with clean water, all shut off and control valves shall be kept fully open. Continuous air venting shall be done. Pump shall be started only after filling up and air venting is completed. Additional flushing pumps may be used over and above system pumps and the primary pump strainer basket mesh shall not be less than 3 mm when flushing starts. Flushing velocity from 1.0 m/s to 1.25 m/s is recommended. Pressure drop across pumps shall be monitored during the process so that pump cavitation is avoided.

17.7.2.1 Dynamic flushing in several steps is recommended. First the primary ring main may be flushed, thereafter the main pipes and lastly the horizontal mains in each floor. After each round of flushing, the strainer basket shall be changed. Each loop needs to be flushed till the water is clean and the strainer basket does not collect sediments. Flushing of horizontal main pipes shall start at the topmost floor and finish at the lowest floor. After flushing in sections is completed, full system flushing shall be carried out. After flushing is complete, the water sample shall be analysed to determine successful flushing.

17.8 Commissioning, Testing and Balancing, Performance Validation, System Handover

The following are guidelines for effective commissioning, testing and balancing, performance validation, and system handover to ensure that all systems operate as per design intent and meet performance requirements:

17.8.1 Commissioning shall mean putting an equipment or a system into active service as intended by the owner.

17.8.1.1 In respect of unitary equipment such as room (window air conditioners), Non – ducted split units, package units or VRF, this process shall involve connecting the unit (after installation) to a suitably sized power outlet, switching on the unit and recording the temperature/RH/ air movement/air quality in different locations in the conditioned space. The process shall also involve whether the unit's contracted features are operational and whether the compressor switches off once the set temperature is achieved. Air flow from the unit as well as noise level shall be appropriately measured and recorded. Capacity/power consumption is verified with factory issued test certificates.

17.8.1.2 For a central air conditioning plant or a mechanical ventilation system, the process of commissioning shall follow a structured and documented process. This shall comply with special publication.

NOTE — Special publication may be ISHRAE Standard 10003-2020.

17.8.1.3 The commissioning flow chart given below in Fig. 40 sets out the stages of this process.

17.8.1.4 Initiating the process. Owner shall designate commissioning authority (CxA) at the start of the process. CxA shall either be a member of the owner's project team or an independent agency appointed for this specific purpose. CxA shall have adequate knowledge and experience to guide the project through various stages of the process. Engagement of CxA shall be for a minimum period extending to one year from date the building/facility is put to use. It shall be the responsibility of CxA that all non-conformances, warranty issues, seasonal and occupancy related performance issues are fully resolved during her tenure with the project.

Owner shall be responsible for defining scope of the commissioning plan, incorporating CxA into the project team and establishing the commissioning budget.

Role of CxA and contractual requirements for commissioning shall be a part of all sub contracts including contracts with architects/consultants.

17.8.1.5 Owner's project requirements (OPR) shall include all functional requirements of the project and owner's expectation regarding its use and operation.

17.8.1.6 Commissioning plan shall be a written document scheduling the commissioning activities. This shall include scope, resources required at each stage, agreed timelines and roles and responsibilities of each member of the project team.

17.8.1.7 Basis of design document details design team's approach to meet OPR.

17.8.1.8 Commissioning specifications shall be established for all equipment and systems.

17.8.1.9 Commissioning design review shall involve verifying that all equipment and systems meet OPR. This shall not be a peer review of the design.

17.8.1.10 Testing shall involve preparation of check lists, test procedures and report forms which shall be agreed by all concerned. Person responsible for executing test protocols shall be identified.

17.8.1.11 Functional performance testing shall involve recording the operation, then initiating a change in one or more parameters and recording the changes in performance. This shall be done in auto mode with functional BMS and controls.

17.8.1.12 All information required to operate, maintain and if required, modify the system in future. Systems manual shall be approved by owner and kept updated.

17.8.1.13 Operation and maintenance training shall be documented. Evaluation and feedback are important.

17.8.1.14 Final commissioning report shall summarize the entire process and shall have owner's acceptance.

17.8.1.15 Post occupancy commissioning shall include all delayed and seasonal tests, warranty actions/records and resolution of all non-conformances with owner's specific approval.

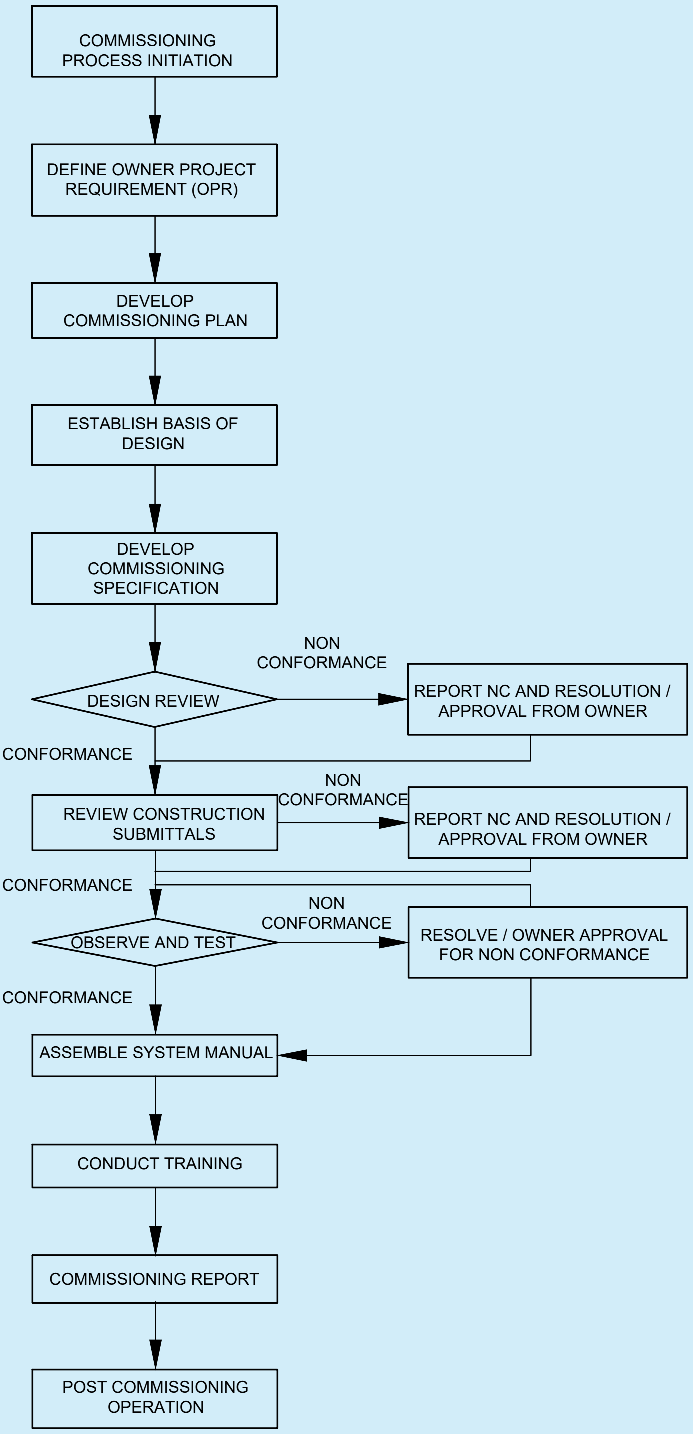

COMMISSIONING PROCESS INITIATION
DEFINE OWNER PROJECT REQUIREMENT (OPR)
DEVELOP COMMISSIONING PLAN
ESTABLISH BASIS OF DESIGN
DEVELOP COMMISSIONING SPECIFICATION
NON CONFORMANCE
DESIGN REVIEW
REPORT NC AND RESOLUTION / APPROVAL FROM OWNER
CONFORMANCE
NON CONFORMANCE
REVIEW CONSTRUCTION SUBMITTALS
REPORT NC AND RESOLUTION / APPROVAL FROM OWNER
CONFORMANCE
NON CONFORMANCE
OBSERVE AND TEST
RESOLVE / OWNER APPROVAL FOR NON CONFORMANCE
CONFORMANCE
ASSEMBLE SYSTEM MANUAL
CONDUCT TRAINING
COMMISSIONING REPORT
POST COMMISSIONING OPERATION

FIG. 40 FLOW CHART FOR HVAC COMMISSIONING

17.8.2 For testing of equipment, receipt and inspection at site, safe storage and handling at site, refer 17.2. For each piece of equipment, sub system and system check lists shall be made use of for delivery, installation, start up and readiness of commissioning. Sample check lists available in special publication may be suitably adapted for use.

NOTE — Special publication maybe ISHRAE Standard 10003-2020.

17.8.3 Individual pieces of equipment, sub systems shall be considered ready for testing only when the complete installation is over, pressure testing/leak testing (as specified) are completed and required utility connections are made to the satisfaction of CxA. It shall be verified that all blank offs, shipping bolts etc have been removed. Where specified, manufacturer/supplier shall inspect and certify that the equipment/system is ready to start.

17.8.4 Testing of all equipment/ systems shall be in line with the documented protocol which is agreed between the manufacturer/vendor, CxA, design consultant, project management consultant and any other agency who may have jurisdiction over the project. Check lists, reporting formats and standards applicable shall all be agreed in writing beforehand.

17.8.5 Training and documentation for data collection leading to energy analysis shall form part of the process. It is recommended that all individual loads greater than 15 KW be monitored for energy management.

17.8.6 Static inspections that verify proper installation (for example, belt tensions, coupling alignments, oil levels, labelling, gauges and instrumentation in place, sensors calibrated etc) shall be submitted by the vendor to CxA with the request for startup.

17.8.7 Pre-commissioning cleaning of the installed ducting and leak testing of the ducts (where specified) shall be carried out prior to staring of AHU/Fans.

17.8.8 Activities where the equipment is initially energized, tested and operated shall be completed before functional performance testing (FPT) (*see* 17.8.1.11). FPT shall involve testing under dynamic situations such as low load, full load, varying ambient, power outage, distress and emergency conditions etc. FPT shall establish that the equipment/system performs as designed under all these conditions. Systems shall be operated integrally through all specified operation sequences. Each step of FTP shall be planned in advance, agreed between vendor and CxA, performed under supervision and results tabulated in a pre-agreed format. In case FPT shall not be performed due to any reason (such as ramp up period) before the equipment /plant is put to beneficial use, same shall be recorded and owner’s approval taken.

17.8.9 Operation of all controls and safety cut outs shall be demonstrated and recorded. All measuring instruments shall have valid calibration certificates which shall be part of the record.

17.8.10 Handover documentation shall include all information owner/user will need to operate, maintain and if required, modify the system at a later date. Hand over documents shall include the following as a minimum requirement:

a) Updated and approved (by owner) systems manual;

b) Final commissioning report;

c) Set of as built drawings;

d) Full set of design calculations;

e) Spare parts lists/ordering procedure;

f) Warranty records, escalation matrix;

g) List of non-conformance with resolution records;

h) List of accessories/tools/spare parts supplied with system;

j) Operation and maintenance manuals provided by equipment supplier; and

k) List of spares and escalation matrix.

17.9 Safety Points Specific to HVAC Systems

The following are safety guidelines specific to HVAC systems to ensure safe operation and maintenance:

17.9.1 Persons working on installation of HVAC Systems, large and small, are exposed to the same risks applicable to any construction activity such as bodily injuries, fall from height, electrical shocks etc. It is of prime importance to follow all safety requirements mandated by national as well as local codes, rules and regulations, including but not limited to, the safety provisions of Indian electricity act and rules framed thereunder and fire safety regulations prescribed by authority having jurisdiction (AHJ).

17.9.2 Following are the safety guidelines specific to HVAC Systems:

17.9.2.1 Nature and level of smoke hazard from the type of insulation material used in the system shall be carefully evaluated and proper ventilation and smoke management provisions shall be made dep, ending on the type and scalability of potential smoke generation.

17.9.2.2 Refrigerant gas being heavier than air, shall cause suffocation in enclosed spaces. Personnel shall use prescribed (by the refrigerant supplier) safety equipment while handling refrigerants and the plant room shall be well ventilated. Refrigerant cylinders shall be stored in upright position. Appropriate safeguard shall be in place based on manufacturer supplied information with respect to physical and chemical health hazards as well as storage and handling information.

17.9.2.3 While pressure testing systems, the following precautions shall be taken:

a) Obtain necessary work permit;

b) Barricade the area;

c) Use calibrated instruments and gauges;

d) Store gas cylinders in covered area and in upright position. Use colour codes to identify the gas inside the cylinder. Avoid exposing cylinders to sunlight;

e) Isolation/relief valves shall be provided appropriately;

f) Air shall be completely purged from water systems before pressure testing. identify drain valves and drainage routes/sumps; and

g) Have documented SOP approved by engineer-in-charge before work is taken up. Maintain appropriate records.

18 POST OCCUPANCY OPERATION AND MAINTENANCE

Proper maintenance schedules, regular inspections, and timely repairs are critical to optimizing system functionality and extending equipment lifespan. These practices also contribute to energy efficiency and occupant comfort in the building.

18.1 Operation and Maintenance Procedures

The following guidelines for post occupancy operation and maintenance to ensure long-term performance, safety, and efficiency of the HVAC systems after installation.

18.1.1 *Operating Plan*

The operating plan is given below:

a) Facility operating plan shall describe the intended use of this facility to ensure safety to the users, maintain thermal comfort, optimize resources efficiency, monitoring and data collection of the systems being operated in the facility;

b) Key focus of this plan to ensure safety, reliability, comfort and healthy environment for the users/occupants;

c) During the post occupancy phase of operations, the facility shall develop a systems operations manual;

d) This manual shall comprise the owner's project requirements (OPR) and also the current facility requirements (CFR);

e) These documents shall be maintained throughout the operations of the facilities and shall update the changes in the operational procedures and functions of the facility;

f) Maintaining the information for the facility/building operators to understand, operate and maintain the building systems for entire life cycle of the facility as per design;

g) Operations and maintenance staffs shall effectively utilize the procedures for documenting and tracking of information on any updates, modifications to systems that occurred during occupancy and post occupancy of the facility;

h) The document shall include the modifications performed and the reasoning for the modification to the building operations;

j) As part of the operating plan the facility/operations team shall ensure all the safe operational practices recommended by the original equipment manufacturers (OEM); and

k) The facility/operations team shall ensure that the design documents like basis of design (BOD), as built drawings/documents updated time to time, are kept intact to ensure the intended operations of the systems in the facility/building.

18.1.2 *Facility Layouts*

This includes simple line diagrams (schematics) capturing the facility site/building plan, floor layouts and locations of major equipment and systems, control centers (like, electrical power isolations points), utility shut off points (like, dampers, isolation valves) to assist orientation/training of operators.

18.1.3 *Data Logging*

Maintain daily log of each system operations, record values as per OEM checklist for daily readings and record any abnormalities like sound, vibration, leakages, etc.

18.1.4 *Scheduling of Operation*

Operating hours for the facility to be described and listed and this should be the basis to perform more detailed scheduled and operational sequences.

18.1.5 *Roles and Responsibilities*

The building owner/operator shall describe their facility team/operating staff on the requirements of the building operations.

18.1.6 *Minimum Qualifications for the Building HVAC Operators*

The minimum qualifications for the HVAC Operators should be:

a) The operator should be having a required education qualification of reading operating manuals, standard operating procedures in the language that written with;

b) *Engineering-in-Charge* — Degree or diploma in electrical/mechanical/HVAC with not less than 5 years of experience respectively in operating and maintaining the HVAC systems;

c) *Supervisor* — Diploma in electrical/ mechanical/ HVAC with 3 years of experience or ITI or equivalent in HVAC with 5 years of experience;

d) *Technician* — Diploma in electrical/mechanical/HVAC with minimum 1 year of experience or ITI or equivalent in HVAC with 3 years of experience;

e) *Operator* — Should have passed 10th Class/Intermediate from a state board of education [like CBSE or higher secondary education (HSC)]. Also, operator should have minimum technical qualification of certificate course or refrigeration and air-conditioning from an institute having reputation with state board of technical education (like ITI/NCVT/ AICTE); and

f) *Trainee* — Anybody not meeting the above qualifications may be inducted as a Trainee attached to any of the above positions. He/she may not be allowed to operate systems without supervision or support during their training period of minimum one year.

18.1.7 *Building and Equipment Operating Schedules, Set Points and Ranges*

The following guidelines for building and equipment operating schedules, set points, and ranges are designed to maintain optimal system performance and energy efficiency:

a) List and describe the planned/intended operating hours of the facility/building;

b) Building owner/operator shall define the initial operating schedules, anticipated occupancy, desired temperatures in the occupied zones;

c) All the set points of equipment with their safe operational requirements/adjustments shall be listed and provided to the operations team to perform their tasks;

d) The list shall comprise safe operating set point values, acceptable ranges and limitations; and

e) Any change to be implemented on the set points shall be recorded and implemented with reason for changing the set values to eliminate human errors.

18.1.8 *Sequence of Operations and Limitations*

The sequence of operations and limitations are listed as follows:

a) List out and provide operational sequences of all equipment to be operated in language and format that is understandable to the operating staffs;

b) The operators shall be briefed on the occupied and un occupied mode of operations of system and components; and

c) The operators shall be briefed on the safe shutdown of plant and equipment.

18.1.9 *Start-Up and Shut Down Procedures/Actions*

Start-up procedures shall be adopted as stated in **18.1.10** to **18.1.12**. The maintenance procedure shall be as laid down in **18.1.15**.

18.1.10 Before starting the plant, the operator shall ensure that:

a) All the valves in the refrigeration system, condenser water lines and chilled water lines are kept open, except those of the standby items of equipment;

b) Adequate water in the cooling tower basin and the make-up water system is working satisfactorily;

c) The make-up water system to the expansion tank of the chilled water circuit is working and there is a regular water supply. Water is lost from the chilled water system through pump gland drips/leaky mechanical seal. If the level in the expansion tank is not maintained, air shall enter the chilled water system, affecting the system performance substantially. It shall even lead to system/plant breakdown;

d) All the air filters and water strainers are clean. Any dirty filter and/or the blocked strainer shall be cleaned periodically;

e) All doors and windows of the air conditioned/refrigerated area are closed;

f) The crankcase of the compressor is warm (to the physical touch). If it is not warm, defects in the crankcase heater and/or circuit should be checked fully. The compressor shall not be started until the defect is rectified and the crankcase warms up, else it will result to poor lubrication, thereby substantially reducing the life of the bearings of the compressor; and

g) The supply voltage is within permissible limits. The windings of the motors shall get affected, if run on low voltage conditions.

18.1.11 The starting sequence shall be as follows:

a) Switch 'ON' the mains. Observe the voltage. If it is less than the permissible level, do not start any component of the system;

b) Start air handling unit motors (all dampers have to be checked based on their specific application);

c) Start condenser water pumps. Check that sufficient water pressure is obtained;

d) Start cooling tower fan;

e) Start chilled water pumps and check the pressure;

f) Switch 'ON' the compressor control switch; and

g) Start the compressor motor.

18.1.12 Following aspects require special attention:

a) In the compressor with oil pump, the compressor oil pressure should build up as the compressor is started. Check that corrects net oil pressure is built up;

b) Check the oil level in the oil sight glass of the compressor. The oil level should be about 40 to 50 percent of the sight glass. In operation, certain amount of oil gets entrained in the refrigerant vapor in the compressor and is carried to the system along with the refrigerant;

c) After the plant operation has stabilized, check all the pressures and temperatures and ensure that the system is working satisfactorily;

d) Record periodically the readings of temperature, pressure, current and other required data in the log sheet;

e) Check for any unusual noise/vibration in the plant. If something unusual is noticed, trace out the reason for it and rectify the cause; and

f) During the operation of the system, if any major component stops suddenly, trace out its reason, before starting the component/system again.

18.1.13 The stopping sequence of the system shall be as follows:

a) Switch off the compressor on the low-pressure switch, as the system gets pumped down;

b) Switch off the power supply to compressor;

c) Check that the crankcase electric heater comes on as soon as compressor stops and ensure that the heater is working;

d) Stop chilled water pumps;

e) Stop air handling units; and

f) Stop condenser water pumps and cooling tower fans.

18.1.14 Following are standard operating instructions which the operator should follow:

a) In case stand-by chiller, pumps, etc, are provided, systematically change over the stand-by components, periodically. This will ensure uniform wear and tear of the system. Further, this also helps in ensuring that all equipment is in good shape and the stand-by is in working condition;

b) Do not switch off the main switch on the main electrical board or switch off any component of the system, when the plant is in operation;

c) All the water valves in the system shall be kept open and need not be closed, unless specifically instructed by designer. But it shall be done to close and open each valve periodically to ensure that the valves work and are not stuck by scale formation or dirt accumulation; and

d) Keep the plant room clean. Do not use the plant room, particularly the air handling unit rooms for storage.

NOTE — An automatic sequence of operation shall be covered under Chapter 15 - Building Management System.

18.1.15 *Maintenance Procedures, Check Points and Records*

Procedure for establishing and maintaining effective maintenance practices, ensuring comprehensive inspection points, and maintaining accurate records for facility management.

18.1.15.1 *Preventive maintenance*

The preventive maintenance is:

a) The goal of preventive maintenance is to prevent equipment failure caused normal wear and necessary action by replacing worn out components prior to actual failure of an equipment;

b) Maintenance activities shall include partial or complete overhauls at specified periods and shall include oil changes, lubrication of components, minor adjustments and so on;

c) Operators shall record equipment deterioration by inspection to facilitate the replacement or repair of worn-out parts prior to any system failures;

d) Implement preventive maintenance of installations and equipment to maintain efficient working of building HVAC system and its components;

e) Implement periodic inspection schedule, testing and maintenance throughout their life cycle;

f) Conduct periodic maintenance and testing, servicing, checking, calibration, overhauls and certification, annual inspection, testing, witness regular test and certification;

g) Perform overhauling or replacement at a certain usage (as recommended by OEM) or due to specific causes. This shall be outlined specifically in a preventive maintenance program;

h) Implement preventive maintenance program (PMP) and shall include the methodology and record for all action that are necessary to maintain the efficient working order of the HVAC system;

j) The maintenance procedures shall be unique to each property and the installations and equipment within these facilities;

k) Conduct preventive maintenance in accordance with statutory requirements. (pressurization system, smoke control system, fire alarm interlock with air handling units are few example);

m) Conduct preventive maintenance and overhauls with clear maintenance schedule, instruction and procedures;

n) Ensure O&M personnel induction training on safety, statutory requirements and performance target and work manner;

p) Adopt condition based/reliability-based maintenance where appropriate;

q) Conduct a regular review of all procedures/standards;

r) Conduct a regular update of relevant procedures/standards against the latest statutory requirements, good industrial practices, maintenance records and fault history by a working/facility team comprising competent personnel; and

s) Adopt a web based/mobile application-based performance monitoring system for maintenance that is contracted out.

18.1.15.2 *Maintenance schedule*

18.1.15.2.1 *Day-to-day maintenance schedule*

a) *Clean the air filters* — Dirty filters cause poor air flow through air handlers and results in thermal discomfort. Unattended filters could result in damage to the filtering media and the unfiltered air shall pass through them and settle on the cooling coils. This results in poor heat transfer and impacts the efficiency of the air handler system and total efficiency of the HVAC system as a cascading effect;

b) *Leak testing for refrigerant leaks* — Check physically for oil traces, which is indicates source of refrigerant leaks. Perform leak testing using soap bubble or electronic leak detectors. Refrigerant leaks impact the system operation and leads to breakdown of system. Refrigerant leaks impact our environment due to global warming potential of the refrigerants being used in the HVAC system;

c) *Water pump (packed) glands* — Certain amount of water should drip through the gland which is necessary to keep the gland cool. However, if the drip develops into a flow of water, then, it is an indication of leak gland. This should be attended by tightening the gland nuts to reduce the water leaks or gland packing to be replace to prevent loss of water from the distribution system. Unattended gland water leaks shall result in loss of water and facilitates air entry into to the system which could result in abnormality in the chilled water distribution system; and

d) Check and monitor any abnormal noise or vibration.

18.1.15.2.2 *Weekly maintenance schedule*:

a) *Belt Tension of belt drives* — Check the belt tensions and tighten whenever necessary if found loose. A loose belt reduces the transmission efficiency, reduced air volume of the air handlers and thus affects the thermal comfort. Loose belts cause noisy air handlers and results disturbance to the building occupants;

b) *Check the cooling coil drain tray* — Check and ensure the drain tray is clean from dirt and debris to prevent mould growth or water leakage due to drain block;

c) *Check the lubrication* — Check the lubrication of bearings to ensure smooth operation and prevent breakdowns due to worn out bearings;

d) *Check the Cooling tower* — Check the cooling tower sumps to keep them clean from debris (tree leaves if the towers are located at ground level). The towers are kept open to ambient and dust from the air shall settle on the fills, sumps and requires cleaning to ensure proper operation of the cooling towers which are very critical for a water-cooled system efficiency and performance; and

e) Conduct water quality test for cooling towers periodically.

18.1.15.2.3 *Monthly Maintenance Schedule*:

a) Replace the air handling unit filters with a set of replacement filters kept under stock;

b) Check the starters and check loose connections of cables and ensure tightness;

c) Check the operation of automatic blow down system for cooling towers;

d) Check and clean the Y-strainers and Pot Strainers;

e) Check the preventive maintenance schedule of components and equipment and conduct maintenance activities; and

f) Check and tighten all base bolts to prevent breakdown due to vibration.

18.1.15.2.4 *Quarterly maintenance schedule*:

a) Perform pre scheduled preventive maintenance activities equipment and components;

b) Check the log book and conduct thorough study of equipment to ensure healthiness of its operation;

c) Check and lubricate all the moving parts;

d) Check and clean the cooling tower sumps;

e) Check and clean all the strainers and pot strainers;

f) Check and replace belts if necessary;

g) Check the safety interlock of all air handling units;

h) Check and replace defective instruments like pressure gauges, thermometers etc;

j) Check and rectify any refrigerant leaks; and

k) Check and replace any defective/malfunctioning components of the system.

18.1.15.2.5 *Half year maintenance schedule*:

a) Perform all the activities listed under quarterly maintenance schedule;

b) Check the conditions of the cooling tower fills and clean them;

c) Check and clean the air handling unit blowers from dust/dirt accumulation; and

d) Check the operation of cooling tower blow down system (automatic) and chemical dosing system.

18.1.15.2.6 *Yearly Maintenance Schedule*:

a) Perform all the activities listed under half yearly maintenance schedule;

b) Collect oil sample from the chiller system and send them for laboratory test to analyze presence of metal particles, viscosity etc;

c) Post lab results replace the oil to ensure safe operation of the compressors to enhance the life cycle;

d) Check and clean the condenser tubes of the water-cooled system to improve heat transfer. If, required only, conduct de-scaling of the tubes. Frequent de-scaling is not recommended and cause potential damage to the copper tubes;

e) Check the operation of auto tube cleaning system if it is in place and ensure its components are intact or replace if required;

f) Conduct vibration test of all major equipment and record the test readings for further comparisons till life cycle of the equipment;

g) Witness maintenance of all the electrical starter panels, switch gears, earthing conductors and perform interlock testing for safe operations of the total system; and

h) Conduct indoor air quality test and if required perform duct cleaning procedures to ensure good indoor air quality.

18.1.15.2.7 *Check points*:

a) Compare the previous maintenance log and record any abnormalities;

b) Conduct necessary actions to rectify or replace component/equipment as noticed on abnormalities;

c) Ensure O&M personnel induction training on safety, statutory requirements and performance targets; and

d) Conduct and analyze on operating costs due to lack of maintenance and ensure corrective actions.

18.1.15.2.8 *Records*:

a) Good maintenance records for ensuring that a piece of equipment is performing in line with OEM recommendations, warranties and thus help to determine an equipment preventive maintenance schedule;

b) Maintenance records to be maintained to assist the service matter experts, (SME's) service technicians for diagnosing any repeat problems with or within the plant or its equipment;

c) Maintain paper records of all maintenance related activities including testing and commissioning certificates, test records, as-built documents, statutory approved submission documents, water quality test reports, oil quality test report, indoor air quality reports, calibration certificates of instruments;

d) Maintain emergency call/fault attendance reports, fault history etc;

e) Maintain records of usage of refrigerants;

f) Maintain soft copies of all the documents listed under paper records;

g) Assign designated persons/s responsible to review and update routine maintenance inspection schedule, emergency call/fault attendance reports etc, on a monthly basis and the findings shall be documented for future reference;

h) Set up record system able to automatically provide alerts for outstanding shutdown notices and annual maintenance renewal etc; and

j) Digitize all documents and records with a standardized file naming system in a reliable database server for easy retrieval. (Facility management system/manager shall perform this activity).

18.1.15.2.9 *Training*:

a) Provide training to equip staff with knowledge to work safely and without risk to health;

b) To Ensure maintenance plans are followed correctly, facility managers and building owners should provide sufficient periodical training to all maintenance technicians. Good sources of trainings are:

    1) An experienced technician or facility staff member;

    2) OEM's training;

    3) Technical and community colleges; and

    4) Videos, seminars and short-term courses by professional associations like ISHRAE.

c) The minimum training content delivered should generally include below:

    1) Basis of design or design brief;

    2) Documentation requirements;

    3) Operating procedures such as startup and shutdown procedures;

    4) Basic diagnostic instructions; and

    5) Fire, life safety and emergency procedures.

18.1.15.10 *Spare parts inventory management*:

a) Managing spare parts in an optimal way is an inherent and substantial part of O&M aimed at ensuring that spare parts are available in a timely manner for corrective maintenance in order to minimize the downtime of a system or equipment;

b) Maintain a spare parts list for plant and equipment;

c) Maintain an updated contact list of suppliers with lead time details of each spare;

d) Review constantly the quality and quantity of spare parts in stock and restock when necessary;

e) Maintain the log of spares utilized;

f) Assign designated person/s responsible for regular updates of any changes in spare parts inventory;

g) Monitor the condition of spare parts to ensure their quality is maintained;

h) Identify long lead items/components for early procurement; and

j) Identify discontinued items (obsolete) for sourcing an alternative parts or upgrade of system.

18.2 Predictive Maintenance

a) Predictive maintenance is a planned maintenance basis diagnosis of equipment condition;

b) Measurements that detect the onset of a degradation mechanism, thereby allowing causal stressors to be eliminated or controlled prior to any significant deterioration in the component physical state;

c) Predictive maintenance techniques may include vibration analysis, thermography, oil analysis, motor current analysis, Eddy current testing and pressure measurement etc; and

d) Performance trending.

18.2.1 *Emergency Operating Procedures*

a) Emergency event requires planning, preparation and practice;

b) Regardless of type of risk, every facility shall have a risk event plan or emergency management in place to minimize the damage and danger to following:

    1) Building occupants;

    2) Documents and assets within facility;

    3) Building, IAQ and surrounding community, air and water; and

    4) Establish and implement environmental management systems and safety management systems. For additional information special publications may be referred.

    NOTE — Special publication maybe ISO 14001 for Environmental Management Systems and OHSAS 18001 or ISO45001 for Safety Management Systems.

18.2.2 *Performance Based Operation and Maintenance Contracts*

a) Performance based or output based operation and maintenance contracts gaining traction;

b) The advantages of performance-based O&M contracts are;

c) Payment for actual performance or usage;

d) Contractor responsibility for full package;

e) Continuous improvement/Innovation; and

f) Reduced risks due to lower capital costs.

18.2.3 User feedback mechanisms for optimizing maintenance schedules or identifying:

a) Metering and sub-metering of energy and resource use is a critical component of a comprehensive O&M program;

b) Metering provides the information that when analyzed allows the building operations staff to make informed decisions on how to best operate mechanical/electrical systems and equipment:

  1) Metering approaches;

  2) One time/spot measurement;

  3) Run time measurement;

  4) Short term monitoring;

  5) Long term monitoring;

  6) Measure, verify, and optimize equipment performance; and

  7) Identify improvement opportunities on environmental (especially energy, water efficiency) and safety aspects.

18.3 Computerized Maintenance Management System (CMMS)

CMMS is a computerized maintenance management system, which is a software application that helps controlling, monitoring and analysing operation of HVAC system. The centralized CMMS would help in optimization of cost, resources, and information at one place.

Benefits that the CMMS shall provide to the facility during operation and maintenance shall include

a) *Electronic records* — Use of electronic records reduces the amount of time spent by office personnel entering data, which improves the efficiency of the maintenance department;

b) *Reduced repair costs* — A CMMS shall store and provide easy access to equipment records. When historical records are easily accessible, they shall be used to determine the most economical decision for a piece of equipment: repair or replace;

c) *Personnel management* — Records for each employee shall be stored and easily accessed and updated. Electronic personnel records shall include, but are not limited to, training and certifications earned by each employee, pay scales, and hire dates;

d) *Asset management* — A CMMS shall be used to store electronic records for any type of asset, including equipment and supplies;

e) *Process automation* — When a CMMS is set up correctly, preventive and predictive maintenance work orders, parts and supply reordering, and other notifications shall be automated, saving time and increasing the efficiency of the maintenance team;

f) *Improved work control* — CMMSs provide increased ability to manage work orders and prioritize and schedule work;

g) *Increased budget accountability* — Accurate records of labour hours and inventory items increase the accuracy of expenses and budgets; and

h) *Increased ability to measure performance and service* — When data are available, performance shall be determined for a period of time, such as that required to complete a specific type of maintenance activity or respond to a service call.

CCMS Modules shall be considered for facility operations are as below:

  1) *Asset management* — Its asset operations, monitoring and control, repair and PM history;
  2) *Work order management* — Helpdesk ticket end-to-end user complaint to closure of calls;
  3) *Procurement* — Inventory management, parts ordering; and
  4) *Dashboard reporting* — This module allows you to generate reports on a variety of maintenance metrics, such as downtime, costs, and asset health.

18.3.1 Broad CMMS selection process that shall be considered as follows:

a) *Team involvement* — To include the facility managers, clients, property management team, consultants and technicians shall be involved during the planning phase to select the suitable CMMS software, scope of working of CMMS and integration requirement with other third-party systems (BMS, EMS and AI); and

b) When selecting the software, the following shall be part of the process:

  1) Continued focus and understanding of the true need for the CMMS; and
  2) Clear understanding of how the CMMS implementation will support maintenance best practices desired by the organization.

18.3.1.1 Process of selection given below shall be followed:

a) For planning:

  1) Establish a CMMS selection task force;
  2) Perform interviews with all members of the facilities team who will use the CMMS;
  3) Determine the needs, wants, reporting features, and goals for the CMMS;
  4) Determine what CMMS outputs are needed to meet the goals;
  5) Determine input data that shall be collected;
  6) Evaluate the value of data versus the cost of collecting, inputting, and maintaining the data within the CMMS;
  7) Integration of third-party software data to CMMS;
  8) Determine available budget;
  9) Determine CMMS modules needed;
  10) Write CMMS specification;
  11) Prepare for CMMS vendor meetings;
  12) Meet with vendors and participate in vendor demonstrations;
  13) Prepare bid package;
  14) Develop a continual implementation plan;
  15) Determine if a phased implementation plan is needed; and

16) Develop a phased implementation plan (if needed).

b) CMMS software/ CMMS module selection shall fulfil the operational needs of facility and shall address the following:

   1) Areas for improvement in current maintenance practices (for example, reduced downtime, improved preventive maintenance);

   2) Advanced features and functionalities (for example, mobile access, work order management, reporting);

   3) Strong asset management, work order creation and tracking, preventive maintenance scheduling, and inventory control;

   4) Consider advance features like AI-based functionalities for predictive maintenance, asset analysis from R and M, PM perspective, dash-board reporting, mobile capabilities for Equipment operative team;

   5) Integration with any existing software you use;

   6) Options for future scalability;

   7) Requirements towards company where CMMS to be installed IT/data security and compliance with relevant regulations;

   8) Implementation costs, licensing fees (one time and recurring), availability of software key, and ongoing software support; and

   9) Strong after sale service and customer support.

18.3.2 *Implement a CMMS, Going-Live Phase*

a) Select a CMMS;

b) Collect input data;

c) Input data into CMMS;

d) Determine how users will be trained;

e) Implement training;

f) Go live and cut over:

   1) Going live is the transition between setting up a system and using the CMMS for daily maintenance activities. This project phase reveals how successful the planning and implementation processes were. Before going live, the CMMS shall be tested and checked to ensure correct system configuration.

g) Implement continual implementation plan; and

h) Create standard operating procedures (SOPs) for using the CMMS.

18.3.3 *Integration of CMMS with Building Automation Systems (BAS) for Data Collection and Analysis*

a) Integrating of CMMS with a building automation system (BAS) will be an intense tool for property and facility management engineering team. The BAS regularly monitors and collects data on several characteristics of a building's management systems;

b) Integration complexity shall be looked during planning phase for example, specific software and desired functionality, shall ensure that both the systems communicate with each other properly;

c) To protect sensitive building information, a common IT security protocol, proper data security protocol shall be ensured;

d) It shall be ensured that periodic data export from the BAS and import into the CMMS be established or worked during RFP phase. Make certain consistent data formats and naming principles between the CMMS and BAS for seamless integration; and

e) Protocol for two-way communication between both the systems, allowing for real-time data exchange shall be established.

18.3.4 *Automation and Integration of Chiller plant and Pumps*

Following systems shall be considered for automation and integration in the BMS and CMMS. Refer to relevant guidelines/best practices (‘Handbook on Asset and Facility Management in Buildings’) for further details.

a) Building automation system (BAS);

b) Chiller plant manager; and

c) Sensors, VFD, communication system/PLCs .

18.4 Controls to Measure and Monitor Building Energy Performance

18.4.1 *System for Data Collection and Analysis*

Building controls such as CMMS and BMS systems shall consists of following metering systems, controls and monitoring systems for data collection and analysis:

a) Main meters for sources of energy used by facility;

b) Submetering for applications that represent 10 percent or more of the total building consumption such as chillers, pumps, cooling towers, AHU’s, ventilation systems, hotel rooms (cumulative), lighting and UPS systems;

c) Data collection systems: collecting data from energy meters, sub-meters on pumps, cooling towers, AHU feeders;

d) Building Automation System (BAS);

e) Chiller plant manager; and

f) Sensors, VFD, communication system/PLCs.

NOTE — Refer to relevant guidelines/best practices (‘Handbook on Asset and Facility Management in Buildings’) for further details.

18.4.2 *Maintenance Strategy and Controls Including Integration of CMMS with Building Automation Systems* (*BAS*)

a) *Predictive maintenance* — Using CMMS/CPM/ BMS, BAS data for example, equipment performance metrics and sensor readings, helps to predict potential breakdowns and shall schedule maintenance before failures occur. CMMS shall be used to analyse this data and initiate work orders;

b) *Condition* — Based Maintenance: BAS/ CMMS shall use this data to prioritize maintenance tasks based on actual equipment condition, optimizing resource allocation;

c) *Preventive maintenance* — CMMS should be used to schedule PM tasks based on OEM recommendations, historical data, and BAS/CMMS/BAS alerts; and

d) A 52 week PPM planner shall be used aligned with checks prescribed in OEM manuals.

18.4.2.1 Critical systems identification and analysis of efficiency and healthiness checks:

a) AHUs;

b) Compressors;

c) Chiller;

d) Condenser;

e) Cooling towers;

f) CMMS, PLC and controls;

g) Electrical, power distribution network;

h) Water cycle – open and closed circuits;

j) Boilers;

k) PAHUs/PACs, domestic air conditioners; and

m) STPs in case STP water is used in cooling towers.

18.4.2.2 Analysis of efficiency and healthiness checks:

a) ikW and COP test shall be performed with the help of OEM and maintenance agency the analysis report should contain performance designed vs actual;

b) Check for the AHU performance; and

c) A regular health check-up should be conducted by a professional HVAC engineer, preferably on annual basis, the test should be considered during Peak load for example, summer.

Further an equipment wise check shall be conducted using calibrated equipment's.

18.4.2.3 *Selection of maintenance class and transitioning from reactive to proactive maintenance*

To transition from one particular maintenance approach to another, a detailed analysis shall be made to determine what will be the most effective. Table 43 below indicates the type of maintenance to be considered for the systems/facility.

Table 43 Type of Maintenance to be Considered for the Systems/Facility

(*Clause* 18.4.2.3)

Sl No.	Maintenance Class	Effect of Failure	Desired Result	Analysis Used to Determine Most Effective Maintenance Technique	Implementation of Maintenance Practices
(1)	(2)	(3)	(4)	(5)	(6)
i)	A: Mission Critical	Significant financial, safety and/or operational impact	Risk mitigation and maximize equipment and system availability	Reliability centered maintenance and risk assessment	Preventive and predictive approaches
ii)	B: Optimize life-cycle costs	Minor impact on core business activities	Minimize equipment LCC over time	Reliability centered maintenance and risk assessment	Preventive, predictive and reactive approaches
iii)	C: Minimize short-term costs	No impact on core business activities	Minimize short-term costs	Risk assessment	Risk mitigation measures, visual inspection, and preventive maintenance
iv)	D: Industry standard maintenance	No impact on core business activities	Minimize short-term costs	Risk assessment	RS Means or original equipment manufacturer job plans, preventive maintenance
v)	E: Out-of-Service	No impact oncore business	Ability to operate	Risk assessment	Minimum maintenance

To select the appropriate maintenance class, the facility mangers to develop an effective maintenance program and shall consider the following:

a) Focus on maintenance that results in the best return on investment (ROI);

b) Make sure results shall be measured;

c) Avoid intrusive maintenance; and

d) Employ an effective management system, such as a computerized maintenance management system (CMMS).

18.4.2.3.1 The Systems to consider for proactive maintenance shall include:

a) AHUs;

b) Compressors;

c) Chiller;

d) Condenser;

e) Cooling towers;

f) CMMS, PLC and controls;

g) Electrical, power distribution network;

h) Water cycle – open and closed circuits;

j) Boilers;

k) PAHUs/PACs, domestic air conditioners; and

m) STPs in case STP water is used in cooling towers.

18.4.2.3.2 Transition from reactive to proactive maintenance shall benefits the facility operation and maintenance and that shall include:

a) Fixing things only when they break is a reactive maintenance, which leads to a sudden failure to equipment, causing down-time, production loss, Impact equipment life span/age and requires more budget/cost to manage;

b) Making a switch towards proactive maintenance for example, prevention over repairs requires time and efforts but helpful enhance equipment life, up-time, reliability, maintenance cost, safety and increased efficiency; and

c) A proactive maintenance should have deep understanding of your assets, thorough study of OEM manuals, drawings, design brief/project reports, regular inspection, analysis of failure history/equipment down-time/break-down historical data, condition monitoring, a regular training to operators understanding various failures code as described in OEM manuals.

18.5 Benchmarking of Building Performance with KPI Index

18.5.1 *Strategies for Implementing the Measurement and Verification* (*M and V*)

M and V strategies/ techniques shall be used by facility owners or energy efficiency project investors for the following purposes:

a) Increase energy savings;

b) Enhance financing for efficiency projects;

c) Improve engineering design and facility operations and maintenance; and

d) Manage energy budgets.

M and V plan produce verifiable savings reports. An M and V Plan shall be developed for each facility by qualified professional. M and V applies to a wide variety of facilities including existing and new buildings and industrial processes. M and V strategies consist of some or all of the following:

1) Meter installation calibration and maintenance.
2) Submetering for applications such as HVAC (Chillers, Pumps, CT), AHU's, ventilation fans, internal lighting, external lighting and UPS.
3) Data gathering and screening,
4) Development of a computation method and acceptable estimates,
5) Computations with measured data, and
6) Reporting, quality assurance and third-party verification of reports.

M and V options to be followed shall include as below:

i) Option-1 – Retrofit Isolation: key parameter measurement
ii) Option-2 – Whole facility

18.5.1.1 *Option-*1 *– Retrofit isolation: key parameter measurement*

Retrofit isolation techniques are best applied where:

a) Only the performance of the systems affected by the ECM is of concern, either due to the responsibilities assigned to the parties in an energy performance contract, or due to the savings of the ECM being too small to be detected;

b) Interactive effects of the ECM on the energy use of other facility equipment shall be reasonably estimated or assumed to be insignificant;

c) Sub-meters already exist to isolate energy use of systems;

d) Meters added at the measurement boundary shall be used for other purposes such as operational feedback or tenant billing; and

e) Long term testing is not warranted.

18.5.1.2 *Option-*2 *– Monitoring performance of whole facility*

Monitoring of whole facility Involves use of utility meters, whole-facility meters, or sub-meters to assess the energy performance of a total facility. The measurement boundary encompasses either the whole facility or a major section. This option determines the collective savings of all ECMs applied to the part of the facility monitored by the energy meter.

Facility team shall select the M and V options based on the energy metering infrastructure availability and energy conservation measures (ECM) implementation and monitoring of ECM.

a) *Overall HVAC system efficiency for benchmarking*

The overall HVAC systems efficiency shall be measured with the help of submetering as suggested in the M and V section and overall HVAC systems efficiency shall be calculated as overall HVAC energy consumption in kWh and divided by conditioned area of the facility.

$$\text{Overall HVAC systems efficiency} = \frac{\text{overall HVAC consumption (kWh)}}{\text{conditioned area-sq.m}}$$

b) Scheduled intervals, equipment performance to be measured and monitored and compared with bench marking of efficiency till the end-of-life cycle of the equipment. The equipment performance to be measured on monthly basis in kWh and performance to be tabulated for comparing with benchmarking.

c) Corrective action to ensure performance of the system.

The corrective actions to ensure performance of systems shall be as per Table 44.

Table 44 Potential Corrective Measures List

(*Clause* 18.5.1.2)

Sl No. (1)	Possible Cause (2)	Recommended Corrective Action (3)
i)	General	
	Human error in data collection and analysis	Train staff in data collection and analysis
	Instrumentation error	Check error and calibrate to attain manufacturer recommended level
	Equipment operating schedules	Change equipment operating schedules to more closely follow actual building activities.
	Equipment load	Identify correct plug load and ensure their proper use
ii)	Lighting	a) Fine tune on hours more closely to reflect actual. b) Measure actual lux level and take corrective action to ensure task-based lux level c) Check voltage level to ensure there is no over voltage to avoid over consumption d) Ensure fixture and accessories cleaning to increase lighting efficiency
iii)	HVAC- Chilled Water System	a) Ensure preventive maintenance as per schedule. b) Check DPT function. c) Check pump operates at its best efficiency point. d) Check COP at full load condition.
iv)	Water	a) Check for leak in pipes, fittings. b) Ensure periodical cleaning of the filters provided at the roof for rainwater harvesting. c) Rainwater collection sumps to be have a maintenance plan in place.

d) Measure the indoor air quality, thermal comfort, water performance and energy performance as part of KPI.

Metrics and trends are important parts of maintenance organization. Metrics, also known as key performance indicators (KPIs), shall be used to drive improvement, minimize problems, help set priorities and goals, and help determine milestones and evaluate success.

To effectively use metrics and trends, reports shall be set up and generated using the CMMS. There are two basic types of reports

1) *KPIs and measures reports* — Reports that contain key performance indicators, trends, and measurements that identify systems and equipment, processes, other maintenance management topics that need the most attention.

2) *Functional reports* — Reports used Measure the indoor air quality, thermal comfort, water performance and energy performance.

18.6 HVAC System Life Expectancy Comparison

a) Comparison of HVAC systems to check the end of life/replacement of systems:

   1) The typical lifespan of an HVAC system is known. Nevertheless, after years of regular use, the efficiency and performance of an HVAC system naturally decreases overtime;

   2) There are few signs that signal this decrease are:

      i) Increase in breakdown frequency;

      ii) Increased energy use;

      iii) Performance degradation; and

      iv) Unusual noise.

   3) Risk based approach to plan and schedule replacement works in accordance with spare parts availability as well as any specific law and safety requirements, etc.

b) Performance based approach to analyse the HVAC systems life served including the factor affecting the HVAC systems lifespans:

   1) Output based approach to understand the life of HVAC system;

   2) Factors that affect the HVAC systems lifespan are:

      i) Quality of installation;

      ii) Utilization time of equipment;

      iii) Location; and

      iv) Operation and maintenance.

19 SMOKE MITIGATION – FIRE AND LIFE SAFETY

Smoke mitigation towards fire and life safety is towards providing human life safety with tenability to enable the occupants ideally to exit from event (fire incident) zone or in some occupancies to have occupants towards defend in place.

Compartmentation to ensure space by space integrity to prevent the spread of fire. Such spaces enable occupants to proceed to exits and to be provided with aspects of smoke mitigation though ideally pressurization or in some cases with smoke ventilation.

Smoke ventilation predominately post fire incident to enable reducing smoke concentration levels for firefighters and emergency responders shall more effectively check reoccurrence of fires and rescue occupants from the defend in place safe zone to exits. This also helps in reducing property damage by purge of smoke post fire incident in the fire incident area/ spaces.

The various strategies and spaces shall be identified to enable designers to adopt the required strategy of smoke mitigation and also have specific design, systems provided and its functions on respective occupancy of the project.

Technical, design, performance aspects with integration to fire alarm system and also importantly evacuation strategy are specified.

Aspects of pressurization (Pascals) for defend in place [One door open], phased evacuation [Three door open], assisted firefighting shaft [Three door open] shall be detailed in the smoke mitigation aspects towards life safety.

The power supplies, fire rating, interlocking of the smoke mitigation system on mechanical systems, equipment, elevators, lobby compartmentation, damper control shall be included for successful implementation of the smoke mitigation system.

19.1 Smoke Mitigation – Sub Structure

19.1.1 *Car Parking in Sub Structure*

19.1.1.1 *Basement car parking non-mechanical*

In case of smoke exhaust and pressurization of areas below ground, each basement shall be separately ventilated. Vents with cross-sectional area (aggregate) not less than 2.5 percent of the floor area spread evenly round the perimeter of the basement shall be provided in the form of grills, or breakable stall board lights or pavement lights or by way of shafts.

19.1.1.2 *Basement car parking stack/ mechanical*

In case of smoke exhaust and pressurization of areas below ground, mechanical ventilation system be provided with following requirements:

a) Mechanical ventilation system shall be designed to permit 12 ACPH in case of fire or distress call. However, for normal operation, air changes schedule shall be as given in **3**;

b) In multi-level basements, independent air intake and smoke exhaust shafts (masonry or reinforced concrete) for respective basement levels and compartments therein shall be planned with its make-up air and exhaust air fans located on the respective level and in the respective compartment. Alternatively, in multi-level basements, common intake masonry (or reinforced cement concrete) shaft may serve respective compartments aligned at all basement levels. Similarly, common smoke exhaust/outlet masonry (or reinforced cement concrete) shafts may also be planned to serve such compartments at all basement levels. All supply air and exhaust air fans on respective levels shall be installed in fire resisting room of 120 min. Exhaust fans at the respective levels shall be provided with back draft damper connection to the common smoke exhaust shaft ensuring complete isolation and compartmentation of floor isolation to eliminate spread of fire and smoke to the other compartments/floors;

c) Due consideration shall be taken for ensuring proper drainage of such shafts to avoid insanitation condition. Inlets and extracts may be terminated at ground level with stall board or pavement lights as before. Stall board and pavement lights should be in positions easily accessible to the fire brigade and clearly marked 'AIR INLET' or 'SMOKE OUTLET' with an indication of area served at or near the opening;

d) Smoke from any fire in the basement shall not obstruct any exit serving the ground and upper floors of the building;

e) The smoke exhaust fans in the mechanical ventilation system shall be fire rated, that is, 250 °C for 120 min;

f) The smoke ventilation of the basement car parking areas shall be through provision of supply and exhaust air ducts duly installed with its supports and connected to supply air and exhaust fans. Alternatively, a system of impulse fans (jet fans) may be used for meeting the requirement of smoke ventilation complying with the following:

    1) Structural aspects of beams and other down stands/services shall be taken care of in the planning and provision of the jet fans;

    2) Fans shall be fire rated, that is, 250 °C for 120 min;

3) Fans shall be adequately supported to enable operations for the duration as above;

4) Power supply panels for the fans shall be located in fire safe zone to ensure continuity of power supply;

5) Power supply cabling shall meet circuit integrity requirement in accordance with accepted standard [D-3(39)];

6) The jet fan system may be validated through final computational fluid dynamics (CFD) analysis of the basement; and

7) The jet fan system after commissioning may be verified by Smoke Gun Test for at least one compartment.

The smoke extraction system shall operate on actuation of flow switch actuation of sprinkler system. In addition, a local and/or remote 'manual start-stop control/switch' shall be provided for operations by the fire fighters. Visual indication of the operation status of the fans shall also be provided with the remote control. Smoke exhaust system having make-up air and exhaust air system for areas other than car parking shall be required for common areas and exit access corridor in basements/underground structures and shall be completely separate and independent of car parking areas and other mechanical areas supply air shall not be less than 5 m from any exhaust discharge openings.

19.1.1.3 *EV Car Parking*

The aspect of smoke ventilation for EV car parking shall be as above in **19.1.1.2**.

19.1.2 *Habitat Spaces in Substructure*

Smoke exhaust system having make-up air and exhaust air system for areas other than car parking shall be required for common areas and exit access corridor in basements/underground structures and shall be completely separate and independent of car parking areas and other mechanical areas.

19.1.3 *Services Spaces in Substructure*

Smoke exhaust system having make-up air and exhaust air system for areas other than car parking shall be required for common areas and exit access corridor in basements/underground structures and shall be completely separate and independent of car parking areas and other mechanical areas.

19.2 Smoke Mitigation – Super Structure/Above Ground

19.2.1 *Group A* (*Residential Buildings*) *to Group G* (*Industrial Buildings*)

For the residential buildings (Group A), all kitchen exhaust fans, where provided shall be fixed to an outside wall or to a duct of non-combustible material, which leads directly to the outside. The ducts shall not pass through areas having combustible materials. However, in case of centralized ducting, the duct shall be provided with adequate protection to limit the spread of fire.

For the industrial buildings (Group G), occupancy requiring undivided floor areas so large that the distances from points within the area to the nearest outside walls where exit doors are 45 m and more, requirements for distance to exits should provide stairs leading to exit tunnels or to overhead passageways. In cases where such arrangements are not practicable, the authority may, by special ruling, permit other exit arrangements for single storeyed buildings with distances higher than distances specified in **4**, if completely automatic sprinkler protection is provided and if the heights of ceiling curtain boards and roof ventilation are such as to minimise the possibility that employees will be overtaken by the spread of fire or smoke within 1.8 m of the floor level before they have time to reach exits, provided, however, that in no case may the distance of travel to reach the nearest exit exceed 65 m where smoke venting is required as a condition for permitting distances of travel to exits in excess of the maximum otherwise allowed.

Additional precautions for smoke mitigation are as follows:

a) In any room in which volatile flammable substances are used or stored, no device generating a glow or flame capable of igniting flammable vapour shall be installed or used, such a room shall be provided with a suitably designed exhaust ventilation system; and

b) Storage buildings, such as for warehouses, natural draft smoke venting shall utilize roof vents or vents in walls at or near the ceiling level; such vents shall be normally open, or, if closed, shall be designed for automatic opening in case of fire, by release of smoke sensitive devices.

19.3 Smoke Mitigation of Exits - Natural/ Mechanical

19.3.1 *Staircases and Exits Passageways*

19.3.1.1 *Smoke control of exits*:

a) In building design, compartmentation plays a vital part in limiting the spread of fire and smoke. The design should ensure avoidance of spread of smoke to adjacent spaces through the various leakage openings in the compartment enclosure, such as cracks, openings annular gaps around pipes ducts, airflow grills and doors;

b) The pressurization of staircases and lift lobbies shall be adopted:

  1) The pressure difference for staircases shall be minimum 50 Pa; and

  2) Pressure differences for lobbies (or corridors) shall be between 25 Pa and 30 Pa. Further, the pressure differential for enclosed staircase adjacent to such lobby (or corridors) shall be 50 Pa. For enclosed staircases adjacent to non-pressurized lobby (or corridors), the pressure differential shall be 50 Pa.

c) Equipment and ductwork for staircase pressurization shall be in accordance with one of the following:

  1) Directly connected to the stairway by ductwork enclosed in non-combustible construction; and

  2) If ducts used to pressurize the system are passed through shafts and grills are provided at each level, it shall be ensured that hot gases and smoke from the building shall not ingress into the staircases under any circumstances.

d) The normal air conditioning system and the pressurization system shall be designed and interfaced to meet the requirements of emergency services. When the emergency pressurization is brought into action, the following changes in the normal air conditioning system shall be affected:

  1) Any re-circulation of air shall be stopped and all exhaust air vented to atmosphere;

  2) Any air supply to the spaces/areas other than exits shall be stopped;

  3) The exhaust system may be continued, provided:

    i) The positions of the extraction grills permit a general air flow away from the means of egress;

    ii) The construction of the ductwork and fans is such that, it will not be rendered inoperable by hot gases and smoke; and

    iii) There is no danger of spread of smoke to other floors by the path of the extraction system which shall be ensured by keeping the extraction fans running.

e) For pressurized stair enclosure systems, the activation of the systems shall be initiated by signalling from fire alarm panel;

f) Pressurization system shall be integrated and supervised with the automatic/manual fire alarm system for actuation;

g) Wherever pressurized staircase is to be connected to unpressurized area, the two areas shall be segregated by 120 min fire resistant wall. Such as, in high-rise office buildings, a pressurized staircase can discharge into an unpressurized ground-level lobby or covered parking floor, provided that the staircase itself remains protected as a smoke-free escape path up to the point of final exit; and

h) Fresh air intake for pressurization shall be away (at least 4 m) from any of the exhaust outlets/grille.

19.3.1.2 In case of smoke exhaust and pressurization of areas above ground, corridors in exit access (exit access corridor) are created for meeting the requirement of use, privacy and layout in various occupancies. These are most often noted in hospitality, health care occupancies and sleeping accommodations. Exit access corridors of guest rooms and indoor patient department/areas having patients lacking self-preservation and for sleeping accommodations such as apartments, custodial, penal and mental institutions, etc, shall be provided with 60 min fire resistant wall and 20 min self-closing fire doors along with all fire stop sealing of penetrations. The fire doors shall be as per the accepted standard [D-3(49)].

Smoke exhaust system having make-up air and exhaust air system or alternatively pressurization system with supply air system for these exit access corridors shall be required. Smoke exhaust system having make-up air and exhaust air system shall also be required for theatres/auditoria. Such smoke exhaust system shall also be required for large lobbies and which have exit through staircase leading to exit discharge. This would enable eased exit of people through smoke-controlled area to exit discharge. All exit passageway (from exit-to-exit discharge) shall be pressurized or naturally ventilated. The mechanical pressurization system shall be automatic in action with manual controls in addition. All such exit passageway shall be maintained with integrity for safe means of egress and evacuation. Doors provided in such exit passageway shall be fire rated doors of 120 min rating.

Smoke exhaust system where provided, for above areas and occupancies shall have a minimum of 12 air changes per hour smoke exhaust mechanism. Pressurization system where provided shall have a minimum pressure differential of 25 Pa to 30 Pa in relationship to other areas. The smoke exhaust fans in the mechanical ventilation system shall be fire rated, that is, 250 °C for 120 min. For naturally cross-ventilated corridors or corridors with operable windows, such smoke exhaust system or pressurization system will not be required.

19.3.2 *Lift Lobby*

Smoke control of exits – pressure differences for lobbies (or corridors) shall be between 25 Pa and 30 Pa.

Firefighting shaft (fire tower) is an enclosed shaft having protected area of 120 min fire resistance rating comprising protected lobby, staircase and fireman’s lift, connected directly to exit discharge or through exit passageway with 120 min fire resistant wall at the level of exit discharge to exit discharge.

19.3.3 *Hoist Way*

If the lift lobby is not provided at any of the levels in air-conditioned buildings or in internal spaces where funnel/flue effect may be created, lift hoist way shall be pressurized at 50 Pa.

19.3.4 *Fire Tower/Firefighting Shaft*

Firefighting shaft (Fire tower) is an enclosed shaft having protected area of 120 min fire resistance rating comprising protected lobby, staircase and fireman’s lift, connected directly to exit discharge or through exit passageway with 120 min fire resistant wall at the level of exit discharge to exit discharge.

If lift lobby shall not be provided at any of the levels in air-conditioned buildings or in internal spaces where funnel/flue effect may be created, lift hoist way shall be pressurized at 50 Pa.

19.3.5 *Egress and Evacuation Strategy*

Staircase and fire lift lobby of a firefighting shaft shall be smoke controlled. It is recommended that the pressurization requirement for staircase in firefighting shaft and for other fire exit staircases in buildings greater than 60 m in height be evaluated to limit the force required to operate the door assembly (in the direction of door opening) to not more than 133 N to set the door leaf in motion. The aspect of pressurization, door area/width and door closure shall be planned in consideration to the above.

19.4 Smoke Mitigation – Special Occupancy and Spaces

19.4.1 *Atrium*

Given below are the requirements for atrium concerning with the smoke prevention and management for occupancy and spaces:

a) Atrium in business occupancy shall be planned with 6 ACPH while atrium in hotels and assembly occupancy shall be planned with 8 ACPH smoke extraction system. Such air changes shall be planned in atrium for a height of 15 m from the top;

b) Smoke exhaust fans shall be capable of operating effectively at 250 °C for 120 minutes;

c) Makeup air supply points shall be located beneath the smoke layer and on the lower levels connected by the atrium. Makeup air shall be provided by fans, openings to outside to allow infiltration, or the combination thereof;

d) It is recommended that makeup air be designed at 85 percent to 95 percent of the exhaust flow rate, not including the leakage through these small paths. The makeup air shall not cause door-opening force to exceed allowable limits. The makeup air velocity shall not exceed 1.02 m/s where the makeup air could come in contact with the plume unless a higher makeup air velocity is supported by engineering analysis; and

e) Atrium smoke management system fans shall be provided with emergency power. If so, required by the authority, an engineering analysis should be performed which demonstrates that the smoke system for the atrium is designed to keep the smoke layer interface 1 800 mm above the highest occupied floor level of exit access, open to the atrium, for a period equal to 1.5 times the calculated egress time or 20 min, whichever is greater.

19.4.2 *Commercial Kitchens*

Given below are the requirements for fire separation for commercial kitchens:

a) Where the flue or exhaust duct passes through the compartment wall or floor, the flue or duct shall be encased by non-combustible construction and no damper shall be permitted to be installed in such flue or duct. Also, such flue or ductwork shall be clear from combustible materials; and

b) It is advisable to locate the kitchen/cooking operations on the external periphery of the building so that in the event of mechanical ventilation failure, it shall be naturally ventilated.

19.4.2.1 *Exhaust ventilation system*

Following guidelines shall be ensured for proper functioning of exhaust ventilation system for cooking equipment:

a) Provision of cleaning of the kitchen exhaust every six months to ensure that the carbon soot accumulated in the exhaust duct is cleaned to avoid the chances of outbreak of fire shall be made;

b) Independent exhaust ducts shall be provided for equipment using dry fuel like wood/ charcoal which produce spark and are likely to ignite the grease which might have accumulated in the common duct; and

c) Alternatively, approved spark arrestors may be provided before the duct from equipment using dry fuel meets the main duct. These spark arrestors shall be so provided that these are easily accessible and removable for cleaning.

19.4.2.2 *Cooking equipment*

Following procedures shall be adopted for handling of cooking equipment:

a) Any penetrations to the outside of a hood, be either welded or fit with a sealing device in accordance to the relevant Indian standard for not allowing cooking grease, oil to migrate to the outer portion of the hood. The fitment arrangements shall be of approved type. Gaskets for the panels shall be certified to withstand a temperature of 815.6 °C;

b) Grease strip shall be readily available for efficient and regular cleaning of concrete or paved floors of kitchen and restaurant and also the drainage areas;

c) The hood or that portion of a primary collection means designed for collecting cooking vapours and residues shall be constructed of and be supported by steel not less than 1.09 mm in thickness or stainless steel not less than 0.94 mm in thickness or other approved material of equivalent strength and fire and corrosion resistance;

d) All seams, joint, and penetrations of the hood enclosure that direct and capture grease-laden vapours and exhaust gases shall have a liquid tight continuous external weld to the hood's lower outermost perimeter;

e) Grease filters shall be of steel rigid construction that will not distort or crush under normal operation handling and cleaning conditions. They shall be so arranged that all exhaust air passes through the grease filters. Filters shall be easily accessible and removable for periodic cleaning;

f) Grease filters shall be installed at an angle not less than 45° from the horizontal;

g) Grease filters shall be equipped with a grease drip tray beneath their lower edges and shall have a suitable minimum depth needed to collect grease. The grease drip trays shall be pitched to drain into an enclosed metal container having a capacity not exceeding 3.8 1itre; and

h) The exhaust ducts shall be constructed of and supported by carbon steel not less than 1.37 mm in thickness or stainless steel not less than 1.09 mm in thickness.

19.4.2.3 *Rooftop terminations — Exhaust systems*

The exhaust system shall terminate either outside the building with a fan or duct or through the roof or to the roof from outside with minimum 3 m of horizontal clearance from the outlet to the adjacent buildings, property lines and air intakes. There shall be a minimum of 1.5 m of horizontal clearance from the outlet (fan housing) to any combustible structure. There shall be a vertical separation of 1.0 m below any exhaust outlets for air intakes within 3.0 m of the exhaust outlet.

19.4.3 *Auditoriums and Cinemas*

Smoke exhaust and pressurization of areas above ground – smoke exhaust system having make-up air and exhaust air system shall also be required for theatres/auditorium.

19.4.4 *Multilevel Car Parking* (*MLCP*) *Non-Mechanical*

Open parking structures (including multi-level parking and stilt parking) specifies the degree to which the structure's exterior walls shall have openings. Parking structures that meet the definition of the term open parking structure provide sufficient area in exterior walls to vent the products of combustion to a greater degree than an enclosed parking structure.

A parking structure having each parking level wall openings open to the atmosphere, for an area of not less than 0.4 m^2 for each linear metre of its exterior perimeter shall be construed as open parking structure. Such openings shall be distributed over 40 percent of the building perimeter or uniformly over two opposing sides. Interior wall lines shall be at least 20 percent open, with openings distributed to provide ventilation, else, the structure shall be deemed as enclosed parking structures.

NOTE — A car park located at the stilt level of a building (not open to sky) shall be considered an open or an unenclosed car park if any part of the car park is within 30 m of a permanent natural ventilation opening and any one of the following is complied with towards the permanent natural ventilation requirement: i) 50 percent of the car park perimeter shall be open to permanent natural ventilation. ii) At least 75 percent of the car park perimeter is having the 50 percent natural ventilation opening.

19.4.5 *Multilevel Car Parking Stack/ Mechanical*

For enclosed multilevel car parking structures utilizing stack or mechanical systems, provisions for smoke ventilation should be considered to enhance safety during fire incidents. Smoke ventilation systems may include natural or mechanical ventilation strategies to ensure the rapid removal of smoke and hot gases. Such systems should comply with the applicable fire safety standards and guidelines, as detailed in Part F 'Fire and Life Safety' of this NBCS.

For smoke ventilation requirement of car parking, *refer* **19.1.1.2**.

19.5 Aspects of Pressurization (Pascals) Smoke Mitigation

Smoke ventilation systems should be designed in line with the principles of pressurization to manage smoke spread effectively. These include:

a) *Defend in Place* (*One Door Open*) — Maintaining a pressure differential to protect occupants who remain within the structure;

b) *Phased Evacuation* (*Three Doors Open*) — Ensuring controlled evacuation by balancing pressurization for multiple door openings;

c) *Firefighting Shaft* (*Three Doors Open*) — Providing safe access for firefighters with maintained pressure differentials;

d) *Pressure Differential Measurement* — Ensuring pressure is appropriately maintained in staircases, lift lobbies, and lifts; and

e) *Door Opening Force Measurement* — Verifying door operation under pressurized conditions to allow safe egress.

19.6 Aspects of Ventilation for Smoke Mitigation

Ventilation systems play a crucial role in maintaining occupant safety during fire emergencies by controlling smoke spread and ensuring adequate air changes per hour (ACPH). Proper compartmentalization, isolation of air handling units, and adherence to fire resistance standards for ducts and dampers to prevent smoke infiltration and maintain safe evacuation routes. These units ensure effective fire containment and support emergency response operations.

19.6.1 *Air Handling Unit*

From fire safety point of view, separate air handling units (AHU) for each floor shall be provided so as to avoid the hazards arising from spread of fire and smoke through the air conditioning ducts. The air ducts shall be separate from each AHU to its floor and in no way shall interconnect with the duct of any other floor. Within a floor it would be desirable to have separate air handling unit provided for each compartment. Air handling unit shall be provided with effective means for preventing circulation of smoke through the system in the case of a fire in air filters or from other sources drawn into the system and shall have smoke sensitive devices for actuation in accordance with best practices.

Shafts or ducts, if penetrating multiple floors, shall be of masonry construction with fire damper in connecting ductwork or shall have fire rated ductwork with fire dampers at floor crossing. Alternatively, the duct and equipment should be installed in room having walls, doors and fire damper in duct exiting/entering the room of 120 min fire resistance rating. Such shafts and ducts shall have all passive fire control meeting 120 min fire resistance rating requirement to meet the objective of isolation of the floor from spread of fire to upper and lower floors through shaft/duct work.

NOTES

1 Zoned and compartmented HVAC systems are encouraged with an approach to avoid common exhaust shafts and fresh air intake shafts which will limit the requirement of such passive measure and fire rated duct work and dampers.

2 The air filters of the air handling units shall be made of non-combustible materials.

3 The air handling unit room shall not be used for storage of any combustible materials.

19.6.2 *Duct Work*

Air ducts serving main floor areas, corridors, etc, shall not pass through the exits/exit passageway/ exit enclosure. Exits and lift lobbies, etc, shall not be used as return air passage.

As far as possible, metallic ducts shall be used even for the return air instead of space above the false ceiling.

Wherever the ducts pass through fire walls or floors, the opening around the ducts shall be sealed with materials having fire resistance rating of the compartment. Such duct shall also be provided with fire dampers at all fire walls and floors unless such ducts are required to perform for fire safety operation; and in such case fire damper may be avoided at fire wall and floor while integrity of the duct shall be maintained with 120 min fire resistance rating to allow the emergency operations for fire safety requirements.

The ducting within compartment would require minimum fire resistance rating of 30 min. If such duct crosses adjacent compartment/floor and not having fire dampers in such compartment/floor, it shall require fire resistance duct work rating of 120 min. The requirements of support of the duct shall meet its functional time requirement as above.

The materials used for insulating the duct system (inside or outside) shall be of non-combustible type. Any such insulating material shall not be wrapped or secured by any material of combustible nature.

Inspection panels shall be provided in the ductwork to facilitate the cleaning accumulated dust in ducts and to obtain access for maintenance of fire dampers. For more information, special publications may be referred.

NOTE — Special publication may be UL 2079 ‘Tests for Fire Resistance of Building Joint Systems’.

19.6.3 *Fire or Fire/Smoke Dampers*

These dampers shall be evaluated to be located in supply air ducts, fresh air and return air ducts/passages at the following points:

a) At the fire separation wall;

b) Where ducts/passages enter the vertical shaft;

c) Where the ducts pass through floors; and

d) At the inlet of supply air duct and the return air duct of each compartment on every floor.

Damper shall be so installed to provide complete integrity of the compartment with all passive fire protection sealing. Damper should be accessible to maintain, test and also replace, if so required. Damper shall be integrated with fire alarm panel and shall be sequenced to operate as per requirement and have interlocking arrangement for fire safety of the building. Manual operation facilities for damper operation shall also be provided.

19.6.4 *Glass Facade*

Openable panels shall be provided on each floor and shall be spaced not more than 10 m apart measured along the external wall from centre-to-centre of the access openings. Such openings shall be operable at a height between 1.2 m and 1.5 m from the floor and shall be in the form of openable panels (fire access panels) of size not less than 1 000 mm × 1 000 mm opening outwards. The wordings, ‘FIRE OPENABLE PANEL — OPEN IN CASE OF FIRE, DO NOT OBSTRUCT’ of minimum 25 mm letter height shall be marked on the internal side. Such panels shall be suitably distributed on each floor based on occupant concentration. These shall not be limited to cubicle areas and shall be also located in common areas/corridors to facilitate access by the building occupants and fire personnel for smoke exhaust in times of distress.

LIST OF STANDARDS

The following list records those standards which are acceptable as ‘good practice’ and ‘accepted standards’ in the fulfilment of the requirements of this NBCS. The standards listed may be as a guide in conformance with the requirements of the referred clauses in this NBCS.

In the following list, the number appearing in the first column within parentheses indicates the number of the reference in this Section of this NBCS.

	IS No.	*Title*
(1)	IS 3615 : 2024	Glossary of terms used in refrigeration and air conditioning (*third revision*)
(2)	IS16656 : 2017/ ISO 817 : 2014	Refrigerants — Designation and safety classification
(3)	IS 7896 : 2023	Air conditioning outdoor design conditions data for Indian cities (*second revision*)
(4)	IS 1391 (Part 1) : 2023	Room Air Conditioners Specification Part 1 Unitary air conditioners (*fourth revision*)
(5)	IS 60335-2-40 : 2018/ IEC 60335-2-40	Household and similar electrical appliances — safety: Part 2-40 Particular requirements for electrical heat pumps air-conditioners and dehumidifiers
(6)	IS 1391 (Part 2) : 2023	Room air conditioners specification: Part 2 Split air conditioners (*fourth revision*)
(7)	IS 18689 : 2024	Household and similar electrical appliances — Safety — Particular requirements for commercial refrigerating appliances and ice-makers with an incorporated or remote refrigerant unit or motor-compressor (IEC 60335-2-89 : 2019, MOD)
(8)	IS 16678 (Part 1) : 2018/ ISO 5149-1 : 2014	Refrigerating systems and heat pumps safety and environmental requirements: Part 1 Definitions, classification and selection criteria
(9)	IS 16678 (Part 2) : 2018/ ISO 5149-2 : 2014	Refrigerating systems and heat pumps — Safety and environmental requirements: Part 2 Design, construction, testing, marking and documentation
(10)	IS 16678 (Part 3) : 2018/ ISO 5149-3 : 2014	Refrigerating systems and heat pumps — Safety and environmental requirements: Part 3 installation site
(11)	IS 16678 (Part 4) : 2024/ ISO 5149-4 : 2022	Refrigerating systems and heat pumps — Safety and environmental requirements: Part 4 Operation, maintenance, repair and recovery (*first revision*)
(12)	IS 5610 : 2025	Refrigerants — Specification (*third revision*)
(13)	IS 3315 : 2024	Direct evaporative air cooler — Specification (*fourth revision*)
(14)	IS 655 : 2006	Air ducts — Specification (*second revision*)
(15)	IS 17570 (Part 1) : 2021/ ISO 16890-1:2016	Air Filters for general ventilation: Part 1 Technical specifications, requirements and classification system based upon particulate matter efficiency (ePM)
(16)	17570 (Part 2) : 2025	Air Filters for general ventilation: Part 2 Measurement of fractional efficiency and air flow resistance (ISO 16890-2 : 2016, MOD)

	IS No.	*Title*
(17)	IS 17570 (Part 3) : 2021/ ISO 16890-3 : 2016	Air Filters for general ventilation: Part 3 Determination of the gravimetric efficiency and the air flow resistance versus the mass of test dust captured
(18)	IS 17570 (Part 4) : 2025/ ISO 16890-4 : 2016	Air Filters for general ventilation: Part 4 Conditioning method to determine the minimum fractional test efficiency
(19)	IS 16753 (Part 1) : 2022/ ISO 29463-1 : 2017	High efficiency filters and filter media for removing particles from air Part 1 Classification, performance, testing and marking (*first revision*)
(20)	IS 8188 : 1999	Treatment of water for cooling towers — Code of practice (*first revision*)
(21)	IS 18794 : 2024	Air handling units — Specification
(22)	IS 12615 : 2018	Line operated three phase a.c. motors (IE CODE) “efficiency classes and performance specification” (*third revision*)
(23)	IS 13204 : 2024	Rigid phenolic foam for thermal insulation — Specification (*first revision*)
(24)	IS 16590 : 2023	Liquid chilling package units — Specification (*first revision*)
(25)	IS 8148 : 2018	Specification for packaged air conditioners (*second revision*)
(26)	IS 18728 : 2024	Multiple split-system air conditioners and air-to-air heat pumps (VRF air conditioners) — Specification
(27)	IS 3601 : 2006	Steel tubes for mechanical and general engineering purposes — Specification (*second revision*)
(28)	IS 661 : 2019	Thermal insulation of cold storage — Code of practice (*fourth revision*)
(29)	IS IS 17773 : 2022	Closed-circuit ammonia refrigeration system — Code of practice for design and installation (ANSI/IIAR 2 : 2014, NEQ)
(30)	IS 1893 (Part 1) : 2025	Design for earthquake hazard and criteria for earthquake-resistant design of structures: Part 1 General provisions (*seventh revision*)
(31)	IS 3043 : 2018	Code of practice for earthing (*second revision*)
(32)	IS/IEC 62305-4 : 2010	Protection against lightning: Part 4 Electrical and electronic systems within structures
(33)	IS 732 : 2019	Code of practice for electrical wiring installations (*fourth revision*)
(34)	IS 1255 : 1983	Code of practice for installation and maintenance of power cables up to and including 33 kV rating (*second revision*)
(35)	IS 16753 (Part 2) : 2018/ ISO 29463-2 : 2011	High-Efficiency filters and filter media for removing particles in air: Part 2 aerosol production, measuring equipment and particle — Counting statistics
(36)	IS 16753 (Part 3) : 2018/ ISO 29463-3 : 2011	High-Efficiency filters and filter media for removing particles in air: Part 3 testing flat sheet filter media
(37)	IS 16753 (Part 4) : 2018/ ISO 29463-4 : 2011	High-Efficiency filters and filter media for removing particles in air: Part 4 testing method for determining leakage of filter elements — Scan method

	IS No.	*Title*
(38)	IS 16753 (Part 5) : 2024/ ISO 29463-5	High-efficiency filters and filter media for removing particles in air: Part 5 Test method for filter elements (*first revision*)
(39)	SP 30 : 2023	National Electrical Code of India 2023 (*second revision*)
(40)	IS 17025 : 2017/ ISO/IEC 17025 : 2017	General requirements for the competence of testing and calibration laboratories (*second revision*)
(41)	IS 13301 : 1992	Vibration isolation for machine foundations — Guidelines
(42)	IS/IEC 60529 : 2001	Degrees of protection provided by enclosures (IP Code)
(43)	IS 4759 : 1996	Hot — Dip zinc coatings on structural steel and other allied products — Specification (*third revision*)
(44)	IS 737 : 2024	Wrought aluminium and aluminium alloy sheet and strip for general engineering purposes — Specification (*fourth revision*)
(45)	IS 10234 : 1982	Recommendations for general pipeline welding
(46)	IS 2075 : 2017	Ready mixed paint, stoving, red oxide zinc chrome, priming — Specification (*third revision*)
(47)	IS 15652 : 2006/ IEC 61111	Insulating mats for electrical purposes — Specification
(48)	IS 1946 (Part 2) : 2025	Fixing devices in walls, ceilings and floors of solid construction: Part 2 Design of post-installed anchorage to concrete — Code of practice (*first revision*)
(49)	IS 3614 : 2021	Fire doors and doorsets — Specification (*first revision*)
	IS 61439-1 : 2020/ IEC 61439-1:2020	Low-voltage switchgear and controlgear assemblies Part 1: General rules (*first revision*)
(50)	IS 2370: 2014	Walk-in cold rooms — Specification

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NATIONAL BUILDING CONSTRUCTION STANDARDS

PART D BUILDING SERVICES

SECTION 4 ACOUSTICS, SOUND INSULATION AND NOISE CONTROL

BUREAU OF INDIAN STANDARDS

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FOREWORD

This NBCS (Part D/Section 4) covers the acoustical, sound insulation and noise control requirements in buildings. Emphasis is laid on planning of buildings *vis-a-vis* its surroundings to reduce noise, and in addition, sound insulation aspects of different occupancies are covered for achieving acceptable noise levels.

This Section was first published in 1970 as part of the National Building Code of India and was subsequently revised in 1983, 2005 and 2016. Some of the important changes in the 1983 version included: specifying of approximate measured noise levels due to various types of traffic (air, rail and road) conditions; elaboration of planning and design features of buildings against outdoor noise; modification of impact sound insulation in residential buildings and hearing damage risk criteria in industrial buildings; recommendations regarding planning of open plan schools against noise; planning and design aspects of hotels and hostels, laboratories and test houses, and other miscellaneous buildings, and planning of office buildings with light weight partitions; and elaboration of the public address system to cover public address system at passenger terminals.

Some of the important changes in the 2005 version included: addition of large numbers of important definitions in line with the existing international practice of usage of terms in the field of acoustics, sound insulation and noise control; inclusion of a new clause on highway noise barrier under provisions on planning and design against outdoor noise; deletion of the clause on public address system; addition of a new clause on cinema; and deletion of existing appendices on ‘Constructional measures for sound insulation of buildings’ and ‘Sound Insulation values for various types of materials and construction’; and addition of eight new informative annexes on noise calculations, specification of sound insulation, noise rating, outdoor noise regulations in India, special problems requiring expert advice, airborne and impact sound insulation, basic design techniques for noise control in HVAC and suggested equipment noise data sheet.

The significant changes that were incorporated in the 2016 revision included the review and update of definitions of various existing terms, along with the introduction of new terms such as noise criteria, sound level difference, ground-borne noise, and structure-borne noise. A new clause on construction noise was introduced, while the provision relating to noise control in open-plan schools was deleted. For auditoria and theatres, a provision for the effective isolation of mechanical equipment, such as lifts, from the building structure was included to prevent noise transmission. Additionally, in auditoria and theatres, a requirement was introduced for adequate damping under lightweight metal roofs, along with an additional lightweight under-deck noise barrier to reduce noise generated by rainfall. The reverberation time of assembly halls in schools, corresponding to ‘Maximum for noise control (empty)’, was modified, and the reverberation times of classrooms were also revised. The requirement for insulation (R_w) for walls or partitions between rooms in hospitals was modified, as also the recommended maximum reverberation times for very large offices and canteens. The recommended sound isolation value (D_w) between one room and another room in office was modified, and a similar modification was made for clerical offices where noise does not constitute a major nuisance. The provisions for assembly for partitions in hotels, including those between guest rooms as well as between rooms, corridors, and floors, were also modified. Examples of common types of wall and floor construction with sound insulation were reviewed and updated as required. Additionally, the provisions were updated to address the requirements of persons with disabilities.

In this revision, this publication has been renamed as National Building Construction Standards (NBCS).

This revision has been brought out to incorporate changes based on the experience gained during usage of the last version of this Section. Following significant changes have been made in this revision:

a) Provisions for open plan offices have been updated to address concerns regarding data theft and protection of sensitive information;

b) Provisions have been added for noise control in specific industrial occupancies;

c) A new clause has been included for neighbourhood acoustic shielding during infrastructure development to reduce noise impact on nearby areas;

d) Provisions on traffic noise barriers has been introduced;

e) A new Annex F has been introduced detailing the design requirements and performance evaluation of noise barriers to ensure effective noise mitigation;

f) Provisions on the integration of noise barriers and noise abatement measures in zonal and urban planning have been included in Annex E; and

g) Room criteria (RC) has been added in Annex J for rating the heating ventilation and air-conditioning system-related noise in buildings.

There are two types of noises, that is, air-borne and structure-borne noise. To reduce the intensity of air-borne noise, sound absorbent materials may be used. An absorbent material is one which reduces the intensity of sound reflected from its surface. It may be applied to walls, floors, ceilings or used as furnishings to reduce the sound level by absorption. However, the materials selected for sound absorption shall be consistent with fire safety requirements of the buildings.

To reduce the transmission of air-borne noise, sound insulating materials may be used. Sound insulating materials block the passage of noise through them by virtue of their mass and physical properties. The extent of noise reduction provided by a single homogeneous panel is proportional to the logarithm of mass per unit area. For high values of sound insulation, normally heavy panels are required. Thin sheets of materials do not have adequate mass for providing any appreciable sound transmission loss by themselves. However, when thin sheet materials are used in a double panel construction with an intervening air cavity, this special construction can give extremely high sound transmission loss values considering the mass of the partition, if designed properly. Porous materials lack the mass required to provide any appreciable sound transmission loss, and readily allow sound at most frequencies to be transmitted through them.

To reduce the transmission of structure-borne noise (such as noise generated by impacts) special construction methods and elastic discontinuity in the structure may be used. Structure-borne noise reduction is effected by corner joints, changes in cross-section, changes in materials, etc, in construction. The reduction by these construction methods is, however, not appreciable especially when a large amount of noise reduction is required over a short distance. In such cases, introduction of an elastic discontinuity in the structure can result in a very large amount of noise reduction. The noise transmission is affected only above a certain lower frequency which depends on the material thickness and the elastic properties of the material. Bonded fibrous materials, rubber elastomers, cork, etc, are suitable for curtailing structure-borne noise transmission.

This Section is largely based on the following standards:

IS 1950 : 1962	Code of practice for sound insulation of non-industrial buildings
IS 3483 : 1965	Code of practice for noise reduction in industrial buildings
IS 4954 : 1968	Recommendations for noise abatement in town planning
IS 11050 (Part 1) : 2023	Rating of sound insulation in buildings and of building elements: Part 1 Airborne sound insulation (*first revision*)
IS 11050 (Part 2) : 2023	Rating of sound insulation in buildings and of building elements: Part 2 Impact sound insulation (*first revision*)

Assistance has also been drawn from the following publication, in the formulation of this Section:

BS 8233 : 2014	Code of practice for sound insulation and noise reduction for buildings

All standards, whether given herein above or cross-referred to in the main text of this Section, are subject to revision. The parties to agreement based on this Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

As the regulation of land development and buildings is a State subject and is dealt by the States and local bodies such as urban local bodies within their jurisdiction through building regulatory documents like building regulations, building byelaws, and fire regulations, this document is voluntary in nature and is non-binding. The implementation depends on adoption by concerned parties or stipulations in a contract or by appropriate adoption by the concerned authorities.

For the purpose of deciding whether a particular requirement of this Section is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 ‘Rules for rounding off numerical values (*second revision*)’. The number of significant places retained in the rounded off value should be the same as that of the specified value in this Section.

Important Explanatory Note for Users of this NBCS

In any Part/Section of this NBCS, where reference is made to **‘good practice’** in relation to design, constructional procedures or other related information, and where reference is made to **“accepted standard”** in relation to material specification, testing, or other related information, the Indian Standards listed at the end of the Part/Section shall be used as a guide to the interpretation.

At the time of publication, the editions indicated in the standards were valid. All standards are subject to revision and parties to agreements based on any Part/ Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

In the list of standards given at the end of a Part/Section, the number appearing within parentheses in the first column indicates the number of the reference of the standard in the Part/Section. For example:

a) Good practice [D-4(1)] refers to the Indian Standard(s) given at serial number (1) of the list of standards given at the end of this Part D/Section 4, that is, IS 11050 (Part 1) : 2023 ‘Rating of sound insulation in buildings and of building elements: Part 1 Airborne sound insulation (*first revision*)’.

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART D BUILDING SERVICES

SECTION 4 ACOUSTICS, SOUND INSULATION AND NOISE CONTROL

1 SCOPE

This NBCS (Part D/Section 4) covers requirements and guidelines regarding planning against noise, acceptable noise levels and the requirements for sound insulation in buildings with different occupancies.

2 TERMINOLOGY

For the purpose of this Section, the definitions given below shall apply.

2.1 Ambient Noise — The sound pressure levels associated with a given environment. Ambient noise is usually a composite of sounds from near and far sources, none of which are particularly dominant.

2.2 Audible Frequency Range — The range of sound frequencies normally heard by the human ear. The audible range spans from 20 Hz to 20 000 Hz.

2.3 A-Weighted Sound Pressure, p_A — Value of overall sound pressure, measured in pascal (Pa), after the electrical signal derived from a microphone has been passed through an A-weighting network.

NOTE — The A-weighting network modifies the electrical response of a sound level meter with frequency in approximately the same way as the sensitivity of the human hearing system.

2.4 A-Weighted Sound Pressure Level, L_{pA} — The quantity of A-weighted sound pressure, in decibels (dB), is given by the following formula:

$$L_{pA} = 10\log_{10}\left(p_A/p_0\right)^2$$

where

p_A = A-weighted sound pressure, in pascal (Pa); and

p_0 = reference sound pressure (20 μ Pa).

NOTE — Measurements of A-weighted sound pressure level can be made with a meter and correlate roughly with subjective assessments of loudness, and are usually made to assist in judging the effects of noise on people. The size of A-weighting in 1/3 octave bands, is shown in Annex A (*see* A-5). An increase or decrease in level of 10 dBA corresponds roughly to a doubling or halving of loudness.

2.5 Background Noise — The sound pressure levels in a given environment from all sources excluding a specific sound source being investigated or measured.

2.6 Break-in — Unwanted sound transmission into a duct or a quiet environment, from outside.

2.7 Break-out — Unwanted sound transmission from the inside of a duct or a noisy enclosure, to the outside.

2.8 Broad Band Noise — Spectrum consisting of a large number of frequency components, none of which is individually dominant.

2.9 Cross-talk — Unwanted sound transmission between one room and another room or space, *via* a duct.

2.10 C_{tr} — Correction term applied against the sound insulation single-number values (R_w, D_w, and $D_{nT,w}$) to provide A-weighting against low frequency performance.

NOTE — The reference values used within the C_{tr} calculation are based on urban traffic noise.

2.11 Decibel — Ten times the logarithm (to the base 10) of the ratio of two mean square values of sound pressure, sound power or sound intensity. The abbreviation for decibel is dB.

2.12 Effective Perceived Noise Level, in Decibel (EPN dB) — The number for rating the noise of an individual aircraft flying overhead is the effective perceived noise level in decibels (EPN dB). The effective perceived noise decibel value takes into account the subjectively annoying effects of the noise including pure tones and duration. In principle, it is a kind of time-integrated loudness level.

2.13 Equivalent Continuous A-Weighted Sound Pressure Level, $L_{\mathrm{Aeq.T}}$ — Value of the A-weighted sound pressure level in decibels (dB) of a continuous, steady sound, that within a specified time interval, *T*, has the same mean squared sound pressure as the sound under consideration that varies with time, and is given by the formula:

$$L_{Aeq.T} = 10\log_{10}\left[\frac{1}{T}\int_0^T \frac{p_{\mathrm{A}}{}^2(t)}{p_0^2}\,dt\right]$$

where

$p_{\mathrm{A}}(t)$ = instantaneous A-weighted sound pressure, in pascals (Pa); and

p_0 = reference sound pressure (20 μ Pa).

NOTE — Equivalent continuous A-weighted sound pressure level is mainly used for the assessment of environmental noise and occupational noise exposure.

2.14 Equivalent Sound Absorption Area of a Room, *A* — Hypothetical area of a totally absorbing surface without diffraction effects, expressed in square metres (m^2) which, if it were the only absorbing element in the room, would give the same reverberation time as the room under consideration.

2.15 Facade Level — Sound pressure level measured 1 m to 2 m in front of the facade.

NOTE — Facade level measurements of L_{pA} are usually 2 dB to 3 dB higher than corresponding free-field measurements.

2.16 Free-Field Level — Sound pressure level measured outside, far away from reflecting surfaces.

NOTE — Measurements made 1.2 m to 1.5 m above the ground and at least 3.5 m away from other reflecting surfaces are usually regarded as being free-field measurements. To minimise the effect of reflections the measuring position should be at least 3.5 m to the side of the reflecting surface (that is, not 3.5 m from the reflecting surface in the direction of the source). Estimates of noise from aircraft overhead usually include a correction of 2 dB to allow for reflections from the ground.

2.17 Frequency — The number of cyclical variations per unit time. Frequency is generally expressed in cycles per second (cps) and is also denoted as Hertz (Hz).

2.18 Impact Sound Pressure Level, L_{i} — Average sound pressure level in a specific frequency band in a room below a floor, when it is excited by a standard tapping machine.

2.19 Indoor Ambient Noise — Pervasive noise in a given situation at a given time, usually composed of noise from many sources, inside and outside the building, but excluding noise from activities of the occupants.

2.20 Insertion Loss (L_{IL}) — Insertion loss is generally defined as the difference, in decibels, between two sound pressure levels (or power levels or intensity levels) which are measured at the same point in space before and after a muffler or any other noise control device is inserted between the measurement point and the noise source.

2.21 Noise — Unwanted sound which may be hazardous to health, interferes with communications or is disturbing.

2.22 Noise Exposure Forecast (NEF) — The noise exposure forecast at any location is the summation of the noise levels in EPN dB from all aircraft types, on all runways, suitably weighted for the number of operations during day time and night time.

2.23 Noise Criteria — Numerical indices used to define design goals for the maximum allowable noise in a given space.

2.24 Noise Rating (NR) — Graphical method for rating a noise by comparing the noise spectrum with a family of noise rating curves.

NOTE — Noise rating is described in Annex B.

2.25 Noise Reduction Coefficient (NRC) — A single figure descriptor of the sound absorption property of a material. It is the arithmetic mean of the sound absorption coefficients at 250 Hz, 500 Hz, 1 000 Hz and 2 000 Hz rounded off to the nearest multiple of 0.05.

2.26 Normalized Impact Sound Pressure Level, L_n — Impact sound pressure level normalized for a standard absorption area in the receiving room.

NOTE — Normalized impact sound pressure level is usually used to characterize the insulation of a floor in a laboratory against impact sound in a stated frequency band (*see* Annex C).

2.27 Octave Band — Band of frequencies in which the upper limit of the band is twice the frequency of the lower limit.

2.28 Percentile Level, $L_{\mathrm{AN,T}}$ — A-weighted sound pressure level obtained using time-weighting '*F*', which is exceeded for *N* percent of a specified time interval.

Example:

$L_{\mathrm{A90,1h}}$ is the A-weighted level exceeded for 90 percent of 1 h.

NOTE — Percentile levels, determined over a certain time interval cannot accurately be extrapolated to other time intervals. Time-weighting '*F*' or '*S*' can be selected on most modern measuring instruments and used to determine the speed at which the instrument responds to changes in the amplitude of the signal. Time-weighting '*F*' is faster than '*S*' and so its use can lead to higher values when rapidly changing signals are measured.

2.29 Pink Noise — Sound with an uninterrupted frequency spectrum and a power which is steady within frequency band and proportional to centre frequency. An example is constant power level per octave band.

2.30 Pure Tone — A sound emitted at a single frequency.

2.31 Rating Level, $L_{\mathrm{Ar},T_{\mathrm{r}}}$ — Equivalent continuous A-weighted sound pressure level of the noise, plus any adjustment for the characteristic features of the noise.

NOTE — This definition is used for rating industrial noise, where the noise is the specific noise from the source under investigation.

2.32 Reverberation Time, T — Time that would be required for the sound pressure level to decrease by 60 dB after the sound source has stopped.

NOTE — Reverberation time is usually measured in octave or third octave bands. It is not necessary to measure the decay over the full 60 dB range. The decay measured over the range 5 dB to 35 dB below the initial level is denoted by T_{30}, and over the range 5 dB to 25 dB below the initial level by $T_{20.}$

2.33 Sound — A vibrational disturbance, exciting hearing mechanisms, transmitted in a predictable manner determined by the medium through which it propagates. To be audible the disturbance shall have to fall within the frequency range of 20 Hz to 20 000 Hz.

2.34 Sound Exposure Level, L_{AE} — Level of a sound, of 1 s duration, that has the same sound energy as the actual noise event considered.

NOTES

1 The L_{AE} of a discrete noise event is given by the formula:

$$L_{\mathrm{AE}} = 10\log_{10}\left(\frac{1}{t_0}\int_{t_1}^{t_2}\frac{p_{\mathrm{A}}^2(t)}{p_0^2}dt\right)$$

where

$P_{\mathrm{A}}(t)$ = instantaneous A-weighted sound pressure in pascals (Pa);

$t_2 - t_1$ = stated time interval in seconds (s) long enough to encompass all significant sound energy of the event;

p_0 = reference sound pressure level (20 μ Pa); and

t_0 = reference time interval (1 s).

2 L_{AE} is also known as L_{AX} (single-event noise exposure level).

2.35 Sound Level Difference, *D* — Difference between the sound pressure level in the source room and the sound pressure level in the receiving room.

NOTE — *D* is given by the following formula:

$$D = L_1 - L_2$$

where

L_1 = average sound pressure level in the source room; and

L_2 = average sound pressure level in the receiving room.

2.36 Sound Power — The acoustic power of a sound source, expressed in Watts.

2.37 Sound Power Level (L_w) — The acoustic power radiated from a given sound source as related to a reference power level (typically 10-12 watt) and expressed in decibel as:

$$L_p = 10log_{10}\left\{\frac{W}{10^{-12}}\right\}$$

or

$$L_w = 10log\, W + 120$$

where

W = acoustic power, in watts.

By definition, 1 W therefore corresponds to 120 dB for L_w.

2.38 Sound Pressure, *p* — Root-mean-square value of the variation in air pressure measured in pascal (Pa), above and below atmospheric pressure, caused by the sound.

2.39 Sound Pressure Level, L_p — Quantity of sound pressure, in decibel (dB), given by the formula:

$$L_p = 10\, log_{10} (p/p_0)^2$$

where

p = root mean square sound pressure in pascals (Pa); and

p_0 = reference sound pressure (20 μ Pa).

NOTE — The range of sound pressures for ordinary sounds is very wide. The use of decibels gives a smaller, more convenient range of numbers. For example, sound pressure levels ranging from 40 dB to 94 dB correspond to sound pressures ranging from 0.002 Pa to 1 Pa. A doubling of sound energy corresponds to an increase in level of 3 dB.

2.40 Sound Receiver — One or more observation points at which sound is evaluated or measured. The effect of sound on an individual receiver is usually evaluated by measurements near the ear or close to the body.

2.41 Sound Reduction Index, *R* — Laboratory measure of the sound insulating properties of a material or building element in a stated frequency band.

NOTE — For further information *see* Annex C.

2.42 Sound Source — Equipment or phenomena which generate sound. Source room is the room containing sound source.

2.43 Spectrum — A quantity expressed as a function of frequency, such as sound pressure versus frequency curve.

2.44 Standardized Impact Sound Pressure Level, L'_{nT} — Impact sound pressure level normalized to that in a receiving room having a reverberation time of 0.5 s.

NOTE — Standardized impact sound pressure level is used to characterize the insulation of floors in buildings against impact sound in a stated frequency band (*see* Annex C).

2.45 Speech Interference Level (SIL) — A descriptor for rating steady noise according to its ability to interfere with conversation between two people. SIL is the arithmetic average of the sound pressure levels in the three octave bands with centre frequencies at 500 Hz, 1 000 Hz and 2 000 Hz.

2.46 Standardized Level Difference, D_{nT} — Difference in sound level between a pair of rooms, in a stated frequency band, normalized to a reverberation time of 0.5 s.

NOTE — Standardized level difference takes account of all sound transmission paths between the rooms (*see* Annex C).

2.47 Structure-borne Noise and Ground-borne

NOTE — When elements of a structure vibrate they radiate noise and, if the vibration is high enough, this noise can be audible. Ground-borne and structure-borne noises are rarely an issue outside buildings or structures.

2.47.1 *Ground-borne Noise* — Audible noise caused by the vibration of elements of a structure, for which the vibration propagation path from the source is partially or wholly through the ground.

NOTE — Common sources of ground-borne noise include railways and heavy construction work on adjacent construction sites.

2.47.2 *Structure-borne Noise* — Audible noise caused by the vibration of elements of a structure, the source of which is within a building or structure with common elements.

NOTE — Common sources of structure-borne noise include building services plant, manufacturing machinery and construction or demolition of the structure.

2.48 Transient Sound — Sound which is audible for a limited period of time, for example sound from over flight of an airplane.

2.49 Third Octave Band — Band of frequencies in which the upper limit of the band is $2\frac{1}{3}$ times the frequency of the lower limit.

2.50 Threshold of Hearing — The lowest continuous sound pressure level which will create an auditory sensation for the average human ear. Any sound below these levels will be inaudible and any sound above the threshold will vary in loudness dependent on intensity.

2.51 Vibration Isolation — Reduction of force or displacement transmitted by a vibratory source, often attained by use of a resilient mount.

2.52 Wavelength — The length in space of one complete cycle of a sound wave given by.

$$\lambda = \frac{Speed\ of\ Sound}{frequency} = \frac{C}{f}$$

2.53 Weighted Level Difference, D_w — Single-number quantity that characterizes airborne sound insulation between rooms but which is not adjusted to reference conditions.

NOTE — Weighted level difference is used to characterize the insulation between rooms in a building as they are; values cannot normally be compared with measurements made under other conditions {*see* good practice [D-4(1)]}.

2.54 Weighted Sound Reduction Index, R_w — Single number quantity which characterizes the airborne sound insulating properties of a material or building element over a range of frequencies.

NOTE — The weighted sound reduction index is used to characterize the insulation of a material or product that has been measured in a laboratory (*see* Annex C).

2.55 Weighted Standardized Impact Sound Pressure Level, $L'_{nT,w}$ — Single number quantity used to characterize the impact sound insulation of floors over a range of frequencies.

NOTE — Weighted standardized impact sound pressure level is used to characterize the insulation of floors in buildings (*see* Annex C).

2.56 Weighted Standardized Level Difference, $D_{nT,w}$ — Single-number quantity, which characterizes the airborne sound insulation between rooms.

NOTE — Weighted standardized level difference is used to characterize the insulation between rooms in a building (*see* Annex C).

2.57 Weighted Normalized Impact Sound Pressure Level, $L'_{n,w}$ — Single number quantity used to characterize the impact sound insulation of floors over a range of frequencies.

NOTE — Weighted normalized impact sound pressure level is usually used to characterize the insulation of floors tested in a laboratory (*see* Annex C).

2.58 White Noise — A noise whose spectrum (level) density is substantially independent of frequency over a specified range and has equal power for any range of frequencies of constant band width.

3 PLANNING AND DESIGN AGAINST OUTDOOR NOISE

3.1 General

Planning against noise should be an integral part of town and country planning proposals, ranging from regional proposals to detailed zoning, and three-dimensional layouts and road design within built-up areas. Noise nuisance should be fully recognized in zoning regulations.

3.1.1 Noise is either generated by traffic (road, air and surface and underground railway) or it arises from zones and buildings within built-up areas (industry, commerce, offices and public buildings), and from public gatherings and social activities. For planning, the noise survey should examine all the possible causes of noise and consider the various factors causing actual nuisance.

3.1.2 Noise by night, causing disturbance of sleep, is more of a nuisance than noise by day. For this reason, housing colonies that adjoin areas with heavy traffic movement during the night are liable to cause serious complaints. Also, the factories that work by night are liable to cause serious complaints if housing estates adjoin them. While planning, care should be taken that housing colonies are adequately set back from busy airports, state and national highways, factories, main railway lines and marshalling yards.

3.1.3 There are two aspects of defence by planning. The first is to plan so as to keep the noise at a distance. Under this aspect comes the separation of housing from traffic noise by interposing buffer zones, and the protection of schools and hospitals by green belts, public gardens, etc. The second is the principle of shading or screening. This consists of deliberately interposing a less vulnerable building to screen a more vulnerable one or by providing a solid barrier, such as a wall, between the source and the location to be protected.

3.2 Traffic Noise Levels

3.2.1 *For Air Traffic*

For guidance, approximate noise levels due to various types of aircrafts, measured on ground, when the aircrafts fly overhead at a height of 450 m, are given in Table 1.

3.2.2 *For Rail Traffic*

Noise levels of some typical railway traffic are given in Table 2.

3.2.3 *For Road Traffic*

The level of noise generated by road traffic depends upon such factors as the number of vehicles passing per hour, the type of traffic, the preponderance of heavy vehicles, average speed, gradient and smoothness of traffic flow. The smoothness of traffic flow also affects variability of the noise and is governed by such features as roundabouts and traffic lights, and the volume of traffic and pedestrian movement with their effects on stopping, starting, overtaking and honking. The level of traffic noise fluctuates continuously and the way it does, has a considerable effect on the nuisance caused. For assessing traffic noise, noise is measured in dBA. Because of the fluctuating nature of traffic, noise levels due to different volumes of traffic flow with a varying mix of vehicles are given in Table 3.

Table 1 Typical Noise Levels of Some Aircraft Types

(*Clause* 3.2.1)

Sl No. (1)	**Type of Aircraft** (2)	**Flyover Noise Levels at 450 m with Take-off Thrust** EPN dB (3)
i)	Boeing 737	107
ii)	Boeing 747 to 200	103
iii)	Airbus A300	101

Table 2 Typical Noise Levels of Railway Trains

(*Clause* 3.2.2)

Sl No. (1)	**Type of Train** (2)	**Noise Level at 30 m, Measured on the Side or in the Direction of Train** dBA (3)
i)	Steam train, 60 km/h	85
ii)	Diesel train, 60 km/h	83
iii)	Electric train, 60 km/h	77

Table 3 Typical Noise Levels Due to Free-Flowing Road Traffic

(*Clause* 3.2.3)

Sl No. (1)	**Type of Traffic** (2)	**L_{10} 30 m from Edge of Road** dBA (3)
i)	5 000 vehicles per 18 hour day (10 percent heavy vehicles), 50 kmph	65
ii)	10 000 vehicles per 18 hour day (20 percent heavy vehicles), 60 kmph	70
iii)	10 000 vehicles per 18 hour day (40 percent heavy vehicles), 80 kmph	75
iv)	20 000 vehicles per 18 hour day (40 percent heavy vehicles), 80 kmph	77

NOTE — The values are applicable to free flowing traffic without honking.

3.3 Outdoor Noise Regulations

The outdoor noise regulations in force from time to time shall be complied with (*see* Annex D).

3.4 Planning and Design

3.4.1 *For Air Traffic*

Near airports two sources of aircraft noise should be considered.

a) *Flyover Noise* — Flyover noise is that which occurs under flight paths close to airports and is the most serious and common problem. As the aircraft passes overhead the noise level at any particular location rises to a peak and then decreases; and

b) *Ground Noise* — The noise emitted by an aircraft during ground operations is less variable in direction than flyover noise, but is usually of a longer duration.

3.4.1.1 Aircraft noise may disturb sleep, rest and communication, and as such may be considered potentially harmful to health. It is important that no new development is carried out within areas where the expected noise levels will cause mental and physical fatigue or permanent loss of hearing. In case development in such areas is essential, adequate sound insulation shall be provided for the building.

3.4.1.2 As the problems caused by aircraft noise have become more acute, a number of methods have been devised for evaluating noise exposure in the vicinity of airports. They all combine many factors into a single number evaluation. A commonly used criterion is the noise exposure forecast (NEF). The NEF is used primarily to develop noise contours for areas around airports. It has been accepted generally that noise exposure forecast levels greater than NEF 40 are unacceptable to people while levels less than NEF 25 are normally acceptable. Levels between NEF 25 and 40 may lead to subjective complaints.

3.4.1.3 While it is theoretically possible to provide sufficient insulation to achieve an acceptable indoor noise environment in the area of very high outdoor noise, there is a level above which aircraft noise seriously affects living conditions no matter how much sound insulation has been applied to the dwelling unit. For this reason, it is recommended that no residential development be allowed beyond the NEF 35 level.

3.4.1.4 During summer months, the windows are normally kept open for adequate ventilation. In view of this, no matter how much sound insulation is provided for the building structure, the noise level inside the room can never be less than 10 dB below the outdoor noise level. For very critical buildings, such as buildings necessary for maintaining and supplementing the airport services, and for commercial development, such as hotels, it is possible to provide sealed windows and to centrally air-condition the entire building. However, it is not feasible for most of the residential developments in the country. In such cases proper zoning regulations and siting of vulnerable buildings away from aircraft noise are of vital importance.

3.4.2 *Rail Traffic*

This is a very serious source of noise in built-up areas, both by day and by night. Railway cuttings reduce the spread of noise, whereas embankments extend it. The elevated railway on viaducts or embankment is very common in built-up areas. The elevation increases exposure to noise but in addition the construction of the viaduct may affect the propagation of noise. In this respect solid embankments are preferable to built-up arches, which tend to act as sound boxes. Worst of all are the steel bridges, which greatly magnify the noise due to vibration. Uphill gradients are another feature tending to increase noise, especially of heavy goods trains.

3.4.2.1 Wherever possible, no residential or public building zone should abut onto railway lines, especially on the marshalling yards which is particularly objectionable because of the shrill, clanging and intermittent noise they generate, often at night. The appropriate zones alongside railway lines are industrial and commercial buildings other than office buildings. Where these precautions are not practicable and housing has to abut on to railway lines, every attempt may be made to house as few people as possible in the vicinity of the railway lines.

3.4.2.2 Underground transportation system can be a major cause of disturbance for the neighbouring community. Very high noise levels are propagated to long distances by the underground high speed railway, as a result of wheel-rail interaction. Both airborne noise and ground or structure-borne vibrations are potential sources of complaints. Noise control measures, therefore, need to be considered for the following:

a) In stations, where high noise levels are produced at the arrival and departure of trains;

b) In tunnels, during high speed train movement;

c) Where an underground rail transit system passes close to existing structures or high rise buildings, adequate attention should also be paid to the problem of ground vibration transmitted to the building, and proper isolation should be provided for critical areas;

d) Wherever elevated railway tracks are provided, adequate measures should be taken to avoid the spread of noise in the surrounding built up areas; and

e) In transit cars, where sound insulation is of vital importance to provide comfortable conditions for the commuters.

3.4.3 *Road Traffic*

3.4.3.1 Convoys of long-distance heavy trucks at night moving past through built-up areas cause serious noise complaints. On busy roads, the noise of continuous traffic may be a worse nuisance than that of railways. At least the same precautions may, therefore, be taken in the planning of dwellings in relation to arterial and trunk roads as with railways. Care may be taken that local housing roads do not provide short cuts for heavy traffic through residential areas. Hilly roads present the additional noise of gear changing. Trees with heavy foliage planted on both sides of carriageway help slightly to muffle the noise, provided the foliage extends for a considerable distance (30 m or above).

3.4.3.2 Road traffic may give rise to serious nuisance particularly on busy thoroughfares, between continuous high buildings in main streets, at the traffic lights, near bus stops, on steep slopes and in parking spaces and enclosed yards.

3.4.3.3 For zoning and planning of new buildings in urban areas, it is recommended that external L_{A10} be limited to a maximum of 70 dBA when the dwellings are proposed to have sealed windows and 60 dBA when the dwellings are proposed to have open windows. Indeed, it is desirable to confine major new residential development to locations subject to L_{A10} levels substantially lower than those given above.

It is recognized, however, that within the large urban areas, the use of sites where the external L_{A10} is greater than 60 dBA to 70 dBA cannot always be avoided. In that case it is suggested to utilize such design solutions as barrier blocks in order to reduce external L_{A10} noise levels to at least 60 dBA to 70 dBA at any point 1.0 m from any inward looking facade. When the orientation of site and the density of development are such that this cannot be fully achieved some form of dwelling insulation will have to be provided. It should be appreciated that where open windows are necessary, the occupants would have to put up with discomfort if the above conditions are not met.

3.4.3.4 Certain other methods can often be utilized to provide economical and effective protection from noise, as follows:

a) Methods should be adopted to improve the smoothness of flow and reduce number of stopping and starting. This leads to an improvement even, if it leads to increased flows. Flow linking of traffic lights, for example, may reduce noise nuisance;

b) Use of roads passing through residential areas should be prohibited to heavy commercial vehicles. An alternative would be to limit use by commercial vehicles to certain times of the day;

c) Use of honking shall be prohibited near sensitive buildings, such as hospitals and the like; and

d) Barriers shall be provided to shield sites from noise.

3.4.4 *Construction Noise*

3.4.4.1 Construction activities relating to building and infrastructure facilities cause noise disturbance to occupants in existing built facilities located around the site.

Construction noise involves both stationary and mobile sources. Common activities and sources of concern in case of construction noise include excavation and site clearing activities, blasting, piling, operation of batching plants, concrete mixers, pumping, running of diesel generators, drilling and chipping, loading/unloading activities, and truck and other vehicular movement.

The source noise intensity and spectrum is primarily characterized by the type of construction activity, equipment used, ground conditions and associated vehicular movement. Apart from the source characteristics, community noise impact is influenced by the time and sequence of construction related activities.

3.4.4.2 Noise control can be done at the source or in the noise propagation path. While it is preferable to adopt noise control at the source, it may not be practically possible to implement it for some of the construction equipment. Given the diversity of noise sources, mitigation strategies in case of construction noise have to be dealt with appropriately depending on the spectral characteristics of sources.

Source noise control strategies include providing acoustic enclosures for sources like diesel generators, choosing less noisy construction machinery and selecting alternative construction practices which involve lesser noise generation.

Noise control in the propagation paths primarily involves provision of noise barriers around the construction sites.

Positioning of major fixed construction equipment/installations such as batching plants and diesel generators have a significant impact on the noise spectrum and its impact. Also, time of operation and duration of noisy construction activities have significant impact on the resultant annoyance.

3.4.4.3 Due consideration for environmental noise regulation should be given while scheduling and sequencing noisy construction activities.

3.5 Zoning

The zoning of the different cities shall be done by the town planning authorities, taking into account besides other aspects, the noise levels from different occupancies. Wherever necessary, experts in the field may be consulted. For detailed information on noise reduction for town planning schemes, reference may be made to good practice [D-4(2)]. Details regarding the integration of noise barriers and noise abatement measures in zonal and urban planning are provided in Annex E.

3.6 Green Belts and Landscaping

Where relief from noise is to be provided by means of green belts these may be of considerable width and be landscaped. In case of railway tracks, a minimum distance of 50 m to 70 m may be provided between the buildings and the tracks. The extent of relief that may be derived from the above may be estimated only after considering other environmental factors. Only thick belts of planting (greater than 30 m) are of real value. Strong leafy trees may be planted to act as noise baffles. Shrubs or creepers may also be planted for additional protection between tree trunks; artificial mounds and banks should be formed where practicable. As little hard paving and as much grass as possible may be used. The creation of green belt is particularly advisable on the perimeter of aerodromes, along railway lines and arterial roads, through or past built-up areas and adjoining noisy industrial zones.

3.7 Highway Noise Barriers

Barriers are often the most effective means of reducing traffic noise around residential areas. They have the great advantage that they generally protect most or all of the site. In nearly all situations, a well-designed barrier of even a modest height (say 3 m) can at least ensure that all areas of open space are free from excessive noise levels.

There are two types of barriers that can be built to protect sites; one which are built solely for the purpose of reducing noise and the other which form part of the building complex (barrier blocks). Free standing walls and artificial mounds are typical examples of the first type while single and multi-storeyed utility buildings and garages are the most common form of the second.

Of the two types, laying out barrier blocks of a complex in an appropriate fashion is a better option because they are cheaper and also tend to form a more effective barrier overall because of their greater height and width. Barrier walls or mounds are more limited in their effect than barrier blocks for they protect little more than the area of the site close to ground level essentially because of the lack of height, as continuous walls much higher than 3m are often difficult to construct.

3.8 Use of Acoustic Barriers for Residential, Educational and Hospital Buildings along Highways on City Outskirts (Approximately 4 m to 5 m in Height)

3.8.1 Noise barriers can be constructed from a wide variety of materials and designs, but the basic purpose of all the noise barriers is to reduce noise levels at noise sensitive receptors.

3.8.2 A reduction in noise levels up to 10 dBA can be obtained at ground level in an area that is close behind a barrier of considerable height with sufficient insulation value and absorption value. Noise barriers are relatively ineffective at more than 250 m distance from the road.

3.8.3 Innovative combinations, including perforated metal sheeting on one side with the inclusion of absorptive material and a corrugated profile, should be utilized to enhance the insertion loss provided by the barrier.

3.8.4 Noise barriers may be constructed from a variety of materials, including but not limited to earth, concrete, masonry, metal and wood. Conventional concrete or masonry structures should be considered the best practicable option for highway noise barriers due to their long-term stability and maintenance-free service characteristics. Laminated glass requires frequent cleaning due to accumulation of dirt, while polycarbonate sheets become opalescent over time as it can absorb water. Plastics are prone to damage from fire and vandalism, and some, such as polyethylene, become brittle after prolonged exposure to sunlight.

3.8.5 The application of multiple-edge noise barriers, also known as profiled noise barriers, should be implemented in specific applications where enhanced acoustical performance is required to effectively screen a single noise source.

3.8.6 The noise barriers, although highly effective in reducing highway noise levels by significant extent, are subject to certain limitations. To ensure effectiveness, noise barriers shall be designed to be of sufficient height and length to block the view of the road. Barriers are less effective for homes on hillsides or buildings that rise above the barrier.

3.8.7 The design of noise barriers (*see* Annex F) should take into account the following factors:

a) Visual impact;

b) Maintenance requirements; and

c) Cost implications.

3.8.8 The noise barriers may also have negative impacts on the surrounding environment, such as blocking views or creating shadows, which should be taken into account during the design process.

3.8.9 Transparent barriers are associated with lower perceived loudness and noise annoyance compared to opaque barriers, contributing to improved user satisfaction.

3.8.10 The utilization of waste materials, such as plastic, rubber, and bottom ash, is recommended for achieving high noise attenuation with improved cost efficiency.

3.9 Special Problems Requiring Expert Advice

The purpose of noise control is to ensure that people are neither harmed nor disturbed by noise. In addition to provisions given in this Section, special advice may be required for more complex situations, such as those listed in Annex G.

4 PLANNING AND DESIGN AGAINST INDOOR NOISE

4.1 Acceptable Indoor Noise Levels in Buildings

The generally acceptable noise levels inside buildings are given in Table 4.

Table 4 Acceptable Indoor Noise Levels for Various Buildings

(*Clause* 4.1)

Sl No.	Location	Noise Level dBA
(1)	(2)	(3)
i)	Auditoria and concert halls	20 to 25
ii)	Radio and TV studios	20 to 25
iii)	Cinemas	25 to 30
iv)	Music rooms	25 to 30
v)	Hospitals	35 to 40
vi)	Apartments, hotels and homes	35 to 40
vii)	Conference rooms, small offices and libraries	35 to 40
viii)	Court rooms and class rooms	40 to 45
ix)	Large public offices, banks and stores	45 to 50
x)	Restaurants	50 to 55

4.2 Vulnerable Buildings

Some buildings or parts of buildings are especially vulnerable to noise, for example, recording and radio studios, hospitals and research laboratories. These should not be sited near loud noise sources. Most vulnerable buildings contain some areas which are themselves noisy and in such buildings, the less vulnerable elements should be planned to act as noise buffers. Most noisy buildings also contain quiet accommodation, which equally may be planned to act as a buffer between the noisy part of the building and adjoining vulnerable buildings.

4.3 The details of site and internal planning and insulation requirements are covered under individual occupancies (*see* **5** to **12**) as applicable to the respective character and sources of noise in different buildings.

4.3.1 *Equitable Inclusion of Hearing Impaired Persons in Public Place*s

People with hearing impairments have particular difficulty in making out sounds and words in noisy environments. Therefore, adequate sound insulation would minimise noise from both outside and inside the building. Also, low reverberation times are more suitable for hearing impaired persons and should thus be planned while designing the size and shape of the room.

Persons using hearing aids may require quiet areas with induction loops in very noisy information counters or where announcements are made. Induction loops may also be provided in all areas where there are verbal inputs provided, such as conference halls, auditoria, class rooms and cinema halls.

4.4 Sound Insulation of Non-Industrial Buildings by Constructional Measures

The desired (acceptable) noise levels and the recommended insulation values for the various areas may be achieved by providing sound insulation treatments by constructional measures. The details of the same are given in Annex H. The recommendations given in Annex H are applicable to non-industrial buildings like residences, educational buildings, hospitals and office buildings.

4.5 Special Problems Requiring Expert Advice — *See* **3.9** and Annex G.

5 RESIDENTIAL BUILDINGS

5.1 Sources of Noise Nuisance

5.1.1 *Outdoor Noise*

The main sources of outdoor noise in residential areas are traffic (aeroplane, railways, roadways), children playing, hawkers, services deliveries, road repairs, blaring loud-speakers, various types of moving machinery in the neighbourhood and building operations, and captive power generation machinery.

5.1.2 *Indoor Noise*

5.1.2.1 As far as indoor noises are concerned, conversation of the occupants, footsteps, banging of doors, shifting of the furniture, operation of the cistern and water closet, playing of radio, television, music system, cooling and ventilation machinery, etc, contribute most of the noise emanating from an adjacent room or an adjacent building. Noise conditions vary from time to time and noise which may not be objectionable during the day may assume annoying proportions in the silence of the night when quiet conditions are essential.

5.1.2.2 In the case of flats the main sources of noise are from other flats and from stairs, lifts and access balconies. Plumbing noise is another cause. In semi-detached buildings, outdoor noises from streets are noticed more than indoor noises from neighbours.

5.2 Recommendations

5.2.1 *Site Planning*

The most desirable method is to locate the residential buildings in a quiet area away from the noisy sources like the industrial areas, rail tracks, aerodromes, roads carrying heavy traffic, etc.

5.2.1.1 To minimize ground reflection, the dwellings should be surrounded by the maximum amount of planting and grassed areas and the minimum amount of hard surfacing. This applies particularly to high density areas. Where for maintenance reasons a large amount of hard paving is necessary, it should be broken up by areas of planting and grassing. Narrow hard paved courts should be avoided between adjacent tall buildings.

5.2.1.2 Roads within a residential area should be kept to a minimum both in width and length, and should be designed to discourage speeding. Area-wise planning, with zones from which vehicular traffic is altogether excluded will greatly help to reduce noise. Roads with through traffic should be excluded from residential areas, but where sites have to be developed adjacent to existing major roads the same principles should be observed in the siting of blocks as with railway lines as covered under **3.4.2.1**.

5.2.1.3 Play areas for older children should be sited as far away from dwellings as possible. Special care should be taken with old peoples' dwellings. They should not be placed immediately adjacent to service entries, play spaces, or to any entrances where children may tend to congregate.

5.2.2 *Internal Planning*

The orientation of buildings in a locality should be planned in such a way as to reduce the noise disturbance from neighbourhood areas. The non-critical areas, such as corridors, kitchens, bathrooms, elevators and service spaces may be located on the noisy side and the critical areas, such as bedrooms and living space, on the quiet side.

5.2.2.1 *Windows and doors*

Windows and doors should be kept away from the noisy side of the building as given below, wherever possible:

a) When windows of a building, particularly those of bedrooms in apartments or flats, face roads carrying heavy traffic or other noises where the external noise is of the order of 80 dBA to 90 dBA, the building should be located at a distance of about 30 m from the road, but a distance of 45 m or more, where possible, should be aimed at for greater relief from noise;

b) When the windows are at right angles to the direction of the above type of noise, the distance from the road should be arranged to be about 15 m to 25 m; and

c) In case another building, boundary wall or trees and plantations intervene between the road traffic and the house/flat further noise reduction is achieved and in such cases the above distances may be reduced suitably.

5.2.2.2 *Layout plans*

It is desirable that rooms adjoining party walls and above/below party floors should be of similar use. By this means, bedrooms are not exposed to noise from adjoining living rooms, and there is less risk of disturbance of sleep.

In semi-detached houses, the staircase, hall and kitchen should adjoin each other on each side of the party wall, thus providing a sound baffle between rooms requiring quiet conditions.

Bedrooms should not be planned alongside access balconies, and preferably not underneath them. Where the approach is by an internal corridor, a sound baffle may usefully be provided by arranging internal passages and bathrooms between the corridor and the living room or bedrooms.

Kitchens and water-closets should not be planned over living rooms and bedrooms, whether within the same dwelling or over other dwellings. Soil pipes should not be carried in ducts which adjoin living rooms or bedrooms unless the side of the duct next to these rooms is a solid wall containing no inspection openings. Refuse chutes should not be planned next to living rooms or bedrooms.

5.2.3 *Sound Insulation*

5.2.3.1 *Reduction of airborne noise*

The weighted sound reduction index, R_w, of partitions between individual rooms or apartments of a building unit shall be as given in Table 5. These values may, however, be suitably increased, where required, for critical areas.

Table 5 Sound Insulation between Individual Rooms (Airborne)

(*Clause* 5.2.3.1)

Sl No. (1)	Situation (2)	R_w dB (3)
i)	Between the living room in one house or flat and the living room and bed-rooms in another	50
ii)	Elsewhere between houses or flats	45
iii)	Between one room and another in the same house or flat	35

NOTES

1 Where communicating doors are provided, all doors should be so designed as to provide recommended insulation between the rooms.

2 There are cases when a set of houses or flats have to be built for the people who work at night and sleep during the day. It is desirable to consider the design of at least one such room in each of the houses or flats which will provide an insulation of about 45 dB in that room.

3 The insulation values referred to are applicable with doors and windows shut.

5.2.3.2 *Suppression of noise at the source itself*

All items of equipment that are potentially noisy should be selected with care. Water-closet cisterns should not be fixed on partitions next to bedrooms or living rooms. Plumbing pipes should be isolated from the structures. Lift motors should be mounted on resilient supports. Access doors from machine rooms to internal staircases should be well fitting and of solid construction. Special noise control measures may be required for electrical and mechanical services such as diesel generators, outdoor air conditioning units, cooling towers, etc.

5.2.3.3 *Reduction of airborne noise transmitted through the structure*

Reduction of airborne noise requires the use of rigid and massive walls, or acoustically designed dry walls, without any openings. Openings are the major cause of penetration of noise through a barrier. While designing it should be borne in mind that all components should provide a sound transmission compatible with that of the rest of the barrier so that an equivalent amount of sound energy is transmitted through each portion of the barrier.

Ventilating ducts or air transfer openings where provided should be designed to minimise transmission of noise. For this purpose, sound attenuating devices having necessary insertion loss may be installed in these openings.

All partitions should be sealed effectively where they butt against rest of the structure. All doors and windows should be properly gasketed where a high degree of sound insulation is desired.

5.2.3.4 *Reduction of structure-borne noise*

This requires the use of discontinuous or non-homogeneous materials in the construction of the structure.

5.2.3.5 *Reduction of impact noise*

The floor of a room immediately above the bed room or living room shall result in an impact sound pressure level ($L'_{\mathrm{nT,w}}$) not greater than 60 dB. Typically, a 150 mm thick concrete floor with thick carpet (12 mm) covering would satisfy this requirement.

5.2.3.6 Main staircases in blocks of flats are often highly reverberant. Some of the surfaces at least (for example, the soffits of stairs and landings) should be finished with sound absorbent materials, wherever required.

6 EDUCATIONAL BUILDINGS

6.1 Sources of Noise Nuisance

6.1.1 *Outdoor Noise*

The outdoor sources of noise produced on school premises, which cause disturbance within the school, include the noise arising from playgrounds, playing fields and open-air swimming pools. Though playgrounds are used mainly during break periods, they are also used for games and physical education at times when teaching is in progress in the adjoining class rooms.

6.1.2 *Indoor Noise*

Indoor sources of noise are as follows:

a) Singing, instrumental and reproduced music which may take place in class rooms and in dining and assembly halls particularly in primary schools. In secondary schools, specialized music rooms are generally provided;

b) Movement of chairs, desks and tables at the end of one period may disturb a class engaged in a lesson in a room below;

c) Shutting and openings of doors and windows which may occur at any time during teaching periods;

d) Audio-visual presentations in class rooms;

e) Wood and metal workshops, machine shops (engineering laboratories), typing rooms, etc that produce continuous or intermittent sound of considerable loudness;

f) Practical work carried out in general teaching areas;

g) Gymnasia and swimming pools;

h) School kitchens and dining spaces where food preparation and the handling of crockery and utensils persist for the greater part of the school day;

j) Corridors and other circulation spaces; and

k) Plumbing and mechanical services.

6.2 Recommendations

6.2.1 *Site Planning*

Where outdoor noise nuisance exists from local industry, busy roads, railway, airfields, sport grounds or other sources beyond the control of the school authority, school buildings should be sited as far away from the sources of noise, as possible.

6.2.1.1 Rooms should be planned in a manner so that the minimum amount of glazing is placed on the side facing the external noise.

6.2.1.2 Noises arising from the activities of a school and from the use of the buildings after school hours may constitute a nuisance to occupants of surrounding property; therefore, it is desirable to place playgrounds, workshops, swimming pools, music rooms, assembly halls and gymnasia as far away as possible from buildings which require a quiet environment.

6.2.2 *Internal Planning*

The following principles should be observed in the detailed planning of educational buildings:

a) *Grouping* — Noisy rooms should be separated from quiet ones, if possible. In general, it is desirable that rooms should be grouped together in accordance with the classification given in **6.2.4.1**;

b) *Windows and ventilators* — Windows of noisy and quiet rooms should not open on to the same courtyard or be near to one another. Skylights and ventilators over noisy rooms should be avoided, if they are likely to be a source of nuisance to adjacent upper floors;

c) *Doors* — Swing doors into rooms should only be used where no problem of sound transmission exists. Reduction of insulation between rooms and corridors due to doors shall be borne in mind. The type and method of fitting of doors is important and necessary care should be paid in this respect;

d) Sliding partitions, if used, should be acoustic operable partitions. Pass-through doors, if provided, should be acoustic doors with drop seals;

e) *Open planning and circulation areas* — Where open planning is used to permit spaces, such as assembly halls, dining rooms or entrance halls to be used in association with each other or for circulation, the degree of disturbance caused by interfering noise to teaching areas needs careful consideration; traffic through such areas should be strictly controlled; full use should be made of sound absorbent treatments to reduce the spread of noise from one space to another (*see* **6.2.3**);

   If rooms have large glazed panels or ventilation openings facing directly on the circulation areas, human traffic passing by the rooms should be controlled. Preferably baffled ventilation system or double windows should be used. Fan-lights over doors should be fixed and glazed; and

f) *Furniture* — In all educational buildings, regardless of the character of the floor finish, rubber buffers should be fitted to the legs of chairs and tables.

6.2.3 *Noise Reduction within Rooms*

Sound absorbent materials play a useful part in reducing the built-up or air-borne noise at source. In rooms, such as class-rooms, assembly halls and music rooms, a fairly short reverberation time under occupied conditions is one of the requirements of the acoustic design. The maximum reverberation times permissible for this purpose are usually short enough to give adequate noise control but in addition, the reverberation time should not be excessive under empty conditions, because noise may occur in these rooms with very few occupants. Table 6 gives the reverberation times often arranged in occupied rooms for acoustic reasons and the maximum times recommended in the empty rooms for noise reduction; the times given are for a frequency of 500 Hz, but they should not be greatly exceeded at any frequency. When rooms are used for a variety of purposes, the reverberation period appropriate to the major use should be adopted.

6.2.3.1 Special attention should be given to noise reduction in schools for the hearing impaired and schools for the visually impaired. Hearing impaired children are taught by means of hearing aids which cannot be used satisfactorily in high noise levels or in reverberant conditions. Visually impaired children depend on good hearing for understanding speech and for detecting changes in environment. In both these types of schools, noise levels should be kept low and reverberation times short. As an example, the reverberation times in empty class-rooms should not exceed 1.0 s in schools for the visually impaired or 0.5 s in schools for the hearing impaired.

Table 6 Reverberation Times in Schools

(*Clause* 6.2.3)

Sl No.	Room	Reverberation Time s Usual for Acoustic Reasons (Full)	 Maximum[1] for Noise Control (Empty)
(1)	(2)	(3)	(4)
i)	Assembly halls	1.0 to 1.25 according to size	1.5 to 2.0 according to volume of hall
ii)	Music teaching rooms	0.75 to 1.25	1.5
iii)	Gymnasia and indoor swimming pools	—	1.5
iv)	Dining rooms	—	1.25
v)	Classrooms	0.6	1.1
vi)	Headmasters room and staff rooms	0.5 to 1.00	1.0

[1] Shorter reverberation times are desirable for noise control, whenever possible.

6.2.4 *Sound Insulation*

6.2.4.1 *Airborne noise*

For purposes of sound insulation, rooms in educational buildings may be classified as follows:

Class A	Noise Producing	a) Workshops b) Kitchens c) Dining Rooms d) Gymnasiums e) Indoor Swimming Pools
Class B	Noise producing but needing quiet at times	a) Assembly halls b) Lecture halls c) Music rooms d) Typing rooms
Class C	Average	a) General class rooms b) Practical rooms c) Laboratories d) Offices
Class D	Rooms needing quiet	a) Libraries b) Studies
Class E	Rooms needing privacy	a) Medical rooms b) Staff rooms

6.2.4.2 The recommended minimum sound reduction (D_w) between rooms of the same class is as follows:

Class A — 25 dB
Class C or D — 35 dB
Class B or E — 45 dB

6.2.4.3 Where a room is likely to have a dual use, for example, a dining room to be used as a class-room, the higher sound insulation value should be used.

6.2.4.4 The recommended minimum sound reduction (D_w) between rooms in different classes is 45 dB subject to the following:

a) In schools or institutes with a technical bias where noisy activities, such as sheet metal work, plumbing and woodwork, are likely to be practised extensively in normal hours, workshops should be regarded as a special category requiring more than 45 dB isolation (D_w) from rooms of any other class;

b) Assembly halls and music rooms are special cases in that, as well as producing noise, they also require protection from it and may need more than 45 dB isolation (D_w) from rooms in Class A, if the latter are very noisy;

c) Circulation spaces may vary from a long and frequented corridor to a small private lobby and it is therefore difficult to give precise recommendations to cover them. For partitions between rooms in Class C and most corridors, an R_w of 35 dB for the partition itself is adequate. For partitions between rooms in other classes and corridors, more or less insulation may be necessary, depending upon the specific usage; and

d) The problem of noise in circulation areas is as a rule greatly mitigated in schools by the fact that classes usually change rooms together at regular times. In colleges and evening institutes, however, this is much less true and in such buildings particular attention should be paid to insulation between rooms and corridors.

6.2.4.5 *Impact noise*

In the case of schools, the concrete floor of the room immediately above the teaching rooms shall provide an impact sound pressure level, $L'_{nT,w}$ not greater than 70 dB. For example, a covering of 6 mm linoleum or cork tiles on concrete floor (hollow or solid) weighing not less than 220 kg/m^2 will usually meet the above requirement.

7 HOSPITAL BUILDINGS

7.1 General

Problems of noise control vary from hospital to hospital but the principles outlined below apply to all types. A quiet environment in hospitals is desirable for patients who are acutely ill. Staffs require quiet conditions for consultations and examinations and also in their living and sleeping quarters. There have been rapid rises in noise levels in hospitals due to the higher levels of outdoor noise, increasing use of mechanical and mobile equipment (some of which is now brought much nearer to the patient in order to facilitate nursing procedure) and the introduction of loudspeaker, radio, television and call systems. Noise control in the hospital is made much more difficult by the extensive use of hard washable surfaces which reflect and intensify the noise. In most hospitals, windows to the open air and fanlights to corridors are usually open for the purpose of ventilation, admitting noise from outside and allowing it to spread through the building.

7.2 Sources of Noise Nuisance

7.2.1 *Outdoor Noise*

This may be classified into two main categories:

a) Noise from sources outside the hospital premises, for example, traffic and industrial noises; and

b) Noise from sources outside the building but usually within the control of the hospital authority, for example, ambulances, motor-cars and service vehicles, fuel and stores deliveries, laundries, refuse collection, trucks and trolleys.

7.2.2 *Indoor Noise*

A hospital is a complex building with many services and the numerous internal sources of structure-borne and airborne noises are grouped into three main categories:

a) Noise consequent upon hospital routines. This category includes sources which transmit noise through both structure-borne and air-borne paths, many of which may be quite near to patients particularly those in wards, such as the following:
   1) Wheeled trolleys of various kinds, for food and medical supplies;
   2) Sterilizing equipment;
   3) Sluice room equipment including bedpan washers;
   4) Ward kitchen equipment;
   5) Footsteps;
   6) Doors banging;
   7) Handling of metal or glass equipment;
   8) Noises caused during maintenance and overhaul of engineering services; and
   9) Vacuum cleaners, mechanical polishers, etc.

b) Loudspeaker, radio or television, audible call system, telephone bells and buzzers, and other air-borne noises, such as loud conversation; and

c) Noises from fixed or mobile equipment and services not directly concerned with hospital routines. These include all the fixed services as given below:
   1) Plumbing and sanitary fittings;
   2) Steam, hot and cold water and central heating pipes;
   3) Ventilation shafts and ducts;
   4) Fans
   5) Boilers;
   6) Pumps;
   7) Air compressors;
   8) Pneumatic tubes;
   9) Electrical and mechanical motors and equipment;
   10) Lifts;
   11) Laundry equipment; and
   12) Main kitchen equipment (refrigerators, mixers, steam boilers, etc).

7.3 Recommendations

7.3.1 *Site Planning*

Hospital sites with their high degree of sensitivity to outside noise should be as far away from outside sources as may be compatible with other considerations, such as accessibility and availability of services. The building should be so arranged on the site that sensitive areas like wards, consulting and treatment rooms, operating theatres and staff bedrooms are placed away from outdoor sources of noise, if possible, with their windows overlooking areas of acoustic shadow.

7.3.2 *Detailed Planning*

There is a very large number of unit and room classification in hospital design and in planning the units in relation to each other and to the common services, (such as X-ray departments, operating theatre suits and main kitchens), noise reduction in the sensitive areas should be weighed carefully against other design factors. Special care in overall planning and internal planning against noise is required in the planning within the building of units which are themselves potential noise sources, for example, children's wards and outpatients' departments, parts of which require protection against noise.

7.3.2.1 Unloading bays, refuse disposal areas, boiler houses, workshops and laundries are examples of service units which should be as far from sensitive areas as possible.

7.3.2.2 The kitchen is a constant source of both air-borne and structure-borne noise and should preferably be in a separate building away from or screened from the sensitive areas. If this is not possible and the main kitchens shall form part of a multi-storey building, noise control is easier if they are placed below and not above the wards and other sensitive rooms so as to facilitate the insulation of the equipment and machinery in order to reduce the transmission of structure-borne noise to a minimum.

7.3.2.3 In ward units, the kitchens, sluice rooms, utility rooms, sterilizing rooms and other ancillary rooms, need to be placed quite near to the beds if they are to fulfil their purposes, which are all sources of noise. Some form of noise baffling between open wards and rooms of this kind will be needed.

7.3.3 *Reduction of Noise at Source*

In view of the difficulty of suppressing noise in hospital buildings, it is important to eliminate noise at its source, wherever possible.

7.3.3.1 *Use of resilient material*

Mats of rubber or other resilient material on draining boards and rubber-shod equipment will greatly reduce noise from utility rooms, sluice rooms and ward kitchens. The use of plastics or other resilient materials for sinks, draining boards, utensils and bowls would also reduce the noise. Many items of equipment especially mobile equipment, such as trolleys, beds and movable furniture, may be silenced by means of rubber-tyred wheels and rubber bumper and the provision of resilient floor finishes (*see* **7.3.4.1**). The latter also reduces footstep noise. Silent type curtain rails, rings and runners should be used. Lift gates and doors should be fitted with buffers and silent closing gear. Fans and other machinery should be mounted on suitable resilient mountings to prevent the spread of noise through the structure.

7.3.3.2 *Other measures*

Noise from water or heating pipes may be reduced by installing systems which operate at comparatively low pressure and velocities. Silencing pipes and specially designed flushing action reduce water closet noise at source and make structural measures easier to apply. The ventilation system should be designed so as not to create a noise problem. Silent closers should be fitted to doors.

7.3.4 *Reduction of Noise by Structural Means*

7.3.4.1 *Insulation*

Since the various departments or units may be planned in many ways, only general guidance on the insulation values for walls and partitions is as given below:

a) It is recommended that walls or partitions between rooms should normally have an R_w of at least 45 dB. Higher values of R_w of at least 50 dB are necessary where a noisy room is adjacent to one requiring quiet conditions. Doors should be solid with close fitting in the frames;

b) There is little insulation value in double swing doors and where these are fitted to a noisy room the opening should be planned so that it is screened from areas requiring quiet by a baffle lobby lined with absorbent material. Very high insulation values may be necessary in special cases and exceptional measures may be required;

c) Solid floors with floating finishes and resilient surfaces are necessary particularly between wards and other parts of the building. Ordinary timber board on joist floors should never be used; and

d) Conduits, ventilation ducts, chases etc, should be constructed so as not to form easy by-pass for disseminating noise about the building, and should be provided with sufficient sound insulation. Pipe ducts should be completely sealed around the pipes where they pass through walls or floors. Ducts carrying waste or water pipes should be lined with sound insulating material to prevent noise from the pipes passing through duct walls into the rooms through which they pass.

7.3.4.2 *Absorption*

Most surfaces in hospitals should be easily cleanable, so as to prevent the build-up of bacteria which may cause cross-infection. Many sound absorbent materials of a soft nature and difficult to clean are unsuitable for use in some hospital areas and lose much of their effectiveness, if painted for hygienic reasons.

Some porous materials with very thin non-porous coverings (like mineral wool covered with thin plastic sheets) have good sound absorption and when covered with a perforated sheet metal facing can be used in most areas requiring a washable acoustical treatment. In noisy areas, such as corridors and waiting rooms, however, a wider choice of absorbents is available.

In the ward, bed curtains, window curtain, etc, add to the absorbent properties of the room and help reduce reverberation in otherwise hard surfaced surroundings.

7.3.5 Sensitive areas such as operation theatres, doctors' consultation rooms, intensive care units (ICU) require special consideration against noise control. Apart from outdoor noise, a common problem is the transmission of sound between the consulting room and the waiting room. To ensure silence, a sound isolation D_w of 45 dBA, between the rooms shall be provided. If the doors are directly connected by a single communicating door it will not be possible to achieve these values of isolation D_w. To obtain 40 dBA to 45 dBA insulation between communicating rooms, it is necessary to provide two doors separated by an air gap, such as a lobby or corridor.

8 OFFICE BUILDINGS

8.1 General

Modern office buildings are often noisier than older buildings due to the use of thinner and more rigid forms of construction, harder finishes, more austere furnishings and use of business machines.

8.2 Sources of Noise Nuisance

8.2.1 *Indoor Noise*

Main sources of indoor noise include the following:

a) Office machines, such as keyboards, typewriters, and printers;

b) Telephonic conversation;

c) Noise from the public admitted to the building;

d) Footsteps, voices and slamming of doors in circulation spaces, lift doors and gates;

e) Sound reproduction in staff training rooms, conference rooms and recreation rooms, etc;

f) Handling of crockery and utensils in canteens and kitchens; and

g) HVAC and lift machinery.

8.3 Recommendations

8.3.1 *Site Planning*

Rooms demanding quiet conditions should be placed on the quiet side of the site. Even on quiet thoroughfares, these rooms should also not be planned at street level. They should also not be planned on enclosed yards used for parking of cars, scooters, etc. Where, however, the problems cannot be resolved by planning, the provision of double windows may be necessary.

8.3.2 *Detailed Planning*

8.3.2.1 *Noise reduction within rooms*

The reverberation time should not exceed 1.0 s in all general offices of the types listed in **8.3.2.2** to **8.3.2.6**. In small private offices, the reverberation time should not exceed 0.75 s, in very large offices the reverberation time may be increased to 1.0 s. For canteens, the recommended maximum reverberation time is 1.0 s.

NOTE — All reverberation times are specified for a frequency of 500 Hz.

8.3.2.2 *Large general offices*

The grouping of departments and machines together in one room should be avoided, wherever possible. Where supervision is necessary the provision of glazed screens carried up to the ceiling should be considered. If it is essential to the work of an office for machine operators and clerks to work side by side in the same room, the machines should be enclosed by panels or low screens lined with absorbent material and the ceiling should be sound absorbent. In addition, the machines should be as quiet as possible in operation and mounted on suitable resilient mountings.

NOTE — A quiet area should be planned for prolonged telephonic conversation.

8.3.2.3 *Light weight construction*

Modern construction methods and economy dictate the use of light weight construction for many office buildings. While the lightweight materials lead to fast fabrication and erection and also effect considerable economy in the building structure, they may lead to tremendous sound insulation problems between adjacent offices and areas. Light weight construction is also frequently employed for the subdivision of large space into executive cabins and secretarial areas. Where such construction is considered desirable, efforts should be made to provide a double-skin panel. The panels should be isolated from each other as far as possible either by the use of separate framing or by the use of elastic discontinuities in the construction, and a sound absorbing material may be introduced in the air cavity between the panel. The partitions should be full height up to the bottom of the roof above and any openings required for air movement should be provided with sound attenuators compatible with the rest of the partition.

When light weight floors are provided in multi-use buildings, adequate attention should be paid to the question of air-borne and structure-borne noise transmission from the upper floors to the floors below. For effective reduction of air-borne noise, a double panel hollow floor construction may be employed with some heavy sound damping material introduced between the panels and the panel isolated from each other. The sound damping material could be sand, mineral wool, etc. In case impact noise isolation is also required, the upper panel should be effectively isolated from the rest of the floors and building structure. The choice of the isolation layer would of course depend upon the lowest frequency of interest.

Another point to be kept in mind when going in for light weight construction is to ensure that the light weight panels are not in resonance with the natural frequencies of any mechanical equipment installed inside the building. Lightweight materials have high natural frequencies well within the audio range and may resonate or vibrate due to an applied vibratory force. This vibratory force is caused by mechanical equipment, road traffic, rail traffic, etc. Special measures also need to be taken to isolate either the source or the building so as to reduce the amount of vibration transmitted to the building structure.

8.3.2.4 *Open plan offices*

A new concept in office planning is the use of open plan offices. Large open floor spaces are converted into an office area with senior executives, junior executives and secretarial staff all seated within the same area without the use of any partitions or walls. While this method of planning is appreciated, it leads to a problem of inadequate acoustical privacy between adjacent work spaces. Speech privacy in open plan offices is defined by the speech interference level of intruding noise. Speech privacy between two adjacent rooms or spaces is, therefore, a function of two key parameters; noise reduction of the intervening partition and background noise levels.

Special design measures are, therefore, required to reduce the level of intruding sounds at work places to acceptable low value so that people are not disturbed and adequate privacy is maintained. Some special measures which might be considered for such open plan offices are the use of an acoustical ceiling together with partial height barriers between work spaces, all designed to provide adequate privacy between adjacent work spaces. In addition, use may have to be made of an electronic background masking noise system which provides a constant level of a generally acceptable background noise in the entire office area. The masking noise system is a very useful concept in open plan office design because by raising the background level at every workplace, intruding noises are made less disturbing. A background music system cannot serve as a noise masking system because the music does not have a constant spectrum or sound level. In fact, the background noise masking system shall be introduced gradually without the knowledge of employees. The air-conditioning system can also be used to generate background masking noise if the noise level from the fans, ducts and grills is suitably tailored to generate the desired frequency spectrum. However, it is not simple to predict the noise level of air-conditioning components accurately. On the other hand, the electronic system enables both the level and the spectrum of the background noise to be accurately adjusted to suit individual job requirements.

8.3.2.4.1 In addition to comfort, speech privacy and sound insulation play a critical role in preventing data theft or leakage of sensitive information. Improper acoustical design can lead to unauthorized access to confidential conversations, especially in organizations handling financial data, legal matters or classified projects. Speech leakage across open-plan offices occurs when sound waves are transmitted either directly or indirectly through reflective surfaces, openings, or poorly isolated barriers. The sound control measures given below should be employed to mitigate this risk and ensure information security.

a) *Control of direct and indirect sound paths*

Partial-height barriers alone are often insufficient to block sound transmission, as sound can travel over the barriers and reflect off ceilings, windows, or walls. To prevent sound leakage, barriers between workstations should be designed with sound-absorptive materials to reduce reflections. In high-security zones, barriers should ideally reach ceiling height to limit the direct path of sound waves. Additional sealing measures, such as acoustic baffles or sound-blocking panels near ceilings, can help to further contain sound within specific zones;

b) *Masking noise for speech concealment*

Even with physical barriers in place, speech masking systems play a crucial role in enhancing speech privacy by rendering conversations unintelligible beyond a specific range. These systems should generate uniform background noise across the entire office, tuned to a frequency spectrum that aligns with typical human speech, thereby reducing the clarity of overheard conversations. Care should be taken to avoid variations in masking noise across different zones, as uneven noise profiles can inadvertently create ‘quiet spots’ where speech becomes more easily discernible;

c) *Acoustic zoning for sensitive areas*

Workspaces dealing with confidential or sensitive data should be zoned acoustically to limit sound propagation beyond their intended boundaries. These zones can be created through sound-dampening partitions, low-noise areas, and placement of workstations away from high-traffic zones. Additionally, team discussions or meetings involving classified topics should occur in acoustically treated rooms with sealed doors and walls to avoid inadvertent sound leakage into adjacent spaces;

d) *Control of reflective surfaces*

Reflective surfaces such as glass partitions, metal ceilings, and large windows can amplify sound reflections, making speech intelligible at greater distances. Such surfaces shall be treated with sound-absorbing films, acoustic panels, or curtains to minimize reflection. Flooring materials such as carpets or rugs may also be used to reduce the transmission of footfall noise, which could otherwise interfere with the effectiveness of masking systems; and

e) *Air-conditioning systems and noise control*

Although air-conditioning systems can generate a degree of background noise, it is critical to ensure that the noise they produce remains predictable and stable. Inconsistent air-conditioning noise can undermine masking systems, creating intermittent quiet periods that increase the risk of speech leakage. Ducts, grilles, and vents shall be designed and placed carefully to maintain a uniform noise level throughout the office area, ensuring no unintended listening opportunities arise.

8.3.2.5 *Office equipment rooms*

It is important that machines like keyboards, typewriters, printers, etc, should be quiet in themselves and also be fitted with resilient pads, to prevent the floors or tables on which they stand from acting as large radiating panels. It is desirable to locate machines further apart and to apply sound absorbent treatment to the ceiling.

8.3.2.6 *Banking halls*

If banking halls are large and lofty, noise nuisance tends to be aggravated. It is advisable to avoid high reflective ceilings. The worst effects may be reduced by segregating the noise from the quiet operations and screening one from the other and by applying sound absorbent materials to the surfaces of the ceilings, screens and nearby walls. Resilient flooring is also recommended.

8.3.2.7 *Public offices and waiting spaces*

Noise nuisance may be minimised by the provision of resilient flooring, sound absorbent ceilings and heavy full height screens between the public space and the clerical office.

8.3.2.8 *Canteens*

The provision of a sound absorbent ceiling, resilient flooring and the use of plastics/wooden trays and tables with quiet tops are recommended.

8.3.2.9 *Circulation spaces*

The effective length of long corridors should be limited by providing swing doors at intervals. Hard floor finishes and board and batten floors in corridors should be avoided. The provision of a sound absorbent ceiling in corridors is recommended. Floor ducts should be planned on one side of corridors.

The noise from slamming of doors may be reduced by fitting automatic quiet action type door closers. Door buffers are useful but may reduce insulation of air-borne sound due to the inevitable gaps between buffers. Continuous soft, resilient strip let into the door frames is preferable. The use of quiet action door latches is recommended.

Staircases and lifts should be isolated from quiet rooms and should have silent type doors.

8.3.3 *Requirement of Sound Insulation*

With open window (single or double) the sound reduction (D_w) will be 5 dB to 10 dB, and with sealed double windows it will be 40 dB to 45 dB. Intermediate values are obtainable with closed openable windows (single or double) but only, of course, at such times as ventilation may be dispensed with. Having to choose between ventilation and noise exclusion is a serious handicap to efficient working in offices. In large office blocks on noisy sites, consideration should be given to the provision of sealed double windows and mechanical ventilation at least in the offices on the sides of the building exposed to noise.

8.3.3.1 The insulation necessary between adjoining rooms, both horizontally and vertically, depends upon the amount of noise created within the rooms, the amount of intruding noise and whether it is important that conversation should not be overheard between rooms. Generally, a sound isolation value (D_w) of 40 dB between one room and another room in office is recommended.

8.3.3.2 The following list may be considered as broad classification of noise producing rooms and rooms requiring quiet though many offices fall into both categories. Where rooms in opposing categories are planned adjacent to each other, a sound reduction (D_w) of at least 45 dB should be provided between them.

Sl No. (1)	*Noise Producing Rooms* (2)
i)	Entrance and reception halls, staircases and corridors used by the public
ii)	Lifts and lift halls

Sl No. (1)	*Noise Producing Rooms* (2)
iii)	Motor and plant rooms
iv)	Lavatories
v)	Public offices
vi)	Canteen and kitchens
vii)	Office machine rooms and typing pools
viii)	Recreation rooms
ix)	Large general offices
x)	Cinemas and projection rooms

Sl No. (1)	*Rooms Requiring Quiet Conditions* (2)
i)	Executive's rooms, Conference rooms and Board rooms
ii)	Interview rooms
iii)	Offices for one or two persons
iv)	Medical officer's rooms
v)	Sick rooms
vi)	Rest rooms
vii)	Libraries
viii)	Telephoning rooms

The recommended sound reductions (D_w) are as follows:

a)	Rooms requiring quiet (as listed above) on a quiet site where privacy is required	45 dB
b)	Rooms requiring quiet (as listed above) but on a noisy site or where a lower degree of privacy is tolerable	40 dB
c)	Clerical offices in which noise does not constitute a major nuisance	30 dB

8.3.3.3 It is recommended that the minimum sound reduction index, R_w for floors should be 45 dB, and the floors should have a resilient finish.

9 HOTELS AND HOSTELS

9.1 General

Hotels and hostels are primarily used as dwelling units, and hotels also provide for public entertainment. The most serious risk, of course, is disturbance to sleep, and adequate care, therefore, needs to be taken to protect the occupants from being disturbed by outdoor and indoor noise.

9.1.1 *Outdoor Noise*

Hotels near railway stations, airports, highways and those situated in highly urbanized areas are especially vulnerable to outdoor noise. The outdoor noise in many of the areas is of a high level even late at night and in the early morning. The noise could also be due to other types of activities such as building construction activity (pile driving, concrete mixing, etc) and various types of portable utility equipment, such as compressors or generators.

9.1.2 *Indoor Noise*

Insofar as indoor noise is concerned, the noise could be due to the occupants themselves, which is transmitted from one room to the other. It could also be due to public functions and late night use of restaurants located in the hotel, as also due to miscellaneous utility equipment installed for providing and maintaining the services in the hotel, such as air-conditioning equipment, pumping equipment, power laundry and kitchen. Sometimes hotels equipped with standby generators are a potential source of noise. Another source which could lead to disturbance to the occupants is the plumbing system.

9.2 Recommendations

9.2.1 *Site Planning*

While it is desirable to locate the hotel, or hostel away from an area where there is a high ambient noise level, many a time these have to be located in noisy areas for public convenience. Hotels near airports and railway stations are becoming popular because they are convenient for passengers in transit. Hotels located in the commercial areas of a city are also a commercially viable proposition and many a time this factor outweighs the other problems associated with such a location. When a reasonably quiet location is not possible, it is desirable that adequate measures be considered to provide a comfortable acoustical environment for the occupants.

9.2.2 *Internal Planning*

Where a hotel is located in a noisy environment, the provision of sealed windows (single or double) and provision of an air conditioning system is desirable for rooms exposed to noise. The requirements for the windows would of course depend upon the level and character of noise in the area.

The general recommendations for satisfactory acoustical design of hotels and hostels are given in **9.2.2.1** to **9.2.2.7**.

9.2.2.1 Hotels of all classes should by necessity provide good protection against indoor noise. Since hotels can be considered as flats, the standards of protection recommended for flats are also applicable to hotels. Partition between guest rooms and between rooms, corridors and floors should not be less than 230 mm brick wall plastered or equivalent (R_w = 50 dB). The floors should have proper impact insulation. Special attention should be paid to built-in wall cupboards as these are potential areas of sound leakage. These will not serve as sound insulating partitions and may not be relied upon to increase the insulation value of partitions against which they may be built. In fact, partitions between adjoining rooms should be continuous behind the cupboards. Use of silent type door gear and cupboard catches is also highly desirable.

9.2.2.2 Door openings on opposite sides of corridors should be staggered and doors shall be provided with gaskets on head, sides and threshold. As an alternative to thresholds, drop seals may be provided. Inter-communicating doors should be double doors, fully gasketed. Doors should also have quiet action latches. Whenever possible, rooms should be entered through a baffle lobby. Wherever possible, corridor walls should not have ventilators unless they are double glazed and non-openable.

9.2.2.3 Corridors and staircases may have resilient floor coverings and sound absorbent ceilings are desirable unless the corridor is fully carpeted. Staircases and lift wells may be cut off from corridors by means of swing doors and, if possible, isolated from guest rooms by linen stores or similar rooms. Room service pantries on floors can also be a source of noise and may be separated from corridors by baffle lobbies, unless the rooms themselves have baffle lobbies.

9.2.2.4 Except within the same suite, bathrooms should not be planned next to bedrooms. Where this is unavoidable, internal pipe shafts with heavy walls, unpierced on bedrooms' side may be used as means of separation. It is important to choose quiet type of sanitary fittings and to design the plumbing system so as not to create noise, that is, by avoiding sharp bends, restrictions of flow, quick-action valves that might cause water hammer, etc.

9.2.2.5 Air-conditioning system should be quiet in operation. Care should also be taken that the air-conditioning ducts do not lead to a cross-talk problem between rooms. Suitable acoustical lining should be provided in the ducts consistent with the fire safety requirements of the buildings.

9.2.2.6 Large hotels often have banquet halls and conference halls which are separately hired out for public and private functions. Late night restaurants and night clubs are also popular and functions in all these areas may go on well into the night. It is therefore essential that these rooms be effectively isolated from bedrooms and effective insulation from all possible noise sources is considered. Here it is not only necessary to consider the air-borne sound insulation but it is also necessary to consider the question of structure-borne and impact noise transmitted from areas where there might be dancing late into the night. Floating floors may be considered for structure borne sound isolation for dance floors and loudspeakers.

9.2.2.7 While most of the noise problems encountered in hotels are applicable to hostels, the latter are normally of more economical construction and, therefore, cannot cater for special sound insulation provisions. However, as far as possible, precautions should be taken to provide comfortable conditions in hostel rooms. This is especially true for student hostels where each room is also a living room. Students might play music or have loud discussions late into the night.

This may disturb sleep or study of other students. Proper precautions should, therefore, be taken to provide satisfactory conditions.

10 INDUSTRIAL BUILDINGS

10.1 General

Industrial buildings are primarily producers rather than receivers of noise. The level of industrial noise commonly exceeds that from any other source with the exception of aircraft. As compared with traffic noise, its effects are less widespread but it is often more annoying in character.

10.1.1 Many industrial noises contain very strong high frequency whines, screeches and clatter **-** these components are relatively more attenuated by passage through the air and by the insulation of light structure than are lower frequencies.

10.1.2 Intermittent noises are either isolated explosions or reports, or noises of a periodic nature, such as those of pressure relief valves of blow off, or the noises of work occurring at random intervals, for example, hammering, grinding and sawing operations; the latter class may be especially irritating because of high frequency components.

10.2 Sources of Industrial Noise

10.2.1 Noises in industrial buildings are mainly of indoor origin. Noise in factories and workshops is generally caused by machine tools and by operations involved in making and handling the product and they are classified into the following groups, depending upon how the noise energy is generated.

10.2.1.1 *Impact*

Noise caused by impact is the most intense and widespread of all industrial noises. It is normally coupled with resonant response of the structural members connected to the impacting surface. Common sources of this type of noise are forging, riveting, chipping, pressing, tumbling, cutting, weaving, etc. Intense impact noise may also be produced during handling of materials as in the case of sheared steel plates falling one over another in collecting trays in a steel factory. Impact noise is usually intermittent and impulsive in character, but it may also be continuous as in the case of tumbling.

10.2.1.2 *Friction*

Most of the noise due to friction is produced in such processes as sawing, grinding and sanding. Friction also occurs at the cutting edge on lathes and other machine tools and in brakes and from bearings. The spectrum of frictional noise often predominates in high frequency and is very unpleasant in character.

10.2.1.3 *Rotation and reciprocation*

A rotating or reciprocating machine generates noise due to unbalanced forces and/or pressure fluctuations in the fluids inside the machines. In many cases, the moving surfaces radiate noise directly and in other cases, the pressure fluctuations are transmitted to the outer casings of the machine from where they are radiated as noise. Interaction of rotating component with the fluid stream can also give rise to pure tone components, such as the whine in a turbine. Since most machine casings have radiation efficiencies of unity in the higher frequency range, the amount of sound radiated is often substantial.

10.2.1.4 *Air turbulence*

Noise may be generated by rapid variation in air pressure caused by turbulence from high velocity air, steam or gases. Common examples are the exhaust noise from pneumatic tools and air jets. The noise is intense, and broad based in character and the frequency criteria depends on the size of the jet. The intensity increases rapidly with the velocity of the air stream.

10.2.1.5 *Noises with pure tone components*

Whining noise from turbines and humming noise from transformers come under this group.

10.3 Noise Criteria

10.3.1 *Hearing Damage – Risk Criteria*

Continuous exposure to high noise levels may result in permanent noise induced hearing loss in the course of time. Damage-risk criteria specify the maximum levels and duration of noise exposure that may be considered safe. Generally accepted damage-risk criteria for exposure to continuous, steady broad band noise are shown in Table 7. Whenever the sound levels at the worker’s position in a factory exceed the levels and the duration suggested, feasible engineering controls shall be utilized to reduce the sound to the limits shown. If such controls fail to reduce sound levels within the levels of Table 7, personal hearing protection equipment shall be provided and used to reduce sound levels within the level shown.

Table 7 Permissible Exposure Limits for Steady-State Noise

(*Clause* 10.3.1)

Sl No. (1)	**Sound Level (Slow Response)** dBA (2)	**Time Permitted, *T*** h : min (3)
i)	85	16 : 00
ii)	86	13 : 56
iii)	87	12 : 08
iv)	88	10 : 34
v)	89	9 : 11
vi)	90	8 : 00
vii)	91	6 : 58
viii)	92	6 : 04
ix)	93	5 : 17
x)	94	4 : 36
xi)	95	4 : 00
xii)	96	3 : 29
xiii)	97	3 : 02

Table 7 (*Concluded*)

Sl No. (1)	Sound Level (Slow Response) dBA (2)	Time Permitted, *T* h : min (3)
xiv)	98	2 : 50
xv)	99	2 : 15
xvi)	100	2 : 00
xvii)	101	1 : 44
xviii)	102	1 : 31
xix)	103	1 : 19
xx)	104	1 : 09
xxi)	105	1 : 00
xxii)	106	0 : 52
xxiii)	107	0 : 46
xxiv)	108	0 : 40
xxv)	109	0 : 34
xxvi)	110	0 : 30
xxvii)	111	0 : 26
xxviii)	112	0 : 23
xxix)	113	0 : 20
xxx)	114	0 : 17
xxxi)	115	0 : 15

NOTES

1 Where the table does not reflect the actual exposure times and levels, the permissible exposure to continuous noise at a single level shall not exceed the time *T* (in h) computed from the formula:

$$T = \frac{16}{2^{[0.2(L-85)]}}$$

where

L = work place sound level measured in dBA.

2 When the daily noise exposure is composed of two or more periods of different levels, their combined effect should be considered rather than the individual effect of each. The combined levels may not exceed a daily noise dose, D of unity where D is computed from the formula:

$$D = \frac{C_1}{T_1} + \frac{C_2}{T_2} + \ldots\ldots + \frac{C_n}{T_n}$$

where, C_1, C_2 ………… C_n indicate the total duration of exposure (in hour) at a given steady-state noise level; and T_1, T_2,…,T_n are the noise exposure limits (in hour for the respective levels given in the table or computed by the equation in Note 1). Exposure to continuous noise shall not exceed 115 dBA regardless of any value computed by the formula for the daily noise dose, *D* or by the equation in Note 2.

10.3.2 *Interference with Communication*

In factories where audible warning signals are used, or where an operator follows the operation of his machine by ear, the background noise should not be so loud as to mask the signal or desired sound (the information sound) to be heard. Noise may be the cause of accidents by hindering communication or by masking warning signals.

10.4 Methods of Reducing Noise

10.4.1 *Noise Control by Location*

Machines, processes and work areas which are approximately equally noisy should be located together as far as possible. Areas that are particularly noisy should be segregated from quiet areas by buffer zones that produce and may tolerate intermediate noise levels.

10.4.2 *Noise Reduction by Layout*

The office space in a factory should be as far as possible located preferably in a separate building. This building should not have a wall common with the production area. Where a common wall is unavoidable, it should be heavy with few connecting doors and no permanent openings.

10.4.3 *Noise Reduction at Source*

10.4.3.1 *Selection of machinery*

Noise should be reduced as near the source as possible. While the operational processes in a factory may be fixed and may have no quieter alternative, careful selection of the machine tools and equipment to be used may considerably help attaining lower noise levels in the machine shop.

10.4.3.2 *Reducing noise from potential sources*

Impact that is not essential to a process should be quietened. Noise from handling and dropping of materials on hard surface may be reduced by using soft resilient materials on containers, fixing rubber tyres on trucks, trolleys, etc. Machine noise may be kept to a minimum by proper maintenance. Proper lubrication reduces noise by friction conveyors, rollers, etc.

10.4.3.3 The noise from the radiating surfaces may be reduced by reducing the radiating area. For example, if the area is halved, the noise intensity will be reduced by 3 dB and at low frequencies the reduction will be much greater.

10.4.3.4 Supporting structures for vibrating machines and other equipment should be frames rather than cabinets or sheeted enclosures. If an enclosure is used, precaution should be taken to isolate it and line it on the inside with sound-absorbent material. Penetration through the enclosure should be adequately sealed. The noise radiated by machinery guards can be minimised by making them of perforated sheet or of wire mesh.

10.4.3.5 *Reducing transmission of mechanical vibration*

A vibrating source does not usually contain a large radiating surface but the vibration is conducted along mechanically rigid paths to surfaces that can act as effective radiator. If the rigid connecting paths are interrupted by resilient materials, the transmission of vibration and consequently the noise radiated may be greatly reduced. The reduction depends on the ratio of the driving (forcing) frequency of the source to the natural frequency of the resilient system. The natural frequency may be determined from static deflection under actual load as given in Fig. 1. The higher the ratio between the two frequencies, the lesser is the transmissibility, which is defined as the ratio of the force transmitted through the resilient isolator to the exciting force applied to it. Transmissibility and the equivalent noise reduction for various frequency ratios are given in Fig. 2. For satisfactory operation, a ratio of 3 : 1 or more between the driving and natural frequencies is recommended.

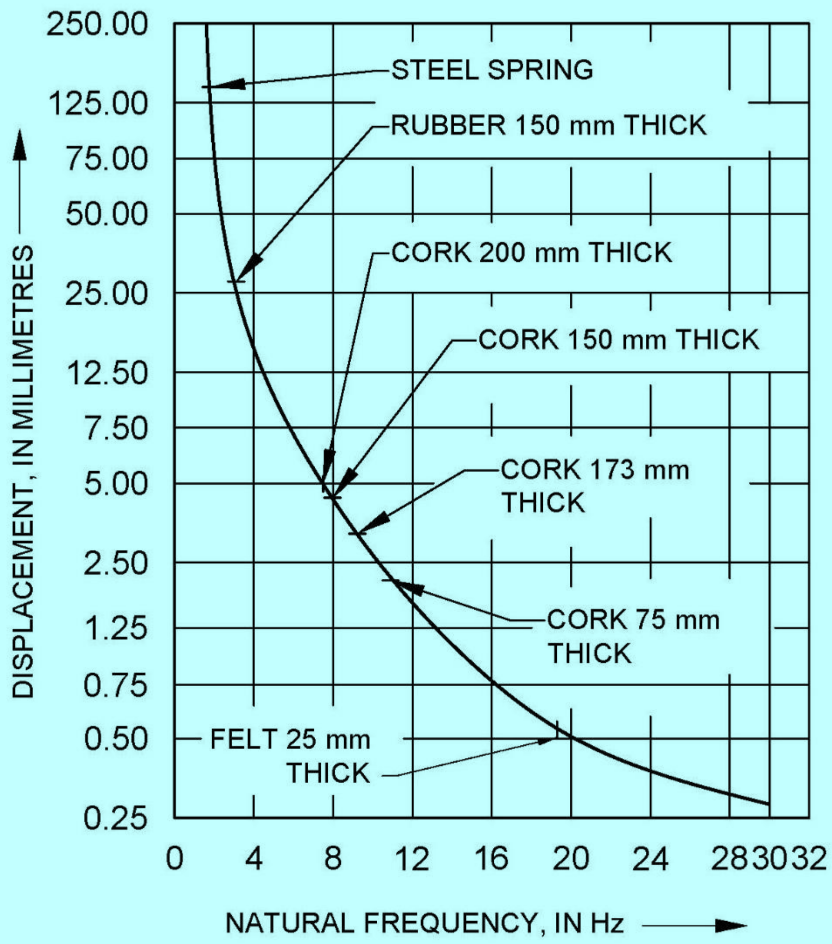


FIG. 1 RELATION BETWEEN STATIC DEFLECTION AND NATURAL FREQUENCY

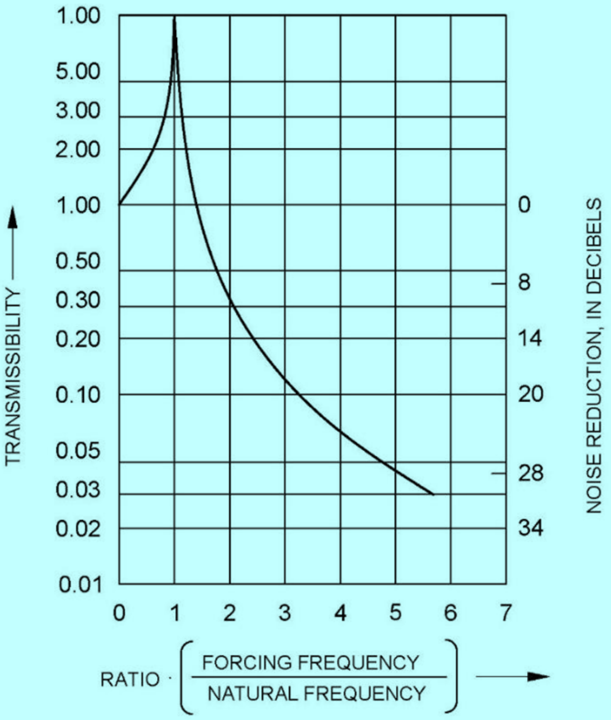


FIG. 2 TRANSMISSIBILITY AND EQUIVALENT NOISE REDUCTION FOR DIFFERENT RATIOS OF FORCING AND NATURAL FREQUENCIES

Materials for isolators and their position are given below:

a) *Material for isolators* — Vibration isolators are usually made of resilient materials like steel in the form of springs and rubber:

   1) Because of the large range of deflections obtainable in coil springs, they may isolate vibrations over a large spectrum of low frequencies. Metal springs transmit high frequency (from about two hundred to several thousand c/s) very readily. Transmission of these frequencies can be reduced by eliminating direct contact between the spring and the supporting structure. Rubber or felt pads may be inserted between the ends of the spring and the surfaces to which it is fastened;

   2) Rubber in the form of pads may be used to isolate very effectively engines, motors, etc. It may be used in compression or in shear. Some rubber mountings use rubber-in-shear as the primary elastic elements and rubber-in-compression as a secondary element which furnishes snubbing action if the mounting is subjected to an overload; and

   3) Felt or cork or both may be used as resilient mats or pads under machine bases. The load per unit area shall be chosen to produce enough deflection for the isolation required; and shall be such that at this deflection, it is not loaded beyond its elastic limit.

b) *Position of isolators* — The normal position of the isolators is between the machine and its foundation. However, if the forcing frequency of the machine is low (less than 10 Hz) and vibration isolators with the requisite deflection for this location are not available, the machine may be bolted directly to an independent heavy inertia concrete base and the available vibration isolators used below the concrete base.

   1) Large press and drop hammers which create serious impact vibration in heavy machine shops may be mounted rigidly on very massive blocks of concrete having weights several times greater than the weights of the supported machines. The inertia blocks may, in turn, be isolated from the building structure by large wooden blocks and with thick pads of cork;

   2) In critical installations (*see* Note), attempt should be made to locate the resilient mounts in a plane which contains the centre of gravity of the mounted assembly. It is also preferable to locate the mounts laterally as far away as possible from the centre of the machine;

      NOTE — Critical installations are those installations where transmission of vibration from these installations seriously hamper the normal working.

   3) Rigid mechanical ties between vibrating machine and building structure, short-circuit or reduce the effectiveness of isolators. Loose and flexible connections should be inserted in all pipes and conduits leading from the vibrating machine. Where flexible connections are impracticable, bends should be inserted into the pipes or the pipes themselves should be supported on vibration mounts for a considerable distance from the source; and

   4) *Flexibility of foundation* — The effect of flexibility of the foundation on the isolator transmissibility shall be considered in the selection of practical vibration isolating mountings. The simplified vibration isolation theory assumes a completely rigid foundation. However, in practice, this can never be achieved. The foundation is never actually completely rigid. Generally, the relatively low stiffness of the isolation system permits the assumption of the foundation to be rigid. However, if the stiffness of the isolator is allowed to become comparable to the foundation stiffness (or greater), the deflection of the isolator will become smaller and the foundation will also deflect with increased transmissibility and decreased isolator efficiency. In a dynamic sense, supporting foundation or floors should have natural frequency as high and be as stiff as possible compared to the system being isolated. Good design practice requires that the isolators should be designed assuming a rigid foundation with the stipulation that the selected machine isolation system frequency should be well below the foundation frequency. This point should specially be kept in mind when installing machines at upper levels in buildings because supported slabs generally have lower natural frequencies (low stiffness) than slabs on grade in basement or ground floor locations.

10.4.4 *Noise Reduction by Enclosures and Barriers*

10.4.4.1 *Enclosures*

Airborne noise generated by a machine may be reduced by placing the machine in an enclosure or behind a barrier. The enclosure may be in the form of close-fitting acoustic box around the machine such that the operator performs his normal work outside the box and thus is not subjected to the high noise levels of the machine. The enclosure may be made of sheet metal lined inside with an acoustical material.

Where size of the machine, working area and the operation do not permit close-fitting enclosures, the machine may be housed in a room of its own. The inside of the enclosure should be lined with sound-absorbing materials to reduce the noise level of the contained sound. The bounding walls of the enclosures should also have adequate transmission loss to provide desired noise reduction.

10.4.4.2 *Barriers*

A partial reduction of noise in certain directions may be obtained by barriers or partial enclosures or partial height walls. Two-sided or three-sided barrier, with or without a top and invariably covered on the machine side with acoustic absorption material should face a wall covered with sound-absorbing material. If the top of the enclosure is open, the reduction may be increased by placing sound-absorbing material on the ceiling overhead.

10.4.5 *Acoustical Absorption Devices*

10.4.5.1 *Acoustical treatment of ceilings and side walls*

In order to reduce the general reverberant noise level in machine shops, acoustical material may be provided on as much of the available area on the ceiling and side walls. With this treatment 3 dB to 6 dB reduction of middle and high frequency noise may be achieved. While the noise level at the source, affecting the operator, may not be reduced materially, the treatment would bring down the built-up noise level away from the source in reverberant field.

10.4.5.2 *Functional sound absorbers*

For efficient noise reduction functional sound absorbers may be clustered as near the machines as possible. These units may be suspended and distributed in any pattern to obtain lower noise levels within the machine shop. Compared on the basis of equal total exposed surface areas, functional sound absorbers have higher noise reduction coefficients (NRC) than conventional acoustical materials placed directly on ceilings and walls.

10.5 Noise Control in Specific Industrial Occupancies

10.5.1 *Manufacturing and Heavy Machinery Industries*

10.5.1.1 Industrial units with high-noise equipment such as stamping presses, crushers, and rolling mills should install vibration isolation platforms or resilient mounts to control structure-borne noise.

10.5.1.2 Machines producing significant noise should be enclosed in acoustic enclosures to prevent noise propagation within the facility and reduce exposure to workers.

10.5.1.3 Partition walls between noisy production areas and quieter zones (such as offices or break rooms) should incorporate sound-insulating materials or be designed with adequate thickness to ensure minimal noise transfer.

10.5.2 *Chemical and Pharmaceutical Plants*

10.5.2.1 Noise-generating equipment such as pumps, compressors, and centrifuges should be fitted with mufflers or acoustic casings to minimize sound emissions.

10.5.2.2 Mechanical rooms containing heating, ventilation, and air conditioning systems and other service units should be acoustically treated and isolated from production spaces to prevent noise transmission.

10.5.2.3 Noise-sensitive spaces such as laboratories and quality control areas should either be located away from noisy zones or separated by floating floors or soundproof partitions to ensure operational efficiency.

10.5.3 *Food Processing Units*

10.5.3.1 Equipment such as blenders, grinders, and packaging machines should use vibration-isolating mounts to control structure-borne noise.

10.5.3.2 Temporary sound barriers may be installed around seasonal operations like bulk-loading zones during periods of high activity.

10.5.3.3 Control rooms and staff areas should be acoustically insulated to ensure noise relief, with soundproof partitions and doors installed where necessary.

10.5.4 *Power Plants and Utilities*

10.5.4.1 Power plants should install noise barriers or walls around high-noise zones such as turbine halls and generator rooms to minimize sound emissions beyond facility boundaries.

10.5.4.2 Cooling towers and exhaust stacks should be equipped with noise control devices like silencers to mitigate low-frequency noise emissions.

10.5.4.3 Control rooms and operational centres should be designed to maintain appropriate noise levels conducive to work, with double-wall partitions or air gaps considered for turbine or engine rooms.

11 LABORATORIES AND TEST HOUSES

11.1 Sources of Noise

11.1.1 *Outdoor Noise*

In a test house or laboratory, where research workers and scientists are engaged in performing sophisticated experiments, the external noise is mostly contributed by noise emitting buildings (workshops, machine rooms), airports, railway stations and general traffic noises. The outdoor sources of noise in a college laboratory include noises produced in a playground as well.

11.1.2 *Indoor Noise*

The following sources mainly contribute to indoor noises in research institutions/college laboratories:

a) Workshops, machine rooms, cafeteria, etc;
b) Air conditioning and exhaust fans;
c) Noise produced within the test house or laboratory while performing experiments; and
d) Typing or other machine noises, telephone service, lift, sanitary services, etc.

11.2 Recommendations

11.2.1 *Site Planning*

While planning for a laboratory or test house, care should be taken in the design that no noise emitting installations should exist in its neighbourhood. However, where outdoor noises exist, such as from local factory, heavy traffic airports, railway lines, sport grounds or busy markets, buildings should be kept as far away as possible from the source of noise.

11.2.1.1 The window and door openings towards the noise sources should be minimum. Minimum amount of glazing should be placed on walls directly facing the noise sources.

11.2.2 *Internal Planning*

11.2.2.1 Noisy places should be kept separate from the quiet ones. The location of laboratories or test houses should be so chosen that it is cut off from the noisy zones. Where there are offices attached to a laboratory, provision should be made to treat the offices and to use acoustical partitions, to achieve a sound isolation D_w of at least 35 dB.

11.2.2.2 In a laboratory, mostly hard reflecting surfaces and bare furnishings are found, which produce very reverberant conditions. The noise condition still deteriorates when noise producing instruments are switched on or a heavy object is dropped on the floor. Under these conditions, sound absorbing treatment of the space is very essential. Sound absorbing ceilings are recommended to deaden such noises. Rubber buffers may also be fitted to the legs of furniture.

11.2.2.3 In large span laboratories or test houses where scientists and researchers are engaged in work and/or simultaneously busy in calculations or desk work requiring high degree of mental concentration, use of sound absorbing screens is recommended.

11.2.2.4 Noise reduction between the test house or laboratory and corridors or general circulation space should be well kept in mind and due care should be taken of the type of doors and the manner of their fittings, etc. Transmission of noise through service ducts, pipes, lifts and staircases should also be guarded.

Telephones should preferably be placed in a separate small enclosure or acoustically efficient telephone booth.

11.2.2.5 To isolate a laboratory or a test house from structure-borne noises originating from upper floor, sandwich type floor construction is recommended.

11.2.2.6 Wherever the provision of double glazed windows is necessary to reduce the heat losses, care should be taken to provide sealed double windows rather than double glazing in a single window.

NOTE — Double glazed windows for sound insulation should have a minimum gap of 100 mm between the two glasses.

12 MISCELLANEOUS BUILDINGS

12.1 Law Courts and Council Chambers

It is important that law courts and council chambers be protected from the intrusion of outdoor noise and from indoor noise arising both from ancillary offices and circulation spaces. The general recommendations on site planning given in **3** apply to law courts and municipal buildings, but in the larger buildings at least, further protection against outdoor noise can be obtained by planning offices and other rooms around the court rooms or chambers, and separating the offices from the central rooms by means of corridors. This arrangement is usually convenient to the function of the buildings.

12.1.1 The wall between the corridors and the central rooms should have a sound reduction index, R_w of not less than 50 dB (for example 230 mm brick) to insulate against airborne noise in the corridors. Entrances from halls or corridors into court rooms or council chambers should be through baffle lobbies with two sets of quiet action doors. Sound absorbing treatment on ceilings and upper parts or walls or entrance lobbies is recommended.

12.1.2 The whole of the floor of the court room or chamber including steps and seating areas set aside for the public should have a resilient floor finish to reduce the noise of footsteps and shuffling of feet. Any tip-up seats should be quiet in action.

12.1.3 Sound absorbing treatment applied for acoustic purposes serves also to reduce the build-up of noise within the room. It is desirable to provide sound absorbing ceiling in the court room.

12.2 Libraries, Museums and Art Galleries

Quiet conditions for reading and study are essential in these types of buildings and, since their occupancy is not noise producing, intruding noise is more noticeable and distracting. Every opportunity therefore should be taken to plan for noise defence, both in respect of siting of the building and internal planning. When possible, stack rooms, store rooms and administrative offices should be planned to screen reading rooms, print rooms and lecture rooms from noise sources. In public libraries, the reference library and lecture rooms should receive first consideration; the lending library, newspaper and periodical rooms have a higher background noise and are secondary in importance.

12.2.1 In large libraries, museums and art galleries echoes from lofty, large domed or concave ceilings are often a nuisance. Small noises such as footsteps, coughs, chair scraping and closing of books are reinforced by reverberation, and concave surfaces even when treated with a sound absorbent may focus these noises. Treated flat ceilings, if not too high, obviate these troubles. Books on shelves in libraries constitute a valuable wall absorbent.

12.2.2 Floor finishes are important. The impact noise of footsteps on marble, terrazzo or wood block flooring, and especially on hardwood strip and batten flooring, can be disturbing both within the room in which the noise is generated and the rooms below. On solid floors, resilient floor finishes, such as rubber, cork and linoleum on an underlay, are highly desirable. In the children's sections of libraries and museums they are essential. In existing buildings, rubber linoleum or vinyl asbestos tiles laid over the floor in the traffic areas are often a solution to the problem.

12.2.3 Reference libraries in universities, research establishments, office buildings and science buildings having machines and testing benches, should be planned in a quiet part of the building. Walls enclosing the library should normally have a sound reduction index, R_w of not less than 50 dB (for example 230 mm brick) and baffle lobbies should be planned between the library and halls and corridors. Walls facing on to corridors or other noisy areas should not have fanlights unless they are double glazed and non-operable.

12.3 Auditoria and Theatres

The sources of noise that have to be considered in concert halls, opera house, theatres and similar auditorium buildings are as follows:

a) Outdoor noise entering through walls, roofs, doors, windows or ventilation openings;

b) Noise from any other hall in the same building, especially if let out separately for revenue;

c) Noise from foyers, service rooms and other ancillary rooms, particularly rehearsal rooms;

d) Noise from air conditioning plant, etc, and the cross-transmission of other internal noises via ventilating duct system; and

e) Impact generated noise due to rainfall on light weight metal roofs.

12.3.1 Because of greatly increased outdoor noise, all auditorium buildings now need more care in siting than formerly. For listening to speech or music, a very low background noise level is desirable; in concert halls especially, the quietest possible conditions should be provided because the pauses and moments of silence which are an essential element of music cannot otherwise be given full value. Therefore, sites at cross-roads or close to steel railway bridges, religious places or near churches where bell ringing is practiced, should be avoided unless very high standards of structural sound insulation are contemplated. Sites adjoining underground railways may also prove unsatisfactory at basement levels owing to low-pitched noise or rumble transmitted through the ground; special isolation measure need to be adopted for isolating large buildings from ground vibration of this sort.

12.3.2 Whenever possible, for concert halls and theatres on city sites a noise survey of the site should be made; a suitable sound reduction value for the structure of the building can then be chosen so as to keep down to certain maximum noise levels within the auditorium. The maximum octave-band sound pressure levels (SPL) recommended are given in Table 8.

Table 8 Maximum Sound Pressure Levels (dB) Due to External and Mechanical Equipment Noise in Auditoria

(*Clause* 12.3.2)

Sl No.	Type of Auditorium	Centre Frequency Hz							
		63	125	250	500	1 000	2 000	4 000	8 000
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
i)	Concert halls [dB*A*-25]	51	39	31	24	20	17	14	13
ii)	Drama theatres and Cinemas [dB*A*-30]	55	44	35	29	25	22	20	18

12.3.3 The minimum standard of sound reduction index, R_w likely to be required for the envelope of an auditorium in a city to protect it against external noise is of the order of 65 dB for a concert hall or 55 dB to 60 dB for a theatre. This reduction should be provided on all sides, but it would be reasonable to make the R_w for the roof 5 dB to 10 dB less provided the building is not unduly exposed to noise from aircraft in flight. Surrounding the auditorium with ancillary rooms and foyers is an obvious and invaluable planning method of obtaining the required insulation against outdoor noise.

12.3.4 Ventilation intakes and returns are vulnerable features in the defence against external noise. They should be positioned so as to avoid exposure to noise, and in addition sufficient length of both inlet and outlet ducts should be provided with carefully designed silencers. The ventilation system should also be designed to avoid transmitting or adding to internal noise.

12.3.5 The most serious internal noise problem arises when there are two halls meant for separate use in the same building, especially if one of them is a concert hall. The latter is a very loud potential source of noise and requires a high standard of protection against extraneous noise. In these circumstances it is doubtful whether a 'single' wall can be adequate for insulating the two halls unless it is designed with a wide unbridged cavity. Separation by planning is preferable.

12.3.6 Other sources of internal noise are rehearsal rooms, scenery bays and workshops, stages of other halls where rehearsals or erection of stage sets might be in progress and foyers and bars where loud conversation might occur. The insulation of the internal walls should be adequate to protect the auditorium from these noise sources and the insulation should not be by-passed by openings, doorways, etc. The general noise due to banging of doors also needs to be taken care of and soft sealing materials should be provided for all doors to ensure quiet closing.

12.3.7 Mechanical equipment such as lifts shall be effectively isolated from the building structure to help avoid noise transmission.

12.3.8 Adequate damping should be provided under light weight metal roofs with an additional light weight under deck noise sound barrier to reduce rainfall generated noise.

12.3.9 For detailed acoustical design of auditoria and conference halls reference may be made to good practice [D-4(3)].

12.4 Cinemas

The main objective of the design should be to control noise from adjacent screens, the projection area, the foyer, and outside the cinema. The first of these, controlling noise from adjacent screens, is likely to be the most difficult with modern digital sound systems. As most cinemas are air-conditioned, there will be some noise from services. To ensure reasonable listening conditions, this should be limited to 30 dBA. This will provide some masking of the noise from adjacent screens, but a high performance partition will still be essential. Masonry or lightweight construction may be used, and a typical performance specification for a lightweight wall separating two screens is given in Table 9. Cinema design, however, normally requires specialist acoustic advice.

Table 9 Typical Sound Insulation Specification for Wall Separating Two Cinema Screens

(*Clause* 12.4)

Sl No. (1)	**Octave band** Hz (2)	**Sound Reduction Index,** R dB (3)
i)	63	38
ii)	125	44
iii)	250	50
iv)	500	61
v)	1 000	57
vi)	2 000	58
vii)	4 000	57
viii)	8 000	55

13 NOISE FROM BUILDING SERVICES

13.1 Mechanical, electrical, air conditioning, heating and mechanical ventilation, and other services are provided in almost all large buildings including residential, commercial and industrial buildings. Noise control measures should be incorporated during the design and installation of such services to adhere to the recommended outdoor and indoor noise criteria for the kind of occupancy. For detailed design of noise control for services, specialist advice should be sought.

Some basic design techniques for noise control in air conditioning, heating and mechanical ventilation system are given in Annex J.

13.2 Control of noise from mechanical equipment can also be done by specifying noise control requirements while purchasing the equipment (*see* Annex K).

14 NEIGHBOURHOOD ACOUSTIC SHIELDING DURING INFRASTRUCTURE DEVELOPMENT

14.1 General

Infrastructure development projects often generate substantial noise that can adversely affect the well-being of residents. Prolonged exposure to noise pollution may lead to health issues such as sleep disturbances, hearing impairments and stress. Hence, effective acoustic shielding of neighbourhood is required to minimize such impacts. The following outlines the provisions for noise control during infrastructure development.

14.2 Pre-Development Noise Assessment

14.2.1 A baseline noise assessment should be conducted prior to the commencement of construction activities to determine ambient noise levels and identify noise-sensitive receptors (NSRs), including residential areas, schools, and healthcare facilities.

14.2.2 Noise modelling should be performed to predict noise levels for each phase of construction. The model shall take into account equipment type, frequency and duration of activities, and the topography of the site.

14.2.3 Predicted noise levels shall be compared with the limits prescribed. If expected levels exceed the permissible limits, additional mitigation measures should be proposed.

14.3 Noise Mitigation Planning

14.3.1 A noise mitigation plan (NMP) should be prepared prior to the commencement of any construction work. The NMP shall include:

a) Identification of potential noise sources and their expected noise levels;

b) Location of noise-sensitive receptors and baseline noise levels;

c) Proposed noise control measures and their implementation timelines;

d) Monitoring strategies for continuous noise assessment; and

e) Community engagement strategies and complaint management procedures.

14.3.2 Construction activities that generate high levels of noise should be scheduled during permissible hours. Noise-intensive operations should be avoided during night time hours unless specific approval is obtained.

14.4 Noise Barriers

14.4.1 Temporary noise barriers should be installed at the perimeter of construction sites to shield NSRs from construction noise. Barriers should be designed to achieve a minimum noise reduction of 10 dBA. The height of the barriers should be at least 2.5 m or as determined by site-specific acoustic analysis.

14.4.2 Permanent noise barriers, such as earth berms, concrete walls, or vegetative buffers, may be considered for long-term infrastructure projects with expected noise impacts exceeding permissible limits.

14.4.3 Recommended guidelines for the design and performance evaluation of noise barriers are given in Annex F.

14.5 Low-Noise Equipment and Practices

14.5.1 Low-noise equipment, such as electric or hydraulic machinery, should be used wherever feasible. Equipment should be fitted with silencers, mufflers or acoustic enclosures to reduce emissions.

14.5.2 Construction techniques that minimize noise generation, such as hydraulic splitting instead of pneumatic hammering for concrete demolition, should be employed wherever possible.

14.6 Maintenance of Equipment

14.6.1 A maintenance schedule for all construction equipment should be implemented to ensure optimal operating conditions and minimize noise emissions.

14.6.2 All equipment should be inspected regularly for defects, such as worn-out parts, loose fittings or damaged mufflers, that may increase noise levels. Defective equipment should be repaired or replaced immediately.

14.7 Noise Monitoring and Compliance

14.7.1 Continuous noise monitoring should be conducted at designated locations near NSRs throughout the construction period. Monitoring equipment should be as per accepted standard [D-4(4)].

14.7.2 Noise levels should be logged at regular intervals. The logged data shall be reviewed daily to ensure compliance with the permissible noise levels.

14.7.3 If noise levels exceed permissible limits, corrective actions, such as modifying work practices, deploying additional noise barriers, should be implemented within 24 h.

14.7.4 A noise monitoring report should be maintained throughout the project, including logged data, incidents of exceedances, corrective actions taken, and community complaints received.

14.8 Community Engagement and Communication

14.8.1 A community noise management plan should be established as part of the noise management plan, outlining strategies for engaging with the local community, informing them about construction activities, expected noise impacts, and mitigation measures.

14.8.2 A public contact point should be established for residents to report noise concerns. All complaints should be logged, investigated, and resolved promptly.

14.9 Vegetative Buffers

14.9.1 Where feasible, vegetative buffers consisting of dense rows of trees or shrubs should be planted around the construction site to serve as supplementary noise barriers.

14.9.2 Vegetative buffers should have a minimum width of 5 m and be composed of mixed species with dense foliage for optimal sound absorption.

14.10 Post-Construction Noise Assessment

14.10.1 Upon completion of construction activities, a post-construction noise assessment should be conducted to verify that ambient noise levels have returned to pre-development conditions or meet permissible limits.

14.10.2 Temporary noise barriers should be dismantled and disposed of responsibly. If permanent barriers or vegetative buffers were installed, they should be integrated into the final landscape design.

15 TRAFFIC NOISE BARRIERS

Noise barriers are one of the most effective ways to mitigate road traffic noise. Noise barriers can reduce the A-weighted noise levels depending on their design and height. If the barrier surface density exceeds 20 kg/m^2, a reduction of 5 dB can be achieved by having a barrier tall enough to break the line of sight from the road to the receiver and an additional 1.5 dB reduction can be achieved for each additional metre of height. The efficiency of noise barrier largely depends upon its geometry. Besides the height of the barrier and its top element form, the cross section of the barrier contributes to its performance. Recommended guidelines for the design and performance evaluation of noise barriers are given in Annex F.

ANNEX A

(*Clause* 2.4)

NOISE CALCULATIONS

A-1 GENERAL

Some of the simpler types of noise calculation are described in this annex.

A-2 ADDITION OF TWO NOISE LEVELS

To determine the combined sound pressure level (L_c) resulting from the sound pressure levels of two or more noise sources (L_1, L_2, etc), it is necessary to calculate and add the mean square values of their individual sound pressures and then convert this back to a sound pressure level. This can be done using the following formula:

$$L_c = 10\, log_{10}(10^{L_1/10} + 10^{L_2/10})$$

As the individual sound pressure levels are logarithms of the mean square sound pressures, they cannot simply be added arithmetically. Fig. 3 shows a graphical method for adding the sound pressure levels from two independent sources to obtain the combined sound pressure level at a particular place. This graph may also be used for multiple sources by combining sources two at a time to produce virtual sources that can then be combined. The most accurate approach is to start with the lowest levels and work towards the highest.

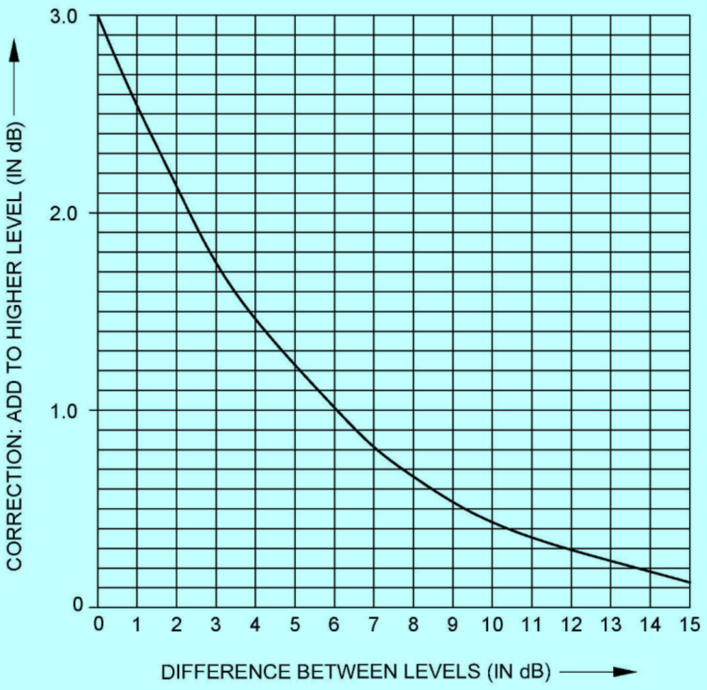


FIG. 3 ADDITION OF TWO NOISE LEVELS

The graph should be used with caution where the noise sources are not independent. For example, the sound pressure level from two large transformers fed with currents in phase will be very sensitive to the receiving position. This is because the effect of the constructive and destructive interference of the sounds from the two sources is very dependent on position.

A-3 SUBTRACTION OF TWO NOISE LEVELS

When measuring noise from a source, the true noise level of the source alone will be less than that shown by the meter if the level of extraneous noise is less than about 10 dB below the total noise level. An estimate of the true source level can be obtained from Fig. 4.

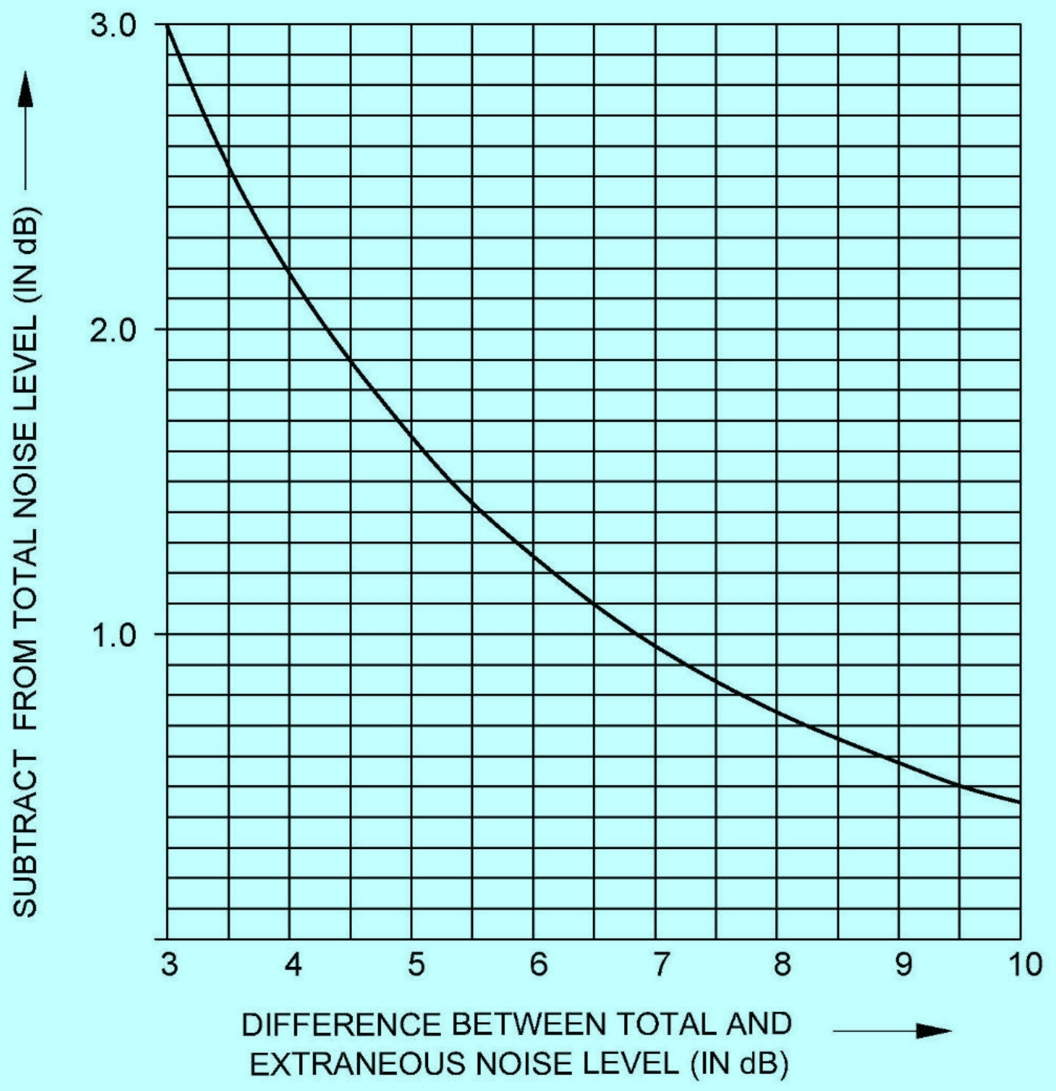


FIG. 4 SUBTRACTION OF NOISE LEVELS

A-4 NON-UNIFORM COMPOSITE PARTITIONS

Figure 5 provides for calculating the overall sound insulation of a composite partition consisting of two parts having different sound-insulating properties, for example, a window in a wall. It may also be used to give an indication of the effect of gaps or holes in a partition by assigning a sound insulation value of 0 dB to the aperture.

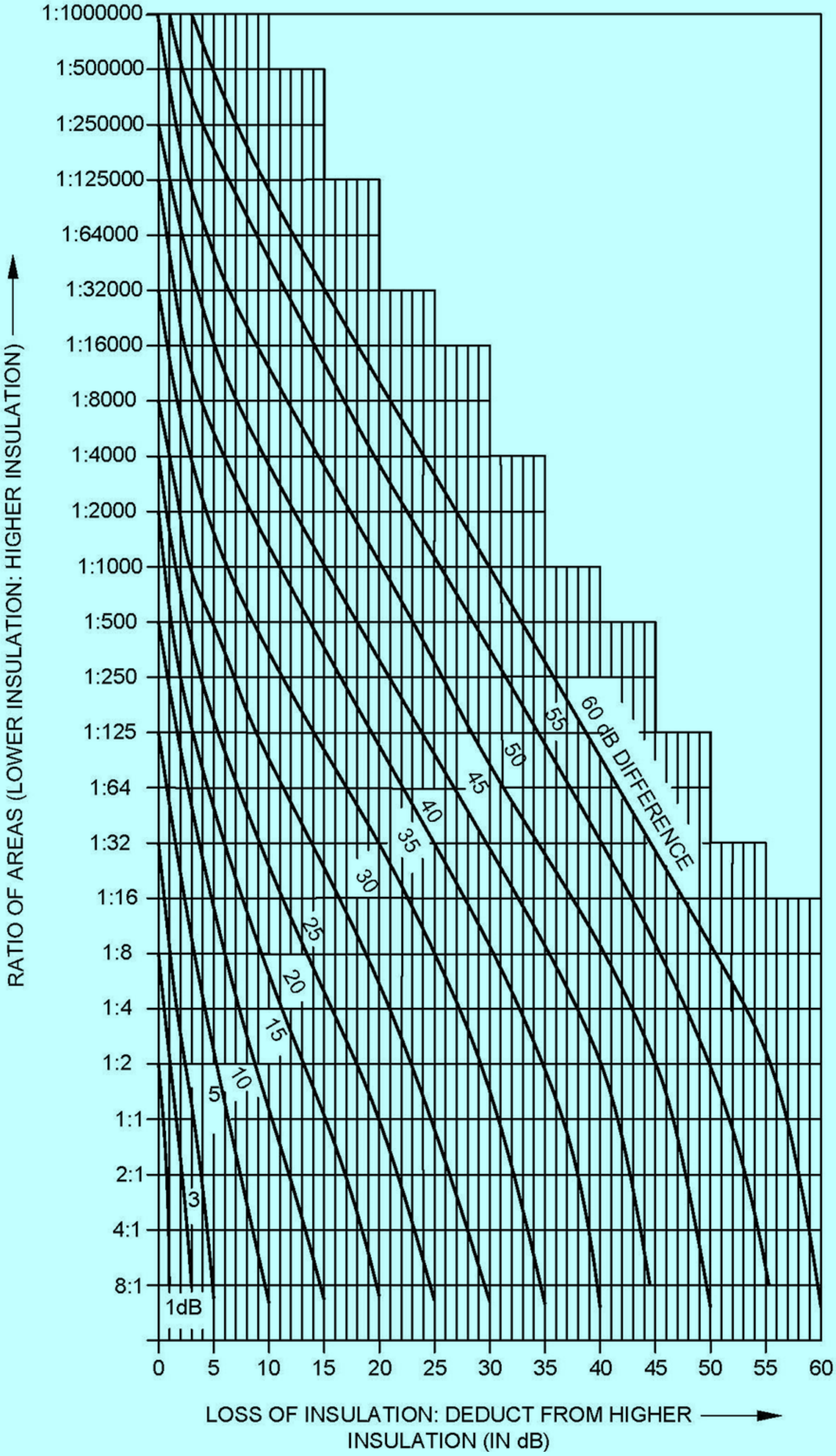


FIG. 5 SOUND INSULATION OF NON-UNIFORM PARTITIONS

A-5 A-WEIGHTING CALCULATIONS

The equivalent A-weighted level is often required when data on a noise source is available as a set of octave band or one-third octave band levels. The conversion can be done manually, using the standard A-weighting values (*see* Table 10) and the graph for combining levels (*see* Fig. 3). For all but the simplest situations it is more convenient to use a computer spreadsheet to do the conversion.

Table 10 Standard A-Weighting Values (dB)

(*Clause* A-5)

Sl No.	Third Octave Band Centre Frequency Hz	A-Weighting dB	Third Octave Band Centre Frequency Hz	A-Weighting dB
(1)	(2)	(3)	(4)	(5)
i)	10	- 70.4	500	-3.2
ii)	12.5	- 63.4	630	-1.9
iii)	16	- 56.7	800	-0.8
iv)	20	- 50.5	1 000	0
v)	25	- 44.7	1 250	0.6
vi)	31.5	- 39.4	1 600	1.0
vii)	40	- 34.6	2 000	1.2
viii)	50	- 30.2	2 500	1.3
ix)	63	- 26.2	3 150	1.2
x)	80	- 22.5	4 000	1.0
xi)	100	- 19.1	5 000	0.6
xii)	125	- 16.1	6 300	-0.1
xiii)	160	- 13.4	8 000	-1.1
xiv)	200	- 10.9	10 000	-2.5
xv)	250	- 8.6	12 500	-4.3
xvi)	315	- 6.6	16 000	-6.6
xvii)	400	- 4.8	20 000	-9.3

A-6 REVERBERATION TIME CALCULATION

An estimate of the reverberation time (T) of a room can be obtained from the Sabine formula:

$$T = \frac{0.16\,V}{\sum A_\mathrm{i}}$$

where

V = volume of the room in cubic metres (m^3); and
A_i = equivalent sound absorbing area in the room, in square metres (m^2).

The A_i are the absorbing areas of each surface, or other permanent fixture in the room. Each A_i is determined by multiplying the area of that surface in square metre (m^2) by its absorption coefficient α_{si}. The surface of each significant fixture or feature of the room should be considered as well as the walls, ceiling and floor.

The total absorption is obtained by summing the individual A_i values. As the values of α_{si} are frequency dependent, this calculation should be repeated for each octave band of interest.

An allowance should also be made for people and furnishings in the room.

ANNEX B

(*Clause* 2.24)

NOISE RATING

B-1 Noise rating (NR) is a graphical method for assigning a single number rating to a noise spectrum. It can be used to specify the maximum acceptable level in each octave band of a frequency spectrum, or to assess the acceptability of a noise spectrum for a particular application. The method was originally proposed for use in assessing environmental noise, but was later also found suitable for describing noise from mechanical ventilation systems in buildings. To make a rating, the noise spectrum is superposed on a family of NR contours; the NR of the spectrum corresponds to the value of the first NR contour that is entirely above the spectrum. The data for drawing NR contours (from NR 0 to NR 75) is given in Table 11 for the frequency range 31.5 Hz to 8 kHz.

Table 11 Noise Rating Values

(*Clause* **B-1**)

Sl No.	**Noise Rating**	**Octave Band Centre Frequency**, Hz **For Sound Pressure Levels dB$_{re}$ 20 µPa**								
		31.5	63	125	250	500	1 000	2 000	4 000	8 000
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
i)	NR75	106	95	87	82	78	75	73	71	69
ii)	NR70	103	91	83	77	73	70	68	66	64
iii)	NR65	100	87	79	72	68	65	62	61	59
iv)	NR60	96	83	74	68	63	60	57	55	54
v)	NR55	93	79	70	63	58	55	52	50	49
vi)	NR50	89	75	66	59	53	50	47	45	43
vii)	NR45	86	71	61	54	48	45	42	40	38
viii)	NR40	83	67	57	49	44	40	37	35	33
ix)	NR35	79	63	52	45	39	35	32	30	28
x)	NR30	76	59	48	40	34	30	27	25	23
xi)	NR25	72	55	44	35	29	25	22	20	18
xii)	NR20	69	51	39	31	24	20	17	14	13
xiii)	NR15	66	47	35	26	19	15	12	9	7
xiv)	NR10	62	43	31	21	15	10	7	4	2
xv)	NR5	59	39	26	17	10	5	2	– 1	– 3
xvi)	NR0	55	35	22	12	5	0	– 4	– 6	– 8

B-2 For computational methods, the curves are defined by the equation:

$$L = a + bN$$

where

L = octave band sound pressure level corresponding to NR level N; and

a and b = constants for each frequency band, as given in Table 12.

NOTE — NR values cannot be converted directly to dBA values but the following approximate relationship applies:

NR = dBA – 6

B-3 Although the NR system is currently the preferred method for rating noise from mechanical ventilation system, other methods which are more sensitive to noise at low frequencies are available, but they are not yet widely accepted. Low frequency noise may be disturbing or fatiguing to occupants, but may not have much effect on the dBA or NR value.

Table 12 Values of a and b

(*Clause* B-2)

Sl No. (1)	**Octave Band Centre Frequency** Hz (2)	***a*** (3)	***b*** (4)
i)	31.5	55.4	0.681
ii)	63	35.4	0.790
iii)	125	22.0	0.870
iv)	250	12.0	0.930
v)	500	4.2	0.980
vi)	1 000	0.0	1.000
vii)	2 000	- 3.5	1.015
viii)	4 000	- 6.1	1.025
ix)	8 000	- 8.0	1.030

ANNEX C

(*Clauses* 2.26, 2.41, 2.44, 2.46, 2.54, 2.55, 2.56 *and* 2.57)

SPECIFICATION OF SOUND INSULATION

C-1 GENERAL

Sound insulating elements work mainly by reflecting sound energy back into the source room, not by absorbing it. The methods of measurement and the terms used are described in **C-2** to **C-4**.

C-2 INSULATION AGAINST AIRBORNE SOUND

As per the standard tests, the insulation between a pair of rooms is measured either in third octave bands having centre frequencies which cover at least the range 100 Hz to 3 150 Hz, or in octave bands which cover at least the range 125 Hz to 4 000 Hz. The noise is produced by a loudspeaker in one of the rooms (called the source room) and at each frequency the average noise levels are measured in the source room (L_S) and in the adjacent receiving room (L_R). The difference between these two levels (D) is a measure of the sound insulation between the rooms regardless of the transmission path(s) the sound energy followed to travel between the rooms. The equation is as follows:

$$D = L_S - L_R$$

The actual level in the receiving room depends on the following:

a) Sound insulation of the separating wall or floor;

b) Area of the separating wall or floor;

c) Volume of the receiving room;

d) Amount of flanking transmission (that is the importance of transmission paths other than the separating wall or floor); and

e) Amount of absorbing material (for example furniture) in the receiving room.

For field measurements, apart from the amount of absorption, these factors are a property of the building and should be taken into account by the measurement procedure. As the amount of absorbing material (for example soft furniture) in the room at the time of measurement is arbitrary, it should be allowed for separately. This is achieved by measuring the reverberation time (T) of the room in seconds (s), which is a measure of how long it takes a sound to die away after the source has been switched off. As the sound energy is dissipated as heat in the absorbing material (T), it is related to the total amount of absorption in the room. The receiving room level may then be corrected to the level it would be if the room had a standard reverberation time (T_0) which is typical of furnished rooms, and is taken to be 0.5 s. The corrected level difference is known as the standardized level difference, which has the symbol D_{nT} and is calculated using the following equation:

$$D_{nT} = L_S - L_R + 10log_{10}(T/T_0)$$

For laboratory measurements, the insulation of the separating wall or floor being tested is required in a way which is independent of the actual measuring laboratory. For this reason, laboratories are designed to have minimal flanking transmission and a different correction is applied to account for the other factors. This correction is $10 \log_{10} (S/A)$.

where

S = common area of the separating wall or floor, in m^2; and

A = equivalent absorption area in the receiving room, in m^2.

The laboratory corrected level difference at each frequency is known as the sound reduction index, which has the symbol R and is calculated using the following equation:

$$R = L_S - L_R + 10\ log_{10}(S/A)$$

If the test wall or floor is mounted in a realistic way in the laboratory and flanking transmission will be low in the field, the sound reduction index may be used to predict its performance in the field. The relation between D_{nT} and R is given by the following equation:

$$D_{nT} = R - 10\ log_{10}(3S/V)$$

where

S = area of the separating wall or floor in the field, in m^2; and

V = volume of the receiving room in the field, in m^3.

This equation shows that if the source and receiving rooms have different volumes, D_{nT} will depend on which is used as the source room; using the larger room as the source room will give lower value.

C-3 INSULATION AGAINST IMPACT SOUND

The procedure to measure the impact insulation of floors is rather different. Instead of a loudspeaker, a machine containing five small hammers is placed on the floor. While the hammers strike the floor at a rate of 10 blows a second, the resulting noise level (L_i) is measured in the receiving room below at each of the same frequency bands used for airborne insulation. In the field, the receiving room levels are again ‘corrected’ to a standard reverberation time (T_0) of 0.5 s to give the standardized impact sound pressure level, L_{nT}, which is calculated as follows:

$$L_{nT} = L_i - 10\ log_{10}(T/T_0)$$

In the laboratory, the noise level depends mainly on the characteristics of the floor being tested and the amount of absorption (A m^2) in the laboratory. It is therefore appropriate to correct the noise level to a standard area of absorption. The area used is 10 m^2. The resulting normalized impact sound pressure level is given the symbol L_n and calculated as follows:

$$L_n = L_i + 10log_{10}(A/10)$$

C-4 RATING SOUND INSULATION

Measurements of insulation against both airborne and impact sounds yield values in a number of frequency bands. To make this information more manageable, rating methods such as those in accordance with [D-4(1)] are used to reduce the frequency band values to single figure ratings. These single figure ratings should be good predictors of subjective assessments of insulation. However, this is not always the case and it is prudent to examine the full measurement data in critical situations. The impact insulation measured on a floor with a carpet is likely to be overestimated by this method.

The more common indices used to describe sound insulation are summarized in Table 13.

Table 13 Common Indices Used to Describe Airborne and Impact Sound Insulation

(*Clause* C-4)

Sl No.	**Airborne (*A*) Impact (*I*)**	**Lab (*L*) Field (*F*)**	**Measured Values**		**Single Number Quantity**	
			Name	Symbol	Name	Symbol
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	*A*	*F*	Standardized level difference	D_{nT}	Weighted standardized level difference	$D_{\mathrm{nT,w}}$
ii)	*A*	*L*	Sound reduction index	R	Weighted sound reduction index	R_{w}
iii)	*I*	*F*	Standardized impact sound pressure level	L'_{nT}	Weighted standardized impact sound pressure level	$L'_{\mathrm{nT,w}}$
iv)	*I*	*L*	Normalized impact sound pressure level	L'_{n}	Weighted normalized impact sound pressure level	$L'_{\mathrm{n,w}}$

ANNEX D

(*Clause* 3.3)

OUTDOOR NOISE REGULATIONS IN INDIA

D-1 Government notifications are issued from time to time on the allowable ambient noise levels in general and specifically in different zones of various metropolitan cities of India.

D-2 Noise regulations and notifications are also issued from time to time specifying the maximum permissible sound levels from equipment commonly used in and around the residential areas and around sensitive buildings, specifically with regard to noise levels from electricity generating sets, construction equipment and HVAC utility equipment installed outdoors.

D-3 These regulations should be referred to by the designer for the design of measures for control of external noise.

ANNEX E

(*Clause* 3.5)

INTEGRATION OF NOISE BARRIERS AND NOISE ABATEMENT MEASURES IN ZONAL AND URBAN PLANNING

E-1 APPLICABILITY

E-1.1 These provisions establish requirements for incorporating noise barriers and noise abatement measures in the preparation of zonal plans to control noise pollution in urban and semi-urban areas.

E-1.2 The provisions apply to all zonal plans developed by municipal corporations, urban development authorities, and town planning bodies.

E-2 IDENTIFICATION AND SEGREGATION OF ZONES

E-2.1 Noise-Sensitive Zones (NSZs)

Zonal plans should identify noise-sensitive zones that include residential areas, educational institutions, healthcare facilities, and public parks, among others.

E-2.2 Noise-Generating Zones (NGZs)

Zonal plans should also identify noise-generating zones that include industrial areas, major transportation corridors, commercial zones, and recreational spaces prone to high noise levels.

E-2.3 Buffer Zones

Buffer zones should be established between NSZs and NGZs to minimize noise impacts. Buffer zones may include green belts, mixed-use developments, or other suitable land uses. The width and nature of buffer zones should be defined based on local conditions and practical feasibility.

E-3 NOISE BARRIERS

E-3.1 Requirement for Noise Barriers

Noise barriers should be required along major transportation corridors, such as highways and railway lines, adjacent to NSZs. The need for noise barriers should be determined based on the predicted noise levels and potential impact on NSZs.

E-3.2 Design criteria for noise barriers may be as per Annex F.

E-3.3 Placement of Noise Barriers

Noise barriers should be placed as close as possible to the noise source or the boundary of NSZs to maximize effectiveness.

E-4 NOISE ABATEMENT MEASURES IN ZONAL PLANS

E-4.1 Noise Mapping and Assessment

Zonal plans should include noise mapping to identify areas with high noise levels and predict future noise impacts based on planned developments.

E-4.2 Green Belts and Vegetative Buffers

Zonal plans should integrate green belts and vegetative buffers as supplementary noise reduction measures wherever feasible. These green belts should consist of dense rows of trees or shrubs and should be positioned strategically to serve as natural sound barriers.

E-4.3 Building Design Considerations

For buildings located in or near NGZs, zonal plans should encourage the use of noise-reducing building materials and construction techniques, such as double-glazed windows, soundproofing walls, and appropriate building orientation. For detailed information on noise reduction for town planning schemes, reference may be made to good practice [D-4(2)].

E-5 REGULATION OF NOISE EMISSION SOURCES

E-5.1 Construction Noise Control

Zonal plans should specify noise control measures for construction sites, including the use of low-noise equipment, temporary barriers, and restricted working hours in NSZs.

E-5.2 Industrial and Commercial Noise Control

Zonal plans should regulate emissions to ensure that industries and commercial establishments comply with noise limits, monitored periodically for compliance.

E-6 MONITORING AND COMPLIANCE

E-6.1 Noise Monitoring Provisions

Zonal plans should include provisions for noise monitoring to assess compliance with noise standards. Monitoring stations should be established in key locations within each zone to regularly measure noise levels.

E-6.2 Review and Enforcement

Zonal plans should be reviewed periodically to ensure the effectiveness of noise abatement measures. Non-compliance with noise regulations should result in penalties, including fines or mandatory implementation of additional noise control measures as per local regulations.

E-7 COMMUNITY ENGAGEMENT AND PUBLIC AWARENESS

E-7.1 Public Consultation

The preparation of zonal plans should involve public consultation to incorporate community concerns related to noise pollution and to inform stakeholders about proposed noise abatement measures.

E-7.2 Awareness Programs

Zonal plans should include provisions for public awareness programs to educate residents and businesses on noise pollution control practices and compliance requirements.

ANNEX F

(*Clauses* 3.8.7, 14.4.3, 15 *and* E-3.2)

DESIGN REQUIREMENTS AND PERFORMANCE EVALUATION OF NOISE BARRIERS

F-1 DESIGN AND GEOMETRY REQUIREMENTS

F-1.1 The barrier should be built as close as possible to either the source or receiver. Noise barriers should be tall enough and long enough to avoid degradations in barrier performance.

F-1.2 Barriers do not necessarily have to be of constant height as varying the height of the barrier may also help to alleviate the monotonous appearance of long length of barriers.

F-1.3 The ‘line of sight’ between the source and receiver should be cut off completely by the barrier. Barrier design also plays a major role where effective noise barriers should be high and long enough to break the line-of-sight between the sound source and the receiver.

F-1.4 Capped barriers of same height as conventional barriers may offer greater noise reductions than conventional barriers. A specified noise reduction may be achieved by a capped barrier of lower height than a conventional barrier. If high quality absorptive materials are available, the relative screening performance of cylinder-profile and mushroom-profile caps can be improved by up to 8 dBA relative to a plane screen of the same overall height. T-profile caps exhibit similar improvement when the uppermost surfaces are treated with the same absorptive materials. Double cylinder-profile caps are comparatively more efficient than single cylinder-profile caps. When absorptive, these provide equivalent average screening performance to T-profile configurations with the same overall height. A 3 m high T-shaped barrier provides the same performance as a 10 m high plain barrier.

F-2 MATERIALS AND CONSTRUCTION

F-2.1 Barriers should be constructed using solid, non-porous materials having minimum density of 20 kg/m^2.

F-2.2 The materials used for fabrication of noise barriers include

a) Steel (painted, galvanized, stainless);

b) Aluminium;

c) Plastics or polymer sheet concrete;

d) Brick or glass fibre reinforced concrete (GFRC);

e) Proprietary-made acoustic panels; and

f) Landscaped earth berms.

F-2.3 Sound absorbing material may be applied on the source side of the barrier to reduce the build-up of sound pressure level. An absorptive treatment may be appropriate to reduce the impact of reflected noise.

F-3 DESIGN MORPHOLOGY AND ADDITIONAL CONSIDERATIONS

F-3.1 Strategic planting may be considered to reduce the monotonous appearance of long length of barriers. The design morphology for noise barriers is shown in Fig. 6.

F-3.2 The height of a noise barrier is directly proportional to its noise reduction capacity, wherein higher barriers result in greater levels of noise reduction.

F-3.3 The insertion loss for barriers of heights between 3 m to 6 m typically ranges between 5 dB to 12 dB.

F-3.4 Barriers with a thickness exceeding 3 m shall be classified as thick barriers.

F-3.5 Noise barriers may become part of the surrounding landscape over time and can have potential impacts on ecosystems, road users, and residents living alongside the road. The loss of sunlight and visual impact should also be considered while designing the noise barriers.

F-3.6 Special attention should be given to the selection of materials used in the construction of noise barriers, particularly in areas experiencing extreme weather conditions.

F-3.7 The design of noise barriers should ensure minimal maintenance, except for routine cleaning or repairs due to damage, over the intended lifespan.

F-3.8 The Insertion loss can be estimated by using the Kurze and Anderson model given by the following equation:

a) $IL = 5dB + 20log\left(\frac{\sqrt{2\pi N}}{tanh\sqrt{2\pi N}}\right) dB\ upto\ N = 12.5$

b) IL = 20 dB for N > 12.5, N is the Fresnel number

Maekawa’s curve is one of the most established methods for predicting the insertion loss behind the barriers.

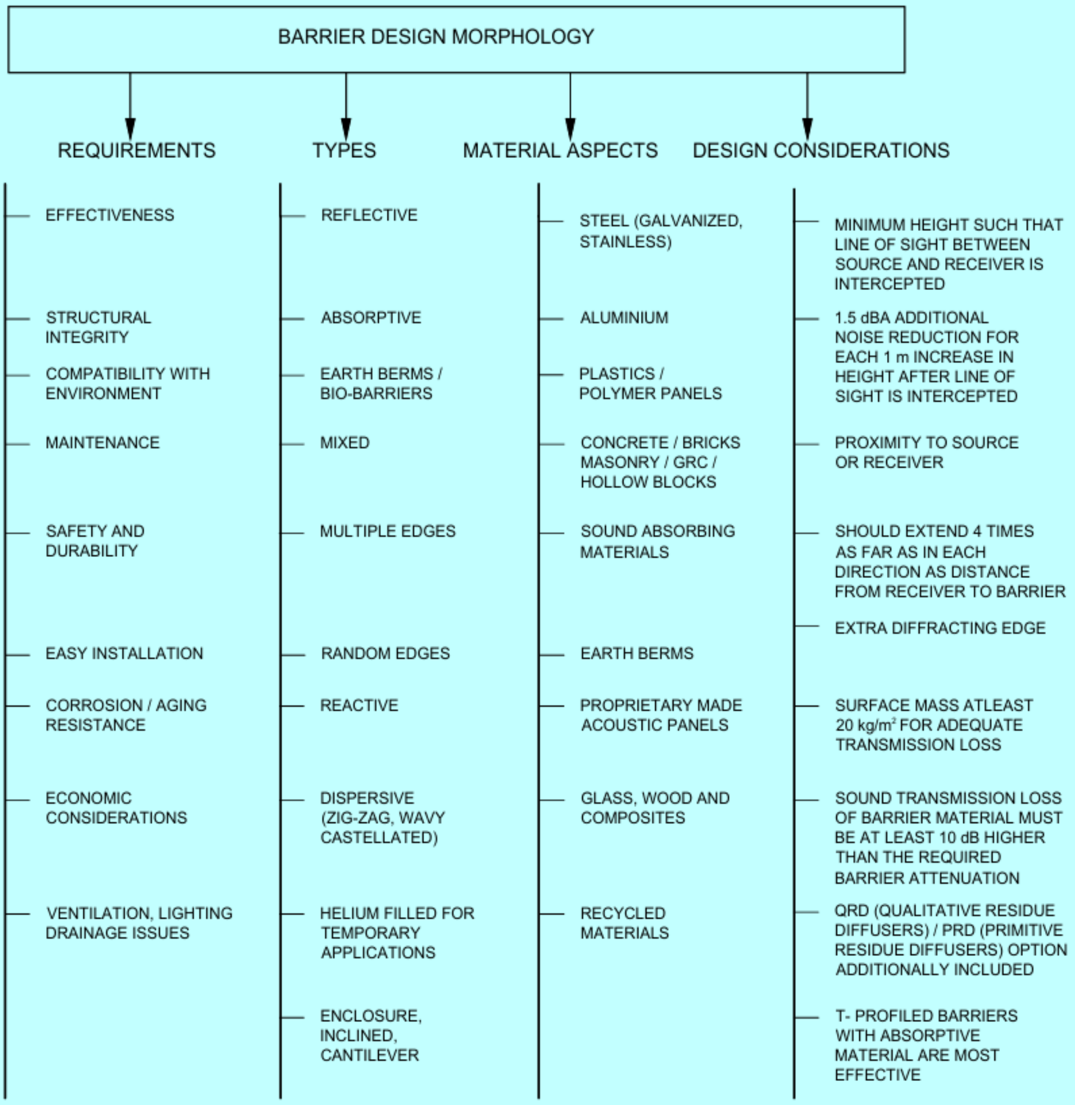

BARRIER DESIGN MORPHOLOGY
REQUIREMENTS
TYPES
MATERIAL ASPECTS
DESIGN CONSIDERATIONS
EFFECTIVENESS
STRUCTURAL INTEGRITY
COMPATIBILITY WITH ENVIRONMENT
MAINTENANCE
SAFETY AND DURABILITY
EASY INSTALLATION
CORROSION / AGING RESISTANCE
ECONOMIC CONSIDERATIONS
VENTILATION, LIGHTING DRAINAGE ISSUES
REFLECTIVE
ABSORPTIVE
EARTH BERMS / BIO-BARRIERS
MIXED
MULTIPLE EDGES
RANDOM EDGES
REACTIVE
DISPERSIVE (ZIG-ZAG, WAVY CASTELLATED)
HELIUM FILLED FOR TEMPORARY APPLICATIONS
ENCLOSURE, INCLINED, CANTILEVER
STEEL (GALVANIZED, STAINLESS)
ALUMINIUM
PLASTICS / POLYMER PANELS
CONCRETE / BRICKS MASONRY / GRC / HOLLOW BLOCKS
SOUND ABSORBING MATERIALS
EARTH BERMS
PROPRIETARY MADE ACOUSTIC PANELS
GLASS, WOOD AND COMPOSITES
RECYCLED MATERIALS
MINIMUM HEIGHT SUCH THAT LINE OF SIGHT BETWEEN SOURCE AND RECEIVER IS INTERCEPTED
1.5 dBA ADDITIONAL NOISE REDUCTION FOR EACH 1 m INCREASE IN HEIGHT AFTER LINE OF SIGHT IS INTERCEPTED
PROXIMITY TO SOURCE OR RECEIVER
SHOULD EXTEND 4 TIMES AS FAR AS IN EACH DIRECTION AS DISTANCE FROM RECEIVER TO BARRIER
EXTRA DIFFRACTING EDGE
SURFACE MASS ATLEAST 20 kg/m² FOR ADEQUATE TRANSMISSION LOSS
SOUND TRANSMISSION LOSS OF BARRIER MATERIAL MUST BE AT LEAST 10 dB HIGHER THAN THE REQUIRED BARRIER ATTENUATION
QRD (QUALITATIVE RESIDUE DIFFUSERS) / PRD (PRIMITIVE RESIDUE DIFFUSERS) OPTION ADDITIONALLY INCLUDED
T- PROFILED BARRIERS WITH ABSORPTIVE MATERIAL ARE MOST EFFECTIVE

Fig. 6 Design Morphology for Noise Barriers

F-4 PERFORMANCE EVALUATION OF NOISE BARRIERS

F-4.1 To ensure the effectiveness of a noise barrier, thorough testing should be conducted to verify its performance. The intrinsic acoustic properties of the noise barriers are tested as follows.

F-4.1.1 *Diffuse Sound Field Method for Testing Sound Absorption*

This method is based on the change of reverberation time inside a reverberation chamber after installing a noise barrier testing sample at the room's surface. This testing method is characterized by a single-number rating of the sound absorption evaluation $\mathrm{DL}_{\alpha,\,\mathrm{NRD}}$, which is described by the following equation:

$$DL_{\alpha,\,\mathrm{NRD}} = -10\log_{10}\left[1-\frac{\sum_{\mathrm{i}=1}^{18}\alpha_{\mathrm{NRD,i}}10^{0.1L_{\mathrm{i}}}}{\sum_{\mathrm{i}=1}^{18}10^{0.1L_{\mathrm{i}}}}\right]$$

where, α_{NRD} is the absorptance of the test sample and L_i is the relative A-weighted sound pressure levels (dB) of the normalized traffic noise spectrum. The classification of $DL_{\alpha,\,\mathrm{NRD}}$ shall be done on the basis of Table 14.

Table 14 Categories of the Absorptive Performance

(*Clause* F-4.1.1)

Sl No. (1)	Category (2)	$DL_{\alpha,\,\mathrm{NRD}}$ (3)
i)	A0	Not determined
ii)	A1	< 4
iii)	A2	4 to 7
iv)	A3	8 to 11
v)	A4	12 to 15
vi)	A5	> 15

The value of $DL_{\alpha,\,\mathrm{NRD}}$ ranges from 0 to 20. $DL_{\alpha,\,\mathrm{NRD}}$ value greater than 8 is required for most highway projects. Close ‘corridors’, high barriers (> 3 m), and reverberant locations require noise barriers with $DL_{\alpha,\,\mathrm{NRD}}$ greater than 12. Figure 7 represents the normalized traffic spectrum in one-third octave band. The spectra is normalized to an overall value of 0 dB as its shape is more important rather than the absolute value.

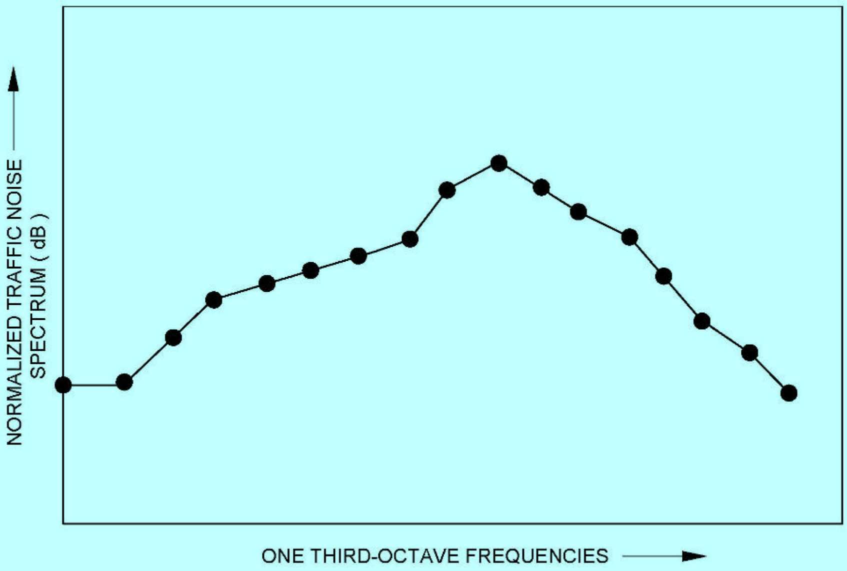


FIG. 7 NORMALIZED TRAFFIC NOISE SPECTRUM (IN DB) AT ONE THIRD OCTAVE FREQUENCY BAND

F-4.1.2 *Diffuse Sound Field Method for Testing Airborne Sound Insulation*

In this method, the noise barrier testing sample is inserted in an opening between two adjacent reverberation rooms, the ‘source room’ and the ‘receiving room’. This testing method is characterized by a single number rating, DL_R for summarizing the airborne sound insulation in third-octave bands and can be given by:

$$DL_R = -10\log_{10}\left[\frac{\sum_{i=1}^{18} 10^{0.1L_i}\, 10^{-0.1R_i}}{\sum_{i=1}^{18} 10^{0.1L_i}}\right]$$

where, R is the airborne sound insulation of the test specimen. Table 15 represents the classification of DL_R.

Table 15 Categories of the Airborne Sound Insulation Performance

(*Clause* F-4.1.2)

Sl No. (1)	Category (2)	DL_R (3)
i)	B0	Not determined
ii)	B1	= < 15
iii)	B2	15 to 24
iv)	B3	= > 24

B3 is required for the majority of highway developments. B2 may be acceptable for low barriers (less than 2 m), however, the rating level of at least 20 dB is required.

F-4.1.3 *Direct Sound Field Method for Testing Sound Reflection*

This method is based on a comparison between the sound energy reflected from the noise barrier and the sound energy emitted towards it. The third-octave band values are then averaged and weighted according to the standardized traffic noise spectrum L_i, to get a single number rating for the NRD, DL_{RI} as:

$$DL_{RI} = -10\log_{10}\left[\frac{\sum_{i=1}^{18} RI_i 10^{0.1L_i}}{\sum_{i=1}^{18} 10^{0.1L_i}}\right]$$

where, RI_i is the reflectance in i-th third-octave bands

F-4.1.4 *Direct Sound Field Method for Testing Airborne Sound Insulation*

This testing method is based on a comparison between the sound energy arriving at the microphone positions with and without the noise barrier. This testing method is characterized by a single number rating, DL_{SI}. The single-number rating by a weighted average with the standardized traffic noise spectrum L_i is described by:

$$DL_{SI} = -10\log_{10}\left[\frac{\sum_{i=1}^{18} 10^{0.1L_i} 10^{-0.1SI_i}}{\sum_{i=1}^{18} 10^{0.1L_i}}\right]$$

F-4.2 These single-number ratings can be used for the performance evaluation of noise barriers or noise reducing devices. The *in-situ* method is comparatively more reliable and yields more realistic values than the laboratory method and additionally facilitates fault detection and ascertains the acoustic durability of the NRD.

ANNEX G

(*Clauses* 3.9 *and* 4.5)

SPECIAL PROBLEMS REQUIRING EXPERT ADVICE

G-1 GENERAL

Certain design problems require reliable advice of a kind which is not easy to find in published material. The advice of an expert should be sought for these kinds of problems, some examples of which are given in G-2 to G-9.

G-2 ACOUSTIC TEST ROOMS

The design of rooms in which acoustic measurements are carried out, such as reverberation chambers, free-field anechoic rooms and audiometric test rooms, usually requires the advice of an expert.

G-3 PERFORMING SPACES

The design of theatres, opera houses, concert halls and similar performing spaces usually requires expertise in room acoustics and noise control. The intrusion of quite low levels of noise may seriously interfere with the enjoyment of the performance and distract the performers. The requirements for low noise levels often mean that more room has to be allocated for low velocity ventilation ductwork and the impact on the design of the ventilation system is often substantial.

G-4 BROADCASTING AND RECORDING STUDIOS

Broadcasting and recording studios have requirements similar to those of performing spaces. For some infrequent intrusive noises, the requirements are sometimes relaxed on the grounds that a retake of a recording can be done, but this can result in higher operating costs.

G-5 AIRCRAFT NOISE

As there are many variables affecting the level of aircraft noise heard on the ground, expert advice is almost always required. Contours of daytime $L_{\mathrm{Aeq,T}}$ levels are available from most major airports. Where measurements of façade insulation are necessary a standard test method may be referred.

G-6 GROUND-BORNE NOISE

Projects involving ground-borne noise from underground trains usually require expert advice.

G-7 LOW-FREQUENCY NOISE

Projects involving low-frequency noise usually require expert advice as accurate measurement is difficult and there is a shortage of reliable data below 100 Hz.

G-8 ACTIVE NOISE CONTROL

Active noise control is the reduction of noise by cancellation with a similar noise (anti-noise) generated by electro-acoustic means. The technique is still under development, but commercial systems are available which successfully reduce low frequency noise from mechanical ventilation systems.

G-9 NOISE SURVEYS

Noise surveys are carried out for a variety of reasons, for example:

a) Before construction, to establish the existing noise climate at the site of a proposed development where reliable prediction is impracticable, as an aid to the design of the building envelope, either to protect against external noise or contain internally produced noise;

b) During construction, to monitor noise from building activity, either to assess the likely nuisance to the local community or the risk of hearing damage to the work force;

c) At the end of a building contract to check the insulation of the building envelope, or the noise levels produced by the services;

d) As part of a planning requirement; and

e) To provide objective evidence to support or defend a legal action.

The expense of carrying out a comprehensive noise survey of any kind is likely to be high, so the cost-effectiveness of a full or partial survey should be weighed against alternatives such as prediction. A survey will generally be more accurate and can take account of factors such as prevailing wind conditions.

ANNEX H

(*Clause* 4.4)

AIRBORNE AND IMPACT SOUND INSULATION

H-1 GENERAL

Airborne sound refers to sources which produce sound by directly setting the air around them into vibration. Impact sound refers to sources which produce sound by impulsive mechanical excitation of part of a building (for example by footsteps, electric light switches, slamming doors). Many sources of impact sound also produce significant levels of airborne sound. The term structure-borne sound has no very precise meaning as the structure can be excited by both airborne and impact sources; it is often used to refer to sound that travels for long distances *via* the structure, especially in connection with vibrating machinery linked directly to the structure.

H-2 DIRECT AND INDIRECT TRANSMISSION

Figure 8 shows diagrammatically a pair of rooms in a house where the construction consists of solid walls, etc, bonded together. Sound travelling from room 1 to room 2 may travel *via* the direct path a-a and by the many indirect, or flanking, paths shown. The term flanking transmission is usually used to mean transmission paths involving the structure, while the term indirect transmission includes flanking paths and airborne paths through gaps and ducts, etc. The indirect paths may limit the sound insulation attainable no matter how much the direct sound is reduced by the separating wall or floor. The indirect transmission can be reduced by measures such as the following:

a) Increasing the mass of the flanking walls;

b) Increasing the mass of the partition and bonding it to the flanking walls;

c) Introducing discontinuities in the indirect paths;

d) Erecting independent wall linings adjacent to the flanking walls to prevent energy entering the flanking construction; and

e) Sealing any air gaps and paths through ducts.

Figure 9 shows a number of indirect paths that have been found in offices.

It is important to remember that standard test laboratories are designed to minimise transmission by all paths other than the direct path. This makes it difficult to relate the results of laboratory measurements to those likely to be obtained in the field.

H-3 AIRBORNE SOUND INSULATION

H-3.1 General

The sound insulation of structural elements such as walls and floors always varies with frequency, the insulation rising in general as the frequency rises.

H-3.2 Terminology

Results from field measurements are usually expressed in terms of the weighted standardized level difference, while laboratory measurements are usually expressed in terms of the sound reduction index. In the absence of significant flanking transmission, the numerical difference between the weighted standardized level difference and the sound reduction index of a wall or floor is usually small for furnished rooms in dwellings, and so either quantity may be used in considering principles; for this purpose, it is, therefore, convenient to use the general term insulation.

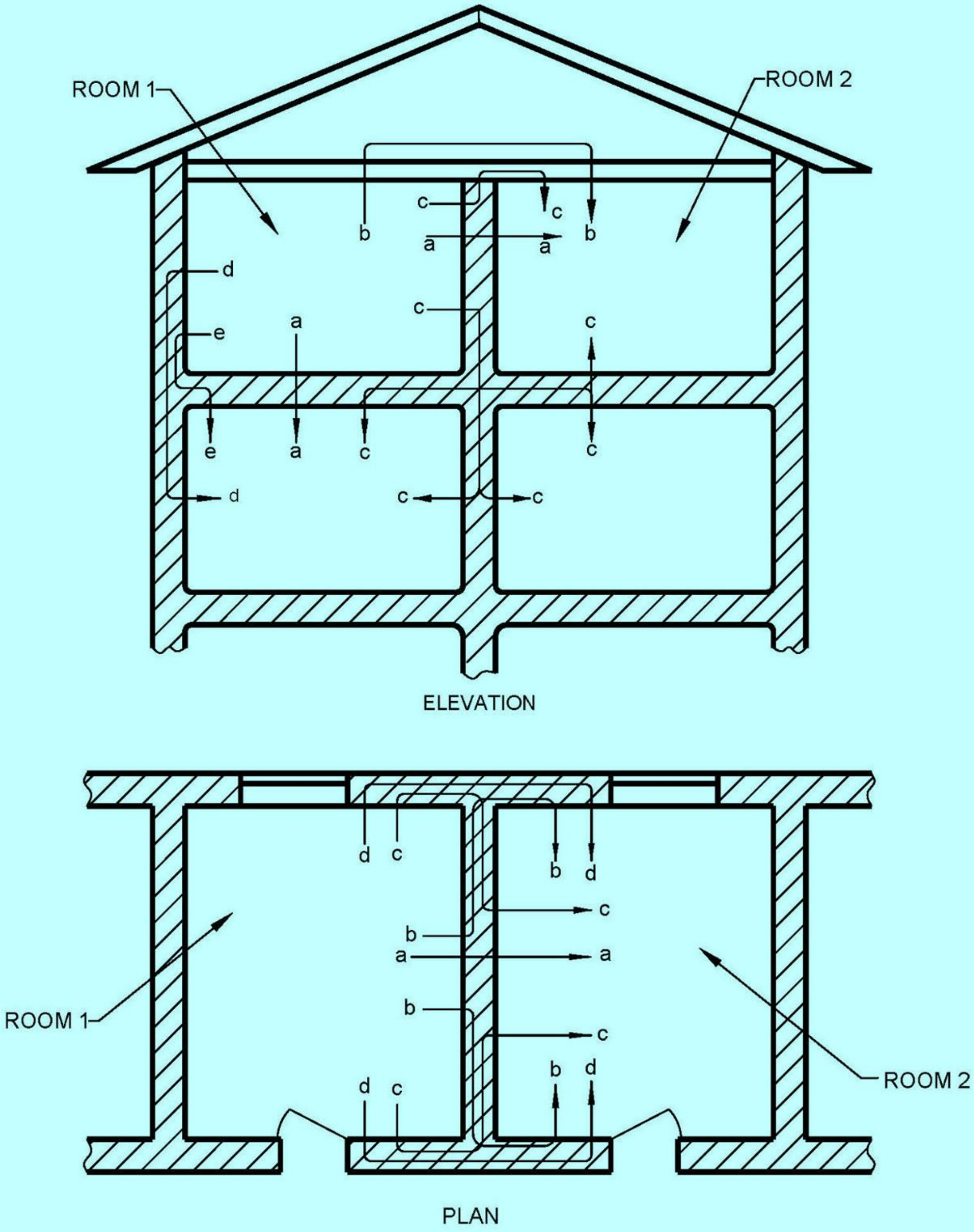
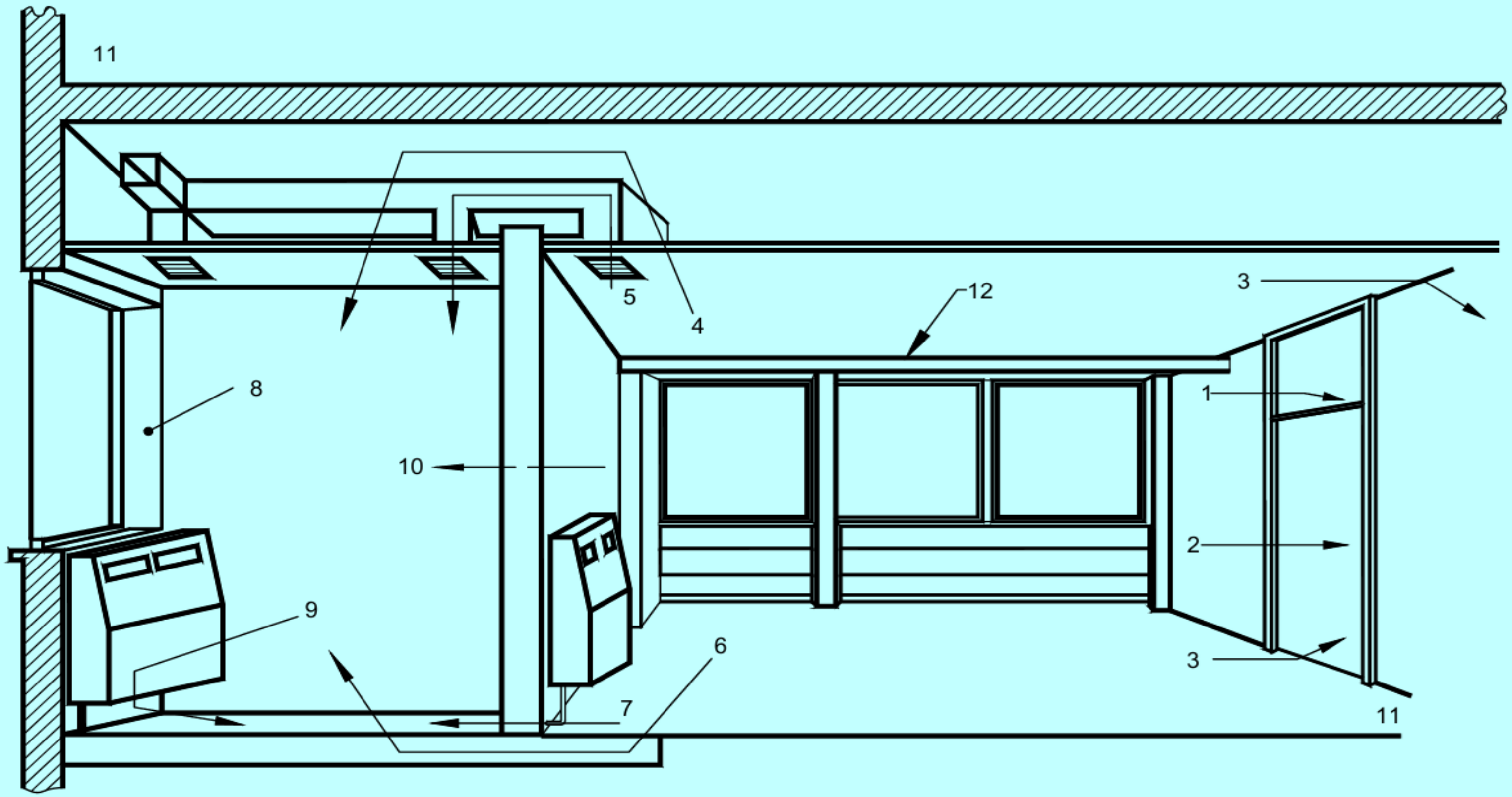

ROOM 1
ROOM 2
c
c
b
a
a
b
d
e
a
c
c
e
a
c
c
d
c
c
ELEVATION
d
c
b
d
c
b
a
a
b
c
ROOM 1
ROOM 2
d
c
b
d
PLAN

FIG. 8 TRANSMISSION PATHS (VIA THE STRUCTURE) OF NOISE ORIGINATING IN ROOM 1 (DIAGRAMMATIC)

H-3.3 Mass Law

An approximate empirical relationship has been established between sound insulation and mass for single leaf constructions as shown in Fig. 10. This so called ‘Mass Law’ gives a useful first approximation to the behaviour of a single sheet or plate. In practice, the sound insulation predicted by the mass law may not be attained because of factors such as the coincidence effect, which is outlined in H-3.4. Results for specific materials vary around the value given by the Mass Law relationship, and so measured data should be used when available.



1 LIGHT WEIGHT PANELS ABOVE DOORS
2 DOORS
3 SOUND LEAKS THROUGH GAPS, CRACKS OR HOLES
4 SOUND TRANSMISSION VIA SUSPENDED CEILINGS/PARTITIONS
5 COMMON VENTILATION SYSTEMS WITHOUT SILENCERS
6 COMMON FLOOR DUCT
7 ELECTRICAL OUTLETS AND SERVICE PIPES
8 LIGHT WEIGHT MULLIONS OR MULLION/PARTITION CLOSERS
9 CONTINUOUS SILL LINE HEATING
10 PARTITION PERFORMANCE
11 APPLIANCES
12 CONTINUOUS LIGHTING FITTINGS

FIG. 9 INDIRECT SOUND LEAKAGE PATHS

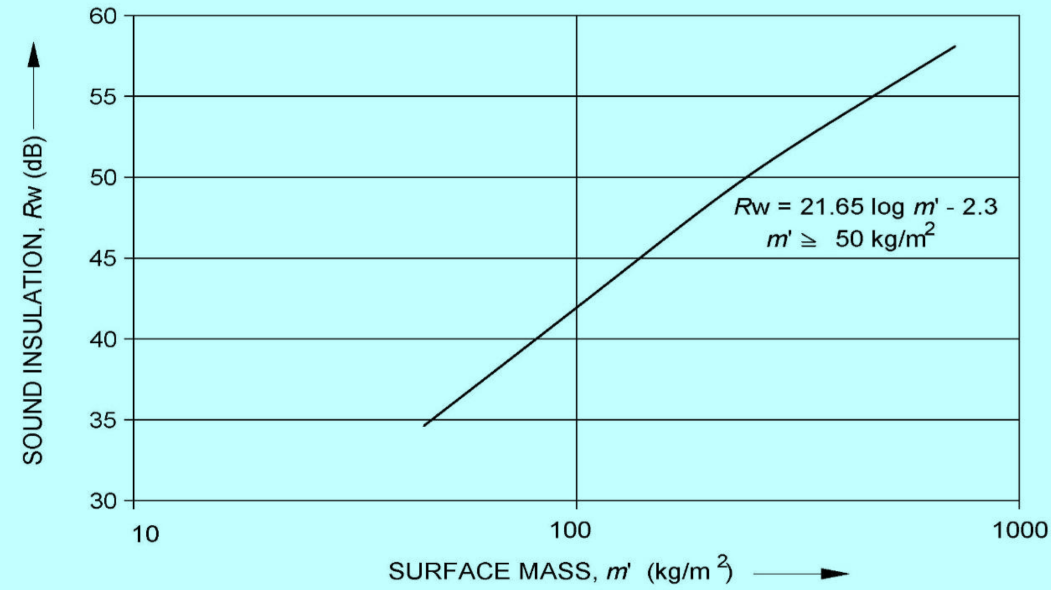


FIG. 10 MASS LAW CURVE

H-3.4 Coincidence Effect

The coincidence effect occurs when the wavelength of the wave impressed on the panel by the incident sound wave is close to the wavelength of free bending waves in the panel. The effect of coincidence is to lower the sound insulation of a construction by as much as 10 dB below the level expected from its mass per unit area over a limited frequency range. The coincidence effect can be pronounced with thin light weight partitions, resulting in loss of insulation at middle and high frequencies. Reducing the stiffness without a corresponding reduction of mass can raise the critical frequency above 3 150 Hz, and so improve the insulation over the important 100 Hz to 3 150 Hz range. An increase of stiffness will have the reverse effect.

It is possible to design lightweight stud partitions so that they perform to their maximum effect in the speech frequency region between 250 Hz and 2 000 Hz, that is between the mass-spring-mass and coincidence regions respectively.

The worst coincidence dips occur in materials such as plate glass and rigid metal sheets. Heavily damped materials such as lead sheets are least affected.

H-3.5 Mass-Spring-Mass Frequency

A double leaf wall can perform better than a single leaf wall of similar mass because the sound has to pass through two barriers. If the two leaves are not connected to each other, the insulation values of the two leaves may be added together. However, in practice the leaves are often connected by ties or studs, and the full insulation cannot be achieved. Even where the two leaves are isolated from each other, the full benefit can only be obtained above a certain frequency that depends on the cavity width. This is because the air in the cavity behaves like a spring connecting the leaves together, and causes a resonance at the mass-spring-mass frequency. Below this frequency, the two leaves behave more like an equivalent single leaf.

Making the cavity width wide can reduce the mass-spring-mass frequency, as in the case of sound insulating secondary glazing. The mass-spring-mass frequency (F_0) may be estimated from the following equation:

$$F_0 = 59.6\sqrt{\frac{1}{d}\left(\frac{1}{m_1}+\frac{1}{m_2}\right)}$$

where

m_1 and m_2 = surface masses of the two leaves, in kilograms per square metre (kg/m^2); and

d = cavity width, in metres (m).

H-3.6 Impact Sound Control

A structure that receives an impact or has a vibrating source in contact with it behaves more like an extension of the source rather than an intervening element between source and listener. For this reason, a relatively small amount of impact energy may produce a loud sound and, if the structure is continuous, the sound may travel a long distance. Control is usually obtained by inserting a resilient surface at the point of contact with the source (for example laying a carpet on a floor) or by introducing a structural discontinuity.

Floating floors, which are an example of the latter approach, are a common method of controlling impact sound from footsteps. However, it should be noted that an effective floating floor may result in increased sound from impacts on the source side of the floor.

H-4 AIRBORNE INSULATION VALUES OF WALLS AND AIRBORNE AND IMPACT INSULATION VALUES OF FLOORS

Table 16 and Table 17 give examples of common types of wall and floor construction with sound insulation in the ranges shown. The insulation indices are for field measurements accessed in accordance with good practice [D-4(5)]. The insulation values given are necessarily approximate since examples of nominally identical constructions may show variations of several decibels. All the figures represent values expected in the field, that is, in actual buildings. Many are based directly on field measurements, though other (in the absence of representative field measurements) have been assessed from laboratory data, with an allowance for typical flanking conditions in normal buildings. Variation in the amount of indirect transmission may affect significantly the insulation between two rooms separated by a given barrier. For example, the sound insulation of some types of floor may be reduced by indirect transmission along the walls supporting them, particularly if these walls are of lightweight masonry and carried past the floor.

Table 16 Airborne Sound Insulation of Walls and Partitions

(*Clause* H-4)

Sl No.	Sound Insulation $D_{nT,w}$ dB	Type of Wall or Partition
(1)	(2)	(3)
i)	26 to 33	a) 1 mm steel sheet panels fixed to steel frame members to form demountable partition units 50 mm overall thickness. Mineral wool cavity insulation b) Plywood or wood fibre board 12 mm thick nailed both sides of 50 mm × 50 mm timber framing members spaced at 400 mm centres c) Paper faced strawboard or wood wool 50 mm thick panels plastered both sides d) Chipboard hollow panels 50 mm thick tongued and grooved edges, hardboard faced. Joints covered with wood trim
ii)	33 to 37	a) Lightweight masonry blockwork. Plaster or drylining on at least one side. Overall mass per unit area not less than 50 kg/m^2 b) Laminated plasterboard at least 50 mm thick fixed to timber perimeter framing, any suitable finish. Approximate mass per unit area 35 kg/m^2 c) Timber stud partitions any size timbers greater than 50 mm × 50 mm, 400 mm centres, cross noggins, 9.5 mm plasterboard lining on both sides, any suitable finish d) Metal stud partition, 50 mm studs 600 mm centres, clad both sides with 12.5 mm plasterboard, joints filled and perimeters sealed. Approximate mass per unit area 18 kg/m^2 e) 50 mm lightweight masonry blockwork, plastered both sides to 12 mm thickness or drylined with 9.5 mm plasterboard

Table 16 (*Continued*)

Sl No.	**Sound Insulation** $D_{nT,w}$ dB	**Type of Wall or Partition**
(1)	(2)	(3)
iii)	37 to 43	a) Lightweight masonry blockwork, plaster or dry lining on at least one side. Overall mass per unit area not less than 75 kg/m^2 b) Metal stud partition, 50 mm studs 600 mm centres, clad both sides with 12.5 mm plasterboard, joints filled and perimeters sealed. 25 mm mineral fibre quilt hung between studs. Approximate mass per unit area 18 kg/m^2
iv)	43 to 50	a) Masonry wall, joints well filled. Either plaster or dry lining on both sides. Overall mass per unit area not less than 150 kg/m^2 b) 100 mm metal stud partition, `C' section studs not greater than 600 mm spacing, not less than nominal 50 mm web depth. Clad on both sides with two layers of plasterboard of not less than 25 mm combined thickness. Mineral fibre quilt hung between studs. Approximate mass per unit area 35 kg/m^2 c) 75 mm x 50 mm timbers framing using staged studs at 300 mm spacing with 25 mm stagger forward and back. Frame clad with two layers of 12.5 mm of plasterboard on both sides. Mineral fibre quilt hung between studs. Approximate mass per unit area 36 kg/m^2; d) 50 mm × 25 mm timber stud partition to form a 25 mm cavity, clad on both sides with minimum 38 mm wood wool slabs having their outer faces screeded or plastered; and e) Solid autoclaved aerated concrete block 215 mm thick plaster or dry lined finish on both sides, blockwork joints well filled. Overall mass per unit area not less than 160 kg/m^2
v)	50 to 54	a) Two separate frames of timber studs not less than 89 mm × 38 mm, or boxed metal studwork with 50 mm minimum web depth studs at 600 mm maximum centres. A 25 mm mineral wool quilt suspended between frames. Frames spaced to give a minimum 200 mm overall cavity. Clad on outside of each frame with a minimum of 30 mm plasterboard layers (for example 19 mm plus 12.5 thickness). Approximate mass per unit area 54 kg/m^2 1) b) Either in situ or pre-cast concrete wall panel not less than 175 mm thick and not less than 415 kg/m^2. All joints well filled 1) c) Brick wall nominal 230 mm thickness, weight (including plaster) not less than 380 kg/m^2. Plaster or dry-lined finish both sides. Brick work joints well filled 1) d) 'No fines' concrete 225 mm thickness, weight (including plaster) not less than 415 kg/m^2. Plaster or dry-lined finish both sides 1) e) Cavity lightweight aggregate block (maximum density of block 1 600 kg/m^3) with 75 mm cavity and wall ties of the butterfly wire type. Dry lined finish on both sides. Joints in blockwork well filled. Overall mass per unit area not less than 300 kg/m^2 1) f) Dense aggregate concrete block cavity wall with 50 mm cavity and wall ties of the butterfly wire type. Dry lined finish on both sides.

Table 16 (*Concluded*)

Sl No.	Sound Insulation $D_{nT,w}$ dB	Type of Wall or Partition
(1)	(2)	(3)
		Joints in block work well filled. Overall mass per unit area not less than 415 kg/m^2 1)
		g) Autoclaved aerated concrete block cavity wall consisting of two leaves, 100 mm blocks not less than 75 mm apart, with wall ties of the butterfly type. Plaster or dry line finish on both sides. Joints in blockwork well filled. Overall mass per unit area not less than 150 kg/m^2 1)
vi)	54 to 60	a) Two separate frames of timber studs not less than 100 mm × 50 mm spaced at 600 mm maximum centres. A 50 mm mineral wool quilt in each frame between studs. Frames spaced to give a minimum 300 mm overall cavity. Each frame clad on outside with three layers of 12.5 mm plasterboard nailed to framing. Approximate mass per unit area 51 kg/m^2 1)
		b) Two separate frames of boxed ‘C’ section galvanized nominal 150 mm steel studs 100 mm apart with a 400 mm overall cavity. 50 mm mineral wool quilt fixed to the back of one frame, each frame clad on outside with three layers of 12.5 mm plasterboard by self drilling or tapping screws. Approximate mass per unit area 47 kg/m^2 1)
		c) Solid masonry with an overall mass per unit area of not less than 700 kg/m^2 fully sealed both sides 1)
		d) Dense aggregate concrete block solid wall 215 mm thick plaster finish to both surfaces. Overall mass per unit area not less than 415 kg/m^2 1)
		e) Cavity lightweight aggregate block (maximum density of block 1 600 kg/m^3) with 75 mm cavity and wall ties of the butterfly wire type. Plaster finish on both sides. Joints in blockwork well filled. Overall mass per unit area not less than 300 kg/m^2 1)
		Dense aggregate concrete block cavity wall with 50 mm cavity and wall ties of the butterfly wire type. Plaster finish on both sides Joints in blockwork well filled. Overall mass per unit area not less than 415 kg/m^2 1)

NOTES

1 Construction details and workmanship are important if the levels of sound insulation indicated are to be achieved.

2 Where plasterboard is specified it is assumed that the surface mass will be at least 6.5 kg/m^2 for 9.5 mm thick board, at least 8.5 kg/m^2 for 12.5 mm thick board, and at least 14.5 kg/m^2 for 19 mm thick board. If less dense plasterboard is used, the thickness should be increased.

1) When considering these constructions for separating walls, expert advice should be sought.

Table 17 Airborne and Impact Sound Insulation of Floor Constructions

(*Clause* H-4)

Sl No.	Sound Insulation dB	Type of Floor Construction
(1)	(2)	(3)
i)	$D_{nT,w}$ = 49 to 54 $L'_{nT,w}$ = 56 to 65	a) A concrete floor having mass per unit area not less than 365 kg/m2, including any screed or ceiling finish directly bonded to the floor slab; together with a floating floor or resilient floor covering equivalent to rubber or sponge rubber underlay or thick cork tile (for example carpet and underlay or sponge rubber backed vinyl flooring) b) A solid floor consisting of: 1) a solid slab; or 2) concrete beams and infilling blocks; or 3) hollow concrete planks; together with a floating floor. A ceiling finish is required for a beam and block floor. In each case the slab should have a mass per unit area of at least 300 kg/m^2, including any screed or ceiling finish directly bonded to it Where a floating floor is laid over a floor of beams and hollow infill blocks or hollow beams along the top of the structural floor, it should be sealed and levelled before the resilient layer is put down. It is also essential to have due regard for conduits and pipework which should be laid and covered so as to prevent any short circuit of the floor's isolating properties If precast units are used as a structural floor, it is essential that the joints are filled to ensure that the sound insulation performance is maintained The resilient material is laid to cover completely the structural floor and turned up against the surrounding wall along all edges. The resilient layer is usually of mineral fibre, or a special grade of expanded polystyrene. When the screed is laid, it is important that none of the mix finds its way through the resilient layer to the structural floor, as this will short circuit the isolation between the two decks and significantly reduce the sound insulation A floor consisting of boarding nailed to battens laid to float upon an isolating layer of mineral fibre capable of retaining its resilience under imposed loading. With battens running along the joists, a dense fibre layer can be used in strips. The ceiling below to be of metal lath and plaster not less than 29 mm thick, with pugging on the ceiling such that the combined mass per unit area of the floor, ceiling and pugging is not less than 120 kg/m^2. This construction will only give values for $D_{nT,w}$ of 50 dB to 53 dB, and a value for $L'_{nT,w}$ of 75 dB c) A floor consisting of 18 mm tongued and grooved chipboard on 19 mm plasterboard laid on battens running parallel to the joists and supported on 25 mm thick mineral wool of about 90 kg/m^3 to 140 kg/m^3 density; 100 mm of fibre

Table 17 (*Concluded*)

Sl No.	Sound Insulation dB		Type of Floor Construction
(1)	(2)		(3)
			absorbent (as used for insulation in roof spaces) laid between the joists on top of the plasterboard ceiling 1)
		d)	A floor consisting of 18 mm tongued and grooved chipboard on 19 mm plasterboard floating on a 25 mm thick mineral wool layer of about 60 kg/m^3 to 80 kg/m^3 density; this on a 12.5 mm plywood platform; 100 mm of fibre absorbent laid between the joists on top of the plasterboard ceiling 1); and
ii)	$D_{nT,w}$ = 32 to 36 $L'_{nT,w}$ = 80 to 85		Timber joist floor consisting of 22 mm tongued and grooved floor boarding or equivalent fixed directly to floor joists. Ceiling of 12.5 mm plasterboard and skim with no floor covering

NOTES

1 Construction details and workmanship are important if the levels of sound insulation indicated are to be achieved.

2 Where plasterboard is specified it is assumed that the surface mass will be at least 8.5 kg/m^3 for 12.5 mm thick board, and at least 14.5 kg/m^2 for 19 mm thick board. If less dense plasterboard is used, the thickness should be increased.

---

1) In these types of floor construction, the ceiling may be 19 mm plus 12.5 mm plasterboard. It is imperative that the resilient layer is not punctured by nails.

In many cases, simple solid partitions give insulation values according to their mass (*see* **H-3.3**). Moreover, with partitions of this type there is usually little variation between field and laboratory test results unless the laboratory insulation exceeds 45 dB. Exceptions may occur in buildings that have not been specially designed to minimise common cavities and strongly coupled elements in lightweight panelling. The examples given are not exhaustive. Flanking structures are not listed since these can vary widely and are often dependent upon other factors such as thermal insulation, which are outside the scope of this NBCS.

ANNEX J

(*Clause* 13.1)

BASIC DESIGN TECHNIQUES FOR NOISE CONTROL IN AIR CONDITIONING, HEATING AND MECHANICAL VENTILATION SYSTEM

J-1 When selecting fans and other related mechanical equipment and when designing air distribution systems to minimise the sound transmitted from different components to the occupied spaces that they serve, the following recommendations should be considered:

a) Design the air distribution system to minimise flow resistance and turbulence. High flow resistance increases the required fan pressure, which results in higher noise being generated by the fan. Turbulence increases the flow noise generated by duct fittings and dampers in the air distribution system, especially at low frequencies;

b) Select a fan to operate as near as possible to its rated peak efficiency when handling the required quantity of air and static pressure. Also, select a fan that generates the lowest possible noise but still meets the required design conditions for which it is selected. Using an oversized or undersized fan that does not operate at or near rated peak efficiency may result in substantially higher noise levels;

c) Design duct connections at both the fan inlet and outlet for uniform and straight air flow. Failure to do this may result in severe turbulence at the fan inlet and outlet and in flow separation at the fan blades. Both of these may significantly increase the noise generated by the fan;

d) Select duct silencers that do not significantly increase the required fan total static pressure;

e) Place fan-powered mixing boxes associated with variable volume air distribution systems away from noise-sensitive areas;

f) Minimise flow-generated noise by elbows or duct branch take-offs, whenever possible, by locating them at least four to five duct diameters from each other. For high velocity systems, it may be necessary to increase this distance to up to ten duct diameters in critical noise areas;

g) Keep airflow velocity in the duct as low as possible (7.5 m/s or less) near critical noise areas by expanding the duct cross-section area. However, do not exceed an included expansion angle of greater than 15°. Flow separation, resulting from expansion angles greater than 15°, may produce rumble noise. Expanding the duct cross-section area will reduce potential flow noise associated with turbulence in these areas;

h) Use turning vanes in large 90° rectangular elbows and branch take-offs. This provides a smoother transmission in which the air can change flow direction, thus reducing turbulence;

j) Place grilles, diffusers and registers into occupied spaces as far as possible from elbows and branch take-offs;

k) Minimise the use of volume dampers near grills, diffusers and registers in acoustically critical situations;

m) Vibration isolates all vibrating reciprocating and rotating equipment if mechanical equipment is located on upper floors or is roof-mounted. Also, it is usually necessary to vibration isolate the mechanical equipment that is located in the basement of a building as well as piping supported from the ceiling slab of a basement, directly below tenant space. It may be necessary to use flexible piping connectors and flexible electrical conduit between rotating or reciprocating equipment and pipes and ducts that are connected to the equipment;

n) Vibration isolates ducts and pipes, using spring and/or neoprene hangers for at least the first 15 m from the vibration-isolated equipment;

p) Use barriers near outdoor equipment when noise associated with the equipment will disturb adjacent properties if barriers are not used. In normal practice, barriers typically produce no more than 15 dB of sound attenuation in the mid-frequency range; and

q) Table 18 lists several common sound sources associated with mechanical equipment noise. Anticipated sound transmission paths and recommended noise reduction methods are also listed in the Table 19. Airborne and/or structure-borne sound can follow any or all of the transmission paths associated with a specified sound source.

Table 18 Sound Sources, Transmission Paths and Recommended Noise Reduction Methods

[*Clause* J-1(q)]

Sl No.	**Sound Source**	**Path No. (*see* Table 19)**
(1)	(2)	(3)
i)	Circulating fans, grilles, registers, diffusers, unitary equipment in room	1
ii)	Induction coil and fan-powered VAV mixing units	1, 2
iii)	Unitary equipment located outside of room served; remotely located air-handling equipment, such as fans, blowers, dampers, duct fitting, and air washers	2, 3

Table 18 (*Concluded*)

Sl No.	**Sound Source**	**Path No.** (*see* Table 19)
(1)	(2)	(3)
iv)	Compressors, pumps, and other reciprocating and rotating equipment (excluding air-handling equipment)	4, 5, 6
v)	Cooling towers; air-cooled condensers	4, 5, 6, 7
vi)	Exhaust fans; window air conditioners	7, 8
vii)	Sound transmission between rooms	9, 10

Table 19 Sound Transmission Paths and Recommended Noise Reduction Methods

[*Clause* J-1(q) *and* Table 18]

Sl No.	**Path No.**	**Transmission Paths**	**Noise Reduction Methods**
(1)	(2)	(3)	(4)
i)	1	Direct sound radiated from sound sources to ear Reflected sound from walls, ceiling and floor	Direct sound can be controlled only by selecting quiet equipment Reflected sound is controlled by adding sound absorption to the room and to equipment location
ii)	2	Air and structure-borne sound radiated from casings and through walls of ducts and plenums is transmitted through walls and ceiling into rooms	Design duct and fittings for low turbulence; locate high velocity ducts in noncritical areas; isolate ducts and sound plenums from structure with neoprene or spring hangers
iii)	3	Airborne sound radiated through supply and return air ducts to diffusers in room and then to listener by Path 1	Select fans for minimum sound power; use ducts lined with sound-absorbing material; use duct silencers or sound plenums in supply and return air ducts
iv)	4	Noise transmitted through equipment room walls and floors to adjacent rooms	Locate equipment rooms away from critical areas; use masonry blocks or concrete for equipment room walls and floor
v)	5	Vibration transmitted via building structure to adjacent walls and ceilings, from which it radiates as noise into room by Path 1	Mount all machines on properly designed vibration isolators; design mechanical equipment room for dynamic loads; balance rotating and reciprocating equipment

Table 19 (*Concluded*)

Sl No. (1)	Path No. (2)	Transmission Paths (3)	Noise Reduction Methods (4)
vi)	6	Vibration transmission along pipes and duct walls	Isolate pipe and ducts from structure with neoprene or spring hangers; install flexible connectors between pipes, ducts, and vibrating machines
vii)	7	Noise radiated to outside enters room windows	Locate equipment away from critical areas; use barriers and covers to interrupt noise paths; select quiet equipment
vii)	8	Inside noise follows Path 1	Select quiet equipment
ix)	9	Noise transmitted to an air diffusers in a room, into a duct, and out through an air diffuser in another room	Design and install duct attenuation to match transmission loss of wall between rooms
x)	10	Sound transmission through, over, and around room partition	Extend partition to ceiling slab and tightly seal all around; seal all pipe, conduit, duct and other partition penetrations

J-2 Room Criteria (RC)

Room Criteria (RC) is the rating methodology specifically intended for rating the heating ventilation and air-conditioning system-related noise in buildings and estimate the subjective response of an occupant. The subjective character or quality of the spectrum is determined by a calculation of the Quality Assessment Index (QAI). The QAI is a measure of the degree to which the shape of the spectrum under evaluation deviates from the shape of the RC reference curve.

NOTE — The ASHRAE-developed HVAC noise rating method, RC Mark II rating is a two-dimensional expression, which takes the form, RC xx(yy). The first term, 'xx', is the value of the RC reference curve corresponding to the arithmetic average of the levels in the 500 Hz, 1 000 Hz, and 2 000 Hz octave bands; it is a quantitative descriptor, in the sense that it identifies the level of the spectrum in the principal speech frequency region. The second term, 'yy', is a qualitative descriptor that identifies the character of the sound as perceived by the listener: (N) for neutral, (LF: 16 Hz to 63 Hz) for low-frequency dominant (rumble), (MF: 125 Hz to 500 Hz) for mid-frequency dominant (roar), and (HF: 1 000 Hz to 4 000 Hz) for high-frequency dominant (hiss). There are also two sub-categories of the low-frequency descriptor: (LF_A), denoting a substantial, clearly noticeable degree of sound-induced vibration of room surfaces in lightweight interior building construction, and (LF_B), denoting a moderate, but perceptible degree of sound-induced vibration.

ANNEX K

(*Clause* 13.2)

SUGGESTED EQUIPMENT NOISE DATA SHEET

K-1 It is recommended that an equipment noise data sheet be furnished to intending bidders of mechanical equipment such as air conditioning, heating and mechanical ventilation machinery or diesel generating units specifying noise requirements at the time of request for quotation. Following is a sample noise data sheet suggested for the purpose:

SAMPLE OF EQUIPMENT NOISE DATA SHEET FOR NOISE SPECIFICATION TO BE SENT TO SUPPLIERS

Equipment Description _______________ **Type** _______________ **Item No.** _______________

Octave-Band Centre Frequency Hz	**Desired Sound Pressure Level,** L_p	**Supplier to Complete**		
		Actual	Special Design	Special Noise Control Measures Recommended
(1)	(2)	(3)	(4)	(5)
63				
125				
250				
500				
1 000				
2 000				
4 000				
8 000				

NOTES

1 The measurements of SPL shall be at a distance of 1.0 m from the equipment and 1.5 m above grade or floor. The measurement method shall be described and the point of maximum levels furnished.

2 Complete column 3 for actual levels of standard equipment.

3 Complete column 4 for special design for low noise (if such alternative is available).

4 Complete column 5 for noise control measures such as enclosure.

5 Indicate if the equipment meets the specified noise levels without modification (Yes/No).

6 If no, additional costs required :

For Column 4 ______________
For Column 5 ______________

It will be observed from the col (3), col (4) and col (5) that the buyer would get quotation for supply of standard equipment at a price P-1, whose noise characteristics would be as per col (3). Col (4) would indicate acoustical performance for a special design at a price P-2. Col (5) would indicate the acoustical performance if the owners were to provide special noise control measures for the installation (whose broad details and approximate estimated cost is also furnished by the vendor).

LIST OF STANDARDS

The following list records those standards which are acceptable as ‘good practice’ and ‘accepted standards’ in the fulfilment of the requirements of this NBCS. The latest version of a standard shall be adopted at the time of enforcement of this NBCS. The standards listed may be used for conformance with the requirements of the referred clauses in this NBCS. In the following list, the number appearing in the first column within parentheses indicates the number of the reference in this Section.

	IS No.	*Title*
(1)	IS 11050	Rating of sound insulation in buildings and of building elements
	(Part 1) : 2023	Airborne sound insulation *(first revision*)
(2)	IS 4954 : 1968	Recommendations for noise abatement in town planning
(3)	IS 2526 : 1963	Code of practice for acoustical design of auditoriums and conference halls
(4)	IS 15575	Electroacoustics — Sound level meters
	(Part 1) : 2016/ IEC 61672-1 : 2013	Specifications (*first revision*)
	IS 15575	Electroacoustics — Sound level meters
	(Part 2) : 2023/ IEC 61672-2 : 2013	Pattern evaluation tests (*second revision*)
(5)	IS 11050	Rating of sound insulation in buildings and of building elements
	(Part 1) : 2023	Airborne sound insulation (*first revision*)
	(Part 2) : 2023	Impact sound insulation (*first revision*)

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART D BUILDING SERVICES

SECTION 5 INSTALLATION OF LIFTS, ESCALATORS, MOVING WALKS AND POWER-DRIVEN PARKING SYSTEMS

5A LIFTS

BUREAU OF INDIAN STANDARDS

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FOREWORD

This NBCS (Part D/Subsection 5A) deals with the requirements for planning, design, installation, operation, maintenance and inspection of lifts (passenger lifts, goods lifts, hospital lifts, service lifts and dumb waiter) so as to ensure safe movement of people with satisfactory performance in buildings.

This Section was first published in 1970 and was subsequently revised in 1983, 2005 and 2016 as part of National Building Code of India. This Section covers the requirements for installation and maintenance of lifts and escalators in buildings. This Section should be read with Part F óFire and Life Safetyô of this NBCS from fire safety requirements point of view. The major changes in the first revision of 1983 were addition of outline dimensions of different types of lifts and requirements of escalators in buildings. Emphasis was laid on coordination between the engineer/architect and the lift manufacturer to arrive at the number and position of lifts for attaining optimum efficiency in serving the building with safety.

The significant changes incorporated in the 2005 revision included addition of new clauses/recommendations on building management system; addition of new clauses on firemanôs lift, infrared light curtain safety, and braille button for the visually impaired people and the updation of provisions as per the revised Indian Standards on lifts on which this section was based.

In the 2016 revision, the erstwhile Section 5 on lifts and escalators was divided into two subsections namely:

5A Installation of lifts

5B Installation of escalators and moving walks

The significant changes incorporated in the 2016 revision included the introduction of high-speed lifts and lifts for tall buildings, the use of lifts for fire-fighting and emergency evacuation, machine room less (MRL) lifts, the introduction to destination control system, seismic resistance aspects in lifts, performance measurements for lifts and introduction of new clause on operation and maintenance of lifts.

In this revision, publication has been renamed as National Building Construction Standards (NBCS). As a result of experience gained since the implementation of the 2016 version of this NBCS and feedback received as well as revisions of Indian Standards on which this Section was based, a need was felt to revise this Section.

The significant changes incorporated in this revision (Subsection 5A) include the following:

a) Definitions of various terms relating to energy dissipation and accumulation types, compensation means, hydraulic and electric systems, and safety mechanisms have been included to enhance clarity in performance measurement, seismic considerations, and maintenance aspects of lifts;

b) Additions have been introduced in the planning and design guidelines to address factors such as absenteeism in office buildings, provision of cafeterias and specialty facilities, population considerations for residential and hotel buildings in **4**;

c) Additions have been made in the earthing provisions to elaborate on system earthing methods (TN, TT, IT), their sub-classifications, applications, and the importance of protective equipotential bonding and earth fault protection, in **6.2.3**;

d) Provisions on flood sensors have been introduced for installation in lift pits to enable early detection of water ingress, alarm activation and safe shutdown of lifts, in **8.7**;

e) Provisions of destination control systems (DCS) for call assignments, improving passenger flow and operational efficiency have been included, in **9.11**;

f) Introduction of double-deck lift systems, with two cabins arranged one above the other, optimizing shaft use and improving efficiency in high-traffic areas and for two independent lift cabins in a single shaft solution to address up-peak and inter-floor traffic demands, in **11.7**;

h) Introduction of passenger evacuation strategies (in **11.8.1** and **11.8.2**) for both independent and joined cabin systems, enhancing safety during emergencies; and

j) Expanded requirements for machine room levels based on lift speed and shaft dimensions.

The information contained in this Section is largely based on the following Indian Standards:

IS No.	*Title*
IS 14665	Electric traction lifts:
(Part 1) : 2000	Guidelines for outline dimensions of passenger, goods, service and hospital lifts
(Part 2/Sections 1) : 2000	Code of practice for installation, operation and maintenance, Section 1 Passenger and goods lifts
(Part 3/Sections 1) : 2000	Safety rules, Section 1 Passenger and goods lifts
(Part 5 : 1999)	Specification ð Inspection manual
IS 14671 : 1999	Code of practice for installation and maintenance of hydraulic lifts
IS 15330 : 2020	Requirements of lifts for persons with disabilities (*first revision*)
IS 15785 : 2007	Installation and maintenance of lift without conventional machine rooms ð Code of practice

Assistance has also been derived from the following publications in preparation of this Subsection:

Other Standards/Other Publication	*Title*
ISO 8100-30 : 2019	Lifts for the transport of persons and goods ð Part 30: Class I, II, III and VI lifts installation
ISO 4190-5 : 2006	Lift (elevator) installation ð Part 5: Control devices, signals and additional fittings
ISO 3008-2 : 2017	Fire-resistance tests ð Part 2: Lift landing door assemblies
ISO 3864-1 : 2011	Graphical symbols ð Safety colours and safety signs ð Part 1: Design principles for safety signs and safety markings
ISO 8100-33:2022	Lifts for the transport of persons and goods Part 33: T-type guide rails for lift cars and counterweights
ISO 18738-1 : 2012	Measurement of ride quality ð Part 1: Lifts (elevators)
ISO/TS 18870 : 2014	Lifts (elevators) ð Requirements for lifts used to assist in building evacuation
EN 81-20 : 2020	Safety rules for the construction and installation of lifts ð Lifts for the transport of persons and goods ð Part 20: Passenger and goods passenger lifts
EN 81-77 : 2022	Safety rules for the construction and installations of lifts ð Particular applications for passenger and goods passenger lifts ð Part 77: Lifts subject to seismic conditions
EN 81-50 : 2020	Safety rules for the construction and installation of lifts ð Examinations and tests ð Part 50: Design rules, calculations, examinations and tests of lift components
CIBSE Guide D: 2015	Transportation Systems in Buildings 2015, The Chartered Institution of Building Services Engineers, London, U.K.

Other Standards/Other Publication	*Title*
CTBUH 2020	Emergency Evacuation: Elevator Systems Guidelines, Council on Tall Buildings and Urban Habitat, Illinois, USA

All standards, whether given herein above or cross-referred to in the main text of this Subsection, are subject to revision. The parties to agreement based on this Subsection are encouraged to investigate the possibility of applying the most recent editions of the standards.

As the regulation of land development and buildings is a State subject and is dealt by the States and local bodies such as urban local bodies within their jurisdiction through building regulatory documents like building regulations, building byelaws, and fire regulations, this document is voluntary in nature and is non-binding. The implementation depends on adoption by concerned parties or stipulations in a contract or by appropriate adoption by the concerned authorities.

For the purpose of deciding whether a particular requirement of this Subsection is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2: 2022 óRules for rounding off numerical values (*second revision*)ô. The number of significant places retained in the rounded off value should be the same as that of the specified value in this Subsection.

Important Explanatory Note for Users of this NBCS

In any Part/Section of this NBCS, where reference is made to **ógood practiceô** in relation to design, constructional procedures or other related information, and where reference is made to **'accepted standard'** in relation to material specification, testing or other related information, the Indian Standards listed at the end of the Part/Section shall be used as a guide to the interpretation.

At the time of publication, the editions indicated in the standards were valid. All standards are subject to revision and parties to agreements based on any Part/Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

In the list of standards given at the end of a Part/Section, the number appearing within parentheses in the first column indicates the number of the reference of the standard in the Part/Section. For example:

a) Good practice [D-5A(1)] refers to the Indian Standard given at serial number (1) of the List of Standards given at the end of this Part D/Subsection 5A, that is, IS 17900 (Part 1) : 2022 óLifts for the transport of persons and goods Part 1: Safety Rulesô.

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART D BUILDING SERVICES

SECTION 5 INSTALLATION OF LIFTS, ESCALATORS, MOVING WALKS AND POWER-DRIVEN PARKING SYSTEMS

5A LIFTS

1 SCOPE

1.1 This NBCS (Part D/Subsection 5A) covers the requirements for planning, design, installation, operation, maintenance and inspection of lifts (passenger lifts, goods lifts, hospital lifts, automobile lifts, service lifts and dumbwaiters) so as to ensure safe movement of people and goods with satisfactory performance.

1.2 This Subsection gives information that should be exchanged among the architect/engineer, the consulting engineer and the lift manufacturer from the stage of planning to installation including maintenance.

NOTE ð The provisions given in this Subsection are primarily for electric traction lifts; however, most of these provisions are also applicable to hydraulic lifts {*see* good practice [D-5A(1)] and [D-5A(2)}.

2 TERMINOLOGY

2.0 For the purpose of this subsection, the following definitions shall apply.

2.1 General Terms Relating to Lifts

2.1.1 *Accessibility* ð Accessibility in the context of this standard is the quality of a building or structure or a lift which enables all people irrespective of their age, gender, or abilities to access it and use its features equally and independently.

2.1.2 *Apron* ð Smooth vertical part extending downwards from the sill of the landing or car entrance.

2.1.3 *Automatic Rescue Device* (*ARD*) ð Device that operates automatically in case of failure or loss of power supply to move the lift car to a nearest landing.

2.1.4 *Automobile Lift* ð A lift designed primarily for the transport of vehicles which may however, carry a lift attendant and/or occupants of the vehicle.

2.1.5 *Available Car Area* ð Area of the car, which is available for passengers or goods during operation of the lift.

2.1.6 *Bottom Car Run-by* ð The distance between the car buffer striker plate and the striking surface of the car buffer when the car is in level with the bottom terminal landing.

2.1.7 *Balancing Weight* ð Mass which saves energy by balancing all or part of the mass of the car.

2.1.8 *Bottom Counterweight Run-by* ð The distance between the counter weight buffer striker plate and the striking surface of the counterweight buffer when the car is in level with the top terminal landing.

2.1.9 *Buffer* ð A device designed to stop a descending car or counter weight beyond its normal limit of travel by storing or by absorbing and dissipating the kinetic energy of the car or counterweight.

The buffer shall be one of the following types:

- a) Energy dissipation type; and
- b) Energy accumulation type:
  - 1) Linear type
  - 2) Non-Linear type

2.1.9.1 *Energy dissipation type* ð These are usually hydraulic buffer that dissipate the energy of the impact in the form of heat during the travel of the buffer. The hydraulic buffer falls in this category.

These types of buffers may be used whatever may be the rated speed of the lift. For example, oil buffer.

2.1.9.1.1 *Oil buffer stroke* ð The oil displacing movement of the buffer plunger or piston, excluding the travel of the buffer plunger accelerating device.

2.1.9.2 *Energy accumulation type* ð These can take the form of simple mechanical springs or polymer buffers which store the absorbed energy of the impact in the form of strain energy.

Energy accumulation type buffers, with linear and non-linear characteristics, shall only be used if the rated speed of the lift does not exceed 1 m/s.

2.1.9.2.1 *Spring buffer load rating* ð The load required to compress the spring by an amount equal to its stroke.

2.1.9.2.2 *Spring buffer stroke* ð The distance, the contact end of the spring can move under a compressive load until the spring is compressed solid.

2.1.10 *Call Indicator* ð A visual and audible device in the car to indicate to the attendant the lift landings from which calls have been made.

2.1.11 *Car Bodywork* ð The enclosing bodywork of the lift car which comprises the sides and roof and is built upon the car platform.

2.1.12 *Car Door Electric Contact* ð An electric device, the function of which is to prevent operation of the driving machine by the normal operating device of the lift unless the car door is in the closed position.

2.1.13 *Car Frame* ð The supporting frame or sling to which the platform of the lift car, its safety gear, guide shoes and suspension ropes are attached.

2.1.14 *Car Platform* ð The part of the lift car which forms the floor and directly supports the load.

2.1.15 *Control* ð The system governing starting, stopping, direction of motion, acceleration, speed and retardation of moving member.

2.1.15.1 *Variable voltage motor control* (*Generator generator field control*) ð A system of control which is accomplished by the use of an individual generator for each lift wherein the voltage applied to the driving machine motor is adjusted by varying the strength and direction of the generator field.

2.1.15.2 *Electronic control* ð A system of control which is accomplished by the use of electronic devices for driving the lift motor at variable speed.

2.1.15.3 *Alternating current variable voltage* (*ACVV*) *control* ð A system of speed control which is accomplished by varying the driving and braking torque by way of voltage variation of the power supply to the driving machine induction motor.

2.1.15.4 *Alternating current variable voltage variable frequency* (*ACVVVF*) *control* ð A system of speed control that is accomplished by varying the voltage and frequency of the power supply to the driving machine induction motor.

2.1.15.5 *Solid-state d.c. variable voltage control* ð A solid-state system of speed control which is accomplished by varying the voltage and direction of the power supply to the armature of driving machine d.c. motor.

2.1.16 *Counterweight* ð A weight or series of weights to counterbalance the weight of the lift car and part of the rated load.

2.1.17 *Compensation Means* ð Includes all ropes/coated synthetic belts/elastomeric coated ropes/chain to counterbalance suspension means.

2.1.18 *Deflector Sheave* ð An idler pulley used to change the direction of a rope lead.

2.1.19 *Door* (*Lift Landing Door and Lift Car Door*) — The door located at each floor entrance of the lift shaft, providing access to the lift car. It remains closed when the lift is not present at that level for safety, which opens and closes in synchronization with the car door, ensuring passengers' safe entry and exit.

2.1.19.1 *Door*, *centre opening sliding* ð A door which slides horizontally and consists of two or more panels which open from the centre and are usually so interconnected that they move simultaneously.

2.1.19.2 *Door*, *mid-bar collapsible* ð A collapsible door with vertical bars mounted between the normal vertical members.

2.1.19.3 *Door*, *multi-panel* ð A door arrangement whereby more than one panel is used such that the panels are connected together and can slide over one another by which means the clear opening can be maximized for a given shaft width. Multipanels are used in centre opening and two speed sliding doors.

2.1.19.4 *Door*, *single slide* ð A single panel door which slides horizontally.

2.1.19.5 *Door*, *two speed sliding* ð A door which slides horizontally and consists of two panels, one of which moves at twice the speed of the other.

2.1.19.6 *Door*, *vertical bi-parting* ð A door which slides vertically and consists of two panels or sets of panels that move away from each other to open and are so interconnected that they move simultaneously.

2.1.19.7 *Door*, *vertical lifting* ð A single panel door, which slides in the same plane vertically up to open.

2.1.19.8 *Door*, *swing* ð A swinging type single panel door which is opened manually and closed by means of a door closer when released.

2.1.20 *Door Closer* ð A device which automatically closes a manually opened door.

2.1.21 *Door Operator* ð A power-operated device for opening and closing doors.

2.1.22 *Dumb Waiter* ð A lift with a car which moves in guides in a vertical direction; has a net floor area not exceeding 1 m^2, total inside height of 1.2 m, whether or not provided with fixed or removable shelves; has a capacity not exceeding 250 kg and is exclusively used for carrying materials and shall not carry any person.

2.1.23 *Direct Acting Lift* ð Hydraulic lift where the ram or cylinder is directly attached to the car or its sling.

2.1.24 *Down Direction Valve* ð Electrically controlled valve in a hydraulic circuit for controlling the descent of the car.

2.1.25 *Drive Control System* ð System controlling and monitoring the running of the lift machine.

2.1.26 *Electrical and Mechanical Interlock* ð A device provided to prevent simultaneous operation of both up and down relays or power contactors.

2.1.27 *Electro-Mechanical Lock* ð A device which combines in one-unit, electrical contact and a mechanical lock jointly used for the landing and/or car doors.

2.1.28 *Electrical Anti-Creep System* ð Combination of precautions for hydraulic lifts against the danger of creeping.

2.1.29 *Electric Safety Chain* ð The total of the electric safety devices connected in such a way as to stop the lift when one of them is activated.

2.1.30 *Evacuation Lift* ð A lift designed to be used for the evacuation of persons, in automatic mode, or under the direction of building management, or by trained evacuation person(s).

2.1.31 *Evacuation Exit Lobby* (*EEL*) ð Destination floor(s) for evacuating persons in the building using lift(s), determined by the fire evacuation plan and which has a safe area(s).

2.1.32 *Existing Lift* ð Lift which is in service at the disposal of its owner.

2.1.33 *Floor Levelling Switch* ð A switch for bringing the car to level at slow speed in case of double speed or variable speed machines.

2.1.34 *Floor Stopping Switch* ð A switch or combination of switches arranged to bring the car to rest automatically at or near any pre-selected landing.

2.1.35 *Full Load Pressure* ð Static pressure exerted on the piping, jack, valve block, etc, with the car and rated load being at rest at the highest landing level.

2.1.36 *Geared Machine* ð A machine in which the power is transmitted to the sheave through worm and worm wheel or spur reduction gearing.

2.1.37 *Gearless Machine* ð A lift machine in which the motive power is transmitted to the driving sheave from the motor without intermediate reduction gearing and has the brake drum mounted directly on the motor shaft.

2.1.38 *Goods Lift* ð Lift mainly intended for the transport of goods and on which only the operator and the persons necessary for loading/unloading of the goods are permitted to ride.

2.1.39 *Guide Rails* ð Rigid components which provide guiding for the car, the counterweight or the balancing weight.

2.1.40 *Guide Rails Fixing* ð The complete assembly comprising the guide rails bracket and its fastenings.

2.1.41 *Guide Shoe* ð An attachment to the car frame or counterweight for the purpose of guiding the lift car or counter weight frame.

2.1.42 *Headroom/Overhead* ð The vertical distance from the level of the top lift landing to the bottom of the machine room slab/ceiling.

2.1.43 *Hoisting Beam* ð A beam, mounted immediately below the machine room ceiling/machinery space ceiling, to which lifting tackle can be fixed for raising or lowering parts of the lift machine.

2.1.44 *Hospital Lift* ð A lift normally installed in a hospital, dispensary or clinic and designed to accommodate one bed or stretcher along its depth, with sufficient space around to carry a minimum of three attendants in addition to the lift operator.

2.1.45 *Hydraulic Lift* ð Lift in which the lifting power is derived from an electrically driven pump transmitting hydraulic fluid to a jack, acting directly or indirectly on the car (multiple motors, pumps and/or jacks may be used).

2.1.46 *Indirect Acting Lift* ð Hydraulic lift where the ram or cylinder is connected to the car or the car sling by suspension means [ropes or coated steel belts (CSBs)].

2.1.47 *Jack* ð Combination of a cylinder and a ram forming a hydraulic actuating unit.

2.1.48 *Home Lift* ð A lift specifically designed for a private home taking into consideration the following:

a) compact design in view of the limitations of space in a private residence and light duty;

b) usage of the lift restricted primarily to the residents of the private home;

c) special facilities to meet the needs of elderly and persons with disabilities, including wheelchair users;

d) quiet, smooth, jerk-free movement of the lift; and

e) controls to have ease of operation.

2.1.49 *Landing Call Push* ð A push button fitted at a lift landing, either for calling the lift car or for actuating the call indicator.

2.1.50 *Landing Door* ð The hinged or sliding portion of a lift well enclosure, controlling access to a lift car at a lift landing.

2.1.51 *Levelling* ð Operation which achieves the accuracy of stopping at landings.

2.1.52 *Levelling Accuracy* ð Vertical distance between car sill and landing sill during loading or unloading of the car.

2.1.53 *Levelling Devices*

2.1.53.1 *Levelling device, lift car* ð Any mechanism which either automatically or under the control of the operator, moves the car within the levelling zone towards the landing only and automatically stops it at the landing.

2.1.53.2 *Levelling device, two-way automatic maintaining* ð A device which corrects the car level on both under run and over-run and maintains the level during loading and unloading.

2.1.53.3 *Levelling device, two-way automatic non-maintaining* ð A device which corrects the car level on both under run and over run but will not maintain the level during loading and unloading.

2.1.54 *Levelling Zone* ð The limited distance above or below a lift landing within which the levelling device may cause movement of the car towards the landing.

2.1.55 *Lift* ð Lift means a hoisting mechanism equipped with a lift car which moves in a substantially vertical direction, is worked by power and is designed to carry passengers or goods/vehicle or both.

2.1.56 *Lift Car* ð The load carrying unit with its floor or platform, enclosing bodywork and car door.

2.1.57 *Lift Landing* ð That portion of a building or structure used for discharge of passengers or goods or both into or from a lift car.

2.1.58 *Lift Machine* ð Unit which drives and stops the lift, including any motor, gear, brake, sheave and drum (traction or positive drive lift) or comprising the pump, pump motor and control valves (hydraulic drive lift).

2.1.59 *Lift Pit* ð The part of the well situated below the lowest landing served by the car.

2.1.60 *Lift Well* ð Space in which the car, the counterweight or the balancing weight travel. This space is usually bounded by the bottom of the pit, the walls and the ceiling of the well.

2.1.61 *Lift Well Enclosure* ð Any structure which separates the lift well from its surroundings.

2.1.62 *Laminated Glass* ð Assembly of two or more glass layers, each of which is bonded together with one or more plastic or liquid interlayers.

2.1.63 *Load Bearing Member* ð Steel wire rope or steel wire strand inside of an elastomeric coated belt.

2.1.64 *Machine Room* ð Fully enclosed machinery space with ceiling, walls, floor and access door(s) in which machinery as a whole or in parts is placed.

2.1.65 *Machine Room Less Lift* ð This special lift does not need a separate machine room.

2.1.66 *Machinery* ð Equipment such as: control cabinet(s) and drive system, lift machine, main switch(es) and means for emergency operations.

2.1.67 *Machinery Space* ð Volume(s) inside or outside of the well where the machinery as a whole or in parts is placed, including the working areas associated with the machinery.

NOTE ð A machinery cabinet with its associated working area(s) is considered as a machinery space.

2.1.68 *Maintenance* ð All the necessary operations to ensure the safe and intended functioning of the installation and its components after the completion of the installation and throughout its life cycle.

NOTE ð Maintenance shall include:

a) Lubrication, cleaning, etc;
b) Checks;
c) Rescue operations;
d) Operations of setting and adjustment; and
e) Repair or changing of components which can occur due to wear or tear and do not affect the characteristics of the installation.

2.1.69 *Minimum Breaking Load* (*MBL*) ð Specified value in kN below which the measured breaking load is not allowed to fall in a breaking load test.

2.1.70 *Mast* ð Structure that supports and guides the cage.

2.1.71 *Mast Section* ð Indivisible piece of mast, between two adjacent mast joints.

2.1.72 *Mast Tie* ð Connection system between the mast and any building structure, providing lateral support for the mast.

2.1.73 *Non-Return Valve* ð Valve which allows flow in one direction only.

2.1.74 *Operation* ð The method of actuating the control of lift machine.

2.1.74.1 *Automatic operation* ð A method of operation in which by a momentary activation of a call button the lift car is set in motion and caused to stop automatically at any required lift landing.

2.1.74.2 *Non-Selective collective automatic operation* ð Automatic operation by means of one button in the car for each landing level served and one button at each landing, wherein all stops registered by the momentary actuation of landing or car buttons are made irrespective of the number of buttons actuated or of the sequence in which the buttons are actuated. With this type of operation, the car stops at all landings for which buttons have been actuated making the stops in the order in which the landings are reached after the buttons have been actuated but irrespective of its direction of travel.

2.1.74.3 *Selective collective automatic operation* ð Automatic operation by means of one button in the car for each landing level served and by up and down buttons at the landings, wherein all stops registered by the momentary actuation of the car button made as defined under non-selective collective automatic operation, but wherein the stops registered by the momentary actuation of the landing buttons are made in the order in which the landings are reached in each direction of travel after the buttons have been actuated. With this type of operation, all óupô landing calls are answered when the car is travelling in the up direction and all ódownô landing calls are answered when the car is travelling in the down direction, except in the case of the uppermost or lowermost calls which are answered as soon as they are reached irrespective of the direction of travel of the car.

2.1.74.4 *Single automatic operation* ð Automatic operation by means of one button in the car for each landing level served and one button at each landing so arranged that if any car or landing button has been actuated, the actuation of any other car or landing operation button will have no effect on the movement of the car until the response to the first button has been completed.

2.1.74.5 *Group automatic operation* ð Automatic operation of two or more non-attendant lifts equipped with power-operated car and landing doors. The operation of the cars is coordinated by a supervisory operation system including automatic dispatching means whereby selected cars at designated dispatching points automatically close their doors and proceed on their trips in a regulated manner.

Typically, it includes one button in each car for each floor served and up and down buttons at each landing (single buttons at terminal landings). The stops set up by the momentary actuation of the car buttons are made automatically in succession as a car reaches the corresponding landings irrespective of its direction of travel or the sequence in which the buttons are actuated. The stops set up by the momentary actuation of the landing buttons may be accomplished by any lift in the group, and are made automatically by the first available car that approaches the landing in the corresponding direction.

2.1.74.6 *Signal operation* ð Same as collective operation, except that the closing of the door is initiated by the attendant.

2.1.74.7 *Continuous pressure operation* ð Operation by means of buttons or switches in the car and at the landings any of which may be used to control the movement of the car as long as the button or switch is manually pressed in the actuating position.

2.1.75 *Operating Device* ð A car switch, push button or other device employed to actuate the control.

2.1.76 *Overhead Beams* ð The members, usually of steel, which immediately support the lift equipment at the top of the lift well.

2.1.77 *Over Speed Governor* ð Device which, when the lift attains a predetermined speed, causes the lift to stop, and if necessary, causes the safety gear to be applied.

2.1.78 *One-Way Restrictor* ð Valve which allows free flow in one direction and restricted flow in the other direction.

2.1.79 *Passenger Lift* ð A lift designed for the transport of passengers.

2.1.80 *Passenger* ð Any person transported by a lift in the car.

2.1.81 *Position and/or Direction Indicator* ð A device which indicates on the lift landing or in the lift car or both, the position of the car in the lift well or the direction in which the lift car is travelling or both.

2.1.82 *Pawl Device* ð Mechanical device for stopping involuntary descent of the car, and maintaining it stationary on fixed supports.

2.1.83 *Positive Drive Lift* ð Lift which is directly driven (not reliant on friction) by drum and ropes.

NOTE ð In this NBCS, the term ópositive drive liftô includes drum drive.

2.1.84 *Preliminary Operation* ð Energizing of the machine and the brake/hydraulic valve as preparation to a normal run when the car is in the door zone and doors are not closed and locked.

2.1.85 *Pressure Relief Valve* ð Valve that limits the pressure to a pre-determined value by exhausting fluid.

2.1.86 *Programmable Electronic System in Safety Related Applications for Lifts* (*PESSRAL*) ð System for control, protection or monitoring based on one or more programmable electronic devices, including all elements of the system such as power supplies, sensors and other input devices, data highways and other communication paths and actuators and other output devices, used in safety-related applications

2.1.87 *Pulley Room* ð Room not containing the machine, in which pulleys are located and in which the overspeed governor should also be housed.

2.1.88 *Pulley Space* ð Space(s) inside or outside of the well where pulleys are placed.

2.1.89 *Rated Load* (*Lift*) ð In a normal operation the maximum load for which the lift car is designed and installed to carry safely at its rated speed.

2.1.90 *Rated Speed* (*Lift*) ð In a normal operation the mean of the maximum speed attained by the lift car in the upward and downward direction with rated load in the lift car at the time of normal operation.

2.1.91 *Refuge Space* ð An area of refuge is a place on the lift car roof or in the pit within the lift well designed to hold the technician/service person in safety when the car is at its highest or lowest position of the lift well, respectively.

2.1.91.1 *Bottom refuge space* ð When the lift car is at its lowest position, at least one clear area on the pit where refuge may be taken.

2.1.91.2 *Top refuge space* ð When the lift car is at its highest position, at least one clear area on the car roof where refuge may be taken.

2.1.92 *Retiring Cam/Coupler* ð A device which prevents the landing doors from being unlocked by the lift car unless it stops at a landing.

2.1.93 *Roping Multiple* ð A system of roping where, in order to obtain a multiplying factor from the machine to the car, multiple falls of rope are run around sheave on the car or counterweight or both. It includes roping arrangement of 2 to 1, 3 to 1, etc.

2.1.94 *Re-levelling* ð Operation, after the lift has stopped, to permit the stopping position to be corrected during loading or unloading.

2.1.95 *Rescue Operations* ð Specific actions required to safely release persons entrapped in the car and well by competent persons.

2.1.96 *Residual Breaking Load* (*RBL*) ð Measured value of suspension member after normal use at the end of expected life span which is detected when discard criteria have been reached.

2.1.97 *Restrictor* ð Valve in which the inlet and outlet are connected through a restricted passage way.

2.1.98 *Rupture Valve* ð Valve designed to close automatically when the pressure drops across the valve, caused by the increased flow in a pre-determined flow direction, exceeds a pre-set amount.

2.1.99 *Rack and Pinion Lift* ð Lift which uses a toothed rack and pinion as the load suspension system.

2.1.100 *Safety Gear* ð A mechanical device attached to the lift car or counterweight or both, designed to stop and to hold the car or counterweight to the guides in the event of free fall, or, if governor operated, of over-speed in the descending and/or ascending direction. Any anticipated impact force shall be added in the general drawing or layout drawing.

2.1.100.1 *Instantaneous safety gear* ð Safety gear in which the full gripping action on the guide rails is almost immediate.

2.1.100.2 *Progressive safety gear* ð Safety gear in which retardation is effected by a braking action on the guide rails and for which special provisions are made so as to limit the forces on the car, counterweight or balancing weight to a permissible value.

2.1.101 *Service Lift* ð A passenger cum goods lift meant to carry goods along with people.

NOTE ð Typically in an office building this may be required to carry food or stationeries, in a residential building to carry luggage or accommodate a stretcher and in a hotel to be used for food trolleys or baggage. There is a need in such lifts, to take care of the dimensions of the car and the door clear opening in line with the type of goods that may have to be carried based on mutual discussion between the supplier and the customer. Also, such lifts shall have buffer railings in the car at suitable height to prevent damage to the car panels when the goods are transported. Typically, such lifts, if provided with an automatic door, may use some means to detect trolleys and stretcher movement in advance to protect the doors against damage. The car floor load calculations and car area of such a lift is as in the case of a passenger lift except that these are not meant to carry heavy concentrated loads.

2.1.102 *Sheave* ð A rope wheel, the rim of which is grooved to receive the suspension ropes but to which the ropes are not rigidly attached and by means of which power is transmitted from the lift machine to the suspension ropes.

2.1.103 *Slack Rope Switch* ð Switch provided to open the control circuit in case of slackening of rope(s).

2.1.104 *Suspension Ropes* ð The ropes by which the car and counter weight are suspended.

2.1.105 *Safety Component* ð Component provided to fulfil a safety function when in use.

2.1.106 *Safety Integrity Level* (*SIL*) ð Discreet level (one out of a possible three) for specifying the safety-integrity requirements of the safety functions allocated to the programmable electronic safety-related system, where safety-integrity level 3 has the highest level of safety integrity and safety-integrity level 1 has the lowest.

2.1.107 *Safety Circuit* ð Circuit containing contacts and/or electronic components which is regarded to fulfill demands of an electric safety device.

2.1.108 *Safety Rope* ð Auxiliary rope attached to the car, the counterweight or balancing weight for the purpose of tripping a safety gear in case of suspension failure.

2.1.109 *Shut-off Valve* ð Manually operated two-way valve which may permit or prevent flow in either direction.

2.1.110 *Single Acting Jack* ð Jack in which displacement in one direction is by fluid action and in the other by influence of gravity.

2.1.111 *Special Tool* ð Tool unique to the equipment required in order to keep the equipment in a safe operating condition or for rescue operations.

2.1.112 *Stopping Accuracy* ð Vertical distance between car sill and landing sill at the moment when a car is stopped by the control system at its destination floor and the doors reach their fully open position.

2.1.113 *Suspension Means* ð Includes all ropes/elastomeric coated belts suspending car/counterweight/balancing weight and is engaged to car/counterweight/balancing weight side termination.

2.1.114 *Suspension Member* ð Is one rope/elastomeric coated belt in the system to suspend car/counterweight and is engaged to car/counterweight side terminations.

2.1.115 *Terminal Slow-Down Switch* ð A switch when actuated shall compulsorily cut off the high speed and switch on the circuitry to run the lift in levelling speed before reaching on terminal landings.

2.1.116 *Terminal Stopping Switch Normal* ð Switch for cutting off all the energizing current in case of car travelling beyond the top or bottom terminal landing or a switch that cuts off the energizing current so as to bring the car to a stop at the top or bottom terminal landing level in the respective direction of travel.

2.1.117 *Terminal Stopping Device Final* ð A device which automatically causes the power to be removed from an electric lift driving machine motor and brake, independent of the functioning of the normal terminal stopping device, the operating device or any emergency terminal stopping device, after the car has passed a terminal landing.

2.1.118 *Top Counterweight Clearance* ð The shortest vertical distance between any part of the counterweight structure and the nearest part of the overhead structure or any other obstruction when the car floor is level with the bottom terminal landing.

2.1.119 *Travel* ð The vertical distance between the bottommost and topmost lift landings served by the lift.

2.1.120 *Traction Lift* ð Lift whose suspension means are driven by friction on the driving sheave of the machine.

2.1.121 *Travelling Cable* ð Flexible electric cable containing multiple cores between the car and a fixed point.

2.1.122 *Unintended Car Movement* ð Non-commanded movement of the car with doors open within the door zone away from the landing, excluding movements resulting from loading/unloading operation.

2.1.123 *Unlocking Zone* ð Zone, extending above and below the landing level, in which the car floor has to be, to enable the corresponding landing door to be unlocked.

2.1.124 *User* ð Person making use of the services of a lift installation which includes passengers, persons waiting at the landings and authorized persons.

2.2 Terms Relating to Performance Requirements for Lifts

2.2.1 *A*95 ð Values of acceleration or vibration within defined boundaries or limits, in which 95 percent of found values are equal to or less than.

NOTE ð This value is used statistically to estimate typical levels.

2.2.2 *Acceleration* ð Rate of change of z-axis velocity, attributed to lift motion control.

NOTE ð It is expressed in metre per second squared (m/s^2).

2.2.3 *Axis of Measurement* ð Orthogonal reference axes for the measurements, where for lifts of conventional configuration:

a) *X-axis* ï Axis perpendicular to the plane of the car front door (that is, back to front);

b) *Y-axis* ï Axis perpendicular to X and Z (that is, side to side); and

c) *Z-axis* ï Axis perpendicular to the car floor (that is, vertical).

2.2.4 *Equivalent Sound Pressure Level* (L_{Aeq}) ð Average sound pressure level, using frequency weighting A and time weighing ófastô, determined within defined boundaries.

2.2.5 *Jerk* ð Rate of change of z-axis acceleration, attributed to lift motion control. It is expressed in meter per second cube (m/s^3).

NOTE ð The passenger perception of vertical ride quality during jerk is represented by the assessment of vertical vibration during non-constant acceleration.

2.2.6 *Lift Ride Quality* ð Sound levels in the car and vibration of the car floor, relevant to passenger perception, associated with lift motion.

2.2.7 *Peak to Peak Vibration Levels* ð Sum of the magnitudes of two peaks of opposite sign separated by a single zero crossing.

2.2.8 *Sound* ð A-weighted sound pressure level measured in decibels (dB).

2.2.9 *Sound Pressure Level* ($L_{p,A}$) ð Sound pressure level using frequency weighting A as defined in Part D óBuilding Services, Section 4 Acoustics, Sound Insulation and Noise Controlô of this NBCS:

$$L_{p,A} = 10 \log (p_A^2/p_0^2) \text{ dBA}$$

NOTES

1 The reference sound pressure level (p_0) is 20 ÕPa (2 Ï 10^{-5} Pa).

2 The measured sound pressure, p_A, is in Pascals (Pa), using frequency weighting A.

2.2.10 *V*95 ð Value of velocity, within defined boundaries or limits, in which 95 percent of found values are equal to or less than the defined limits.

NOTE ð This value is used statistically to estimate typical levels.

2.2.11 *Velocity* ð Rate of change of z-axis displacement, attributed to lift motion control.

NOTE ð Velocity is reported as speed and direction of travel. It is given in meters per second (m/s).

2.2.12 *Vibration* ð Variation with time of the magnitude of acceleration, when the magnitude is alternately greater and smaller than the average acceleration of the lift when no lift motion acceleration is present.

NOTES

1 It is expressed in metre per second squared (m/s^2).

2 The deprecated unit Gal (Galileo) is sometimes used: 1 Gal = 0.01 m/s^2

2.3 Terms Relating to Planning and Design of Lifts

2.3.1 *Door Closing Time* (t_c) ð Time period measured from the instant that car doors start to close until the doors are closed.

NOTE ð The door closing time is expressed in second (s).

2.3.2 *Door Opening Time* (t_o) ð Time period measured from the instant that car doors start to open until they are open to a specified width.

NOTES

1 Measurement may be completed at the instant that the doors are either 800 mm open or until the doors are fully open.

2 The opening width used shall be reported.

3 The door opening time is expressed in second (s).

2.3.3 *Performance time/Door-to-Door Time* (t_{pref}) ð Period of time between the instant the car doors start to close and the instant that the car doors are open to a specified width at the next adjacent floor.

NOTES

1 The performance time is expressed in seconds (s).

2 Measurements may be completed at the instant that the doors are 800 mm open or until the doors are fully open.

2.3.4 *Handling Capacity* (C_h) ð Maximum sustainable number of passengers per specified time period that a single lift or a group can transport for a specific traffic mix under specified loading constraints.

NOTES

1 Handling capacity is usually expressed as a number of passengers per five minutes (C_h) or as a percentage of population per 5 min (percent C_h).

2 Typical loading constraints are limiting the number of passengers in the cars and are determined by comfort and/or safety considerations that may reflect cultural and/or national norms.

3 The average waiting time increases rapidly and passengers are constantly left behind the departing lift, when passenger demand exceeds handling capacity.

2.3.5 *Interval* (*INT*) ð Time period between successive car arrivals at the main terminal floor with cars loaded to any value.

2.3.6 *Nominal Travel Time/Theoretical Time of Travel* (t_{nt}) ð Time period in seconds for a lift to travel from the lowest floor to the highest floor without any stops at rated speed.

NOTE ð The nominal travel time is expressed in second (s).

2.3.7 *Passenger Arrival Rate* ð Percentage of a buildingôs population arriving within a 5 min period.

2.3.8 *Passenger Transfer Time* (t_p) ð Average time for a single passenger to enter or leave the lift car.

NOTES

1 The passenger usually moves out faster than they move in. Transfer time is an average of both of them.

2 The passenger transfer time is expressed in second (s).

2.3.9 *Passenger Waiting Time* (*WT*) ð Period of time from when a passenger either registers a call on a landing, or joins a queue, until the responding lift that will accommodate the passenger begins to open its doors at the boarding floor.

NOTES

1 The passenger waiting time continues if a passenger does not enter the responding lift, that is, it is full (a refusal).

2 The passenger waiting time is zero, if the responding lift doors are open or opening when the passenger arrives.

3 There may be difference between waiting times measured at a site and waiting times produced by a simulation due to the difficulty of accurately measuring waiting times at an actual site.

2.3.10 *Round Trip Time* (t_{rt}) ð Average period of time for a single lift car trip during up-peak traffic conditions, measured from the time the car doors open at the main terminal until the car doors reopen at the main terminal after serving the registered car calls.

NOTE ð The round-trip time is expressed in second (s).

2.3.11 *Single Floor Flight Time* (t_{f1}) ð Period of time measured from the instant that the car doors are locked until the lift is level at the next adjacent floor.

2.3.12 *Single Floor Transit Time* (t_v) ð Period of time required to transit two adjacent floors at rated speed.

2.3.13 *Sky Lobby* ð A sky lobby is the main floor for local groups in the upper part of a very tall building.

2.3.14 *Door Closing Delay Time* (t_{cd}) ð Delay after passenger clearance before start of door closing.

NOTE ð The door closing delay time is expressed in second (s).

2.3.15 *Express Zone* — Building zone situated between an entrance floor and served floors where lift travel nonstop.

2.3.16 *Door Pre-Opening Time/Advance Door Opening Time* (t_{pre}) ð Time period measured from the instant that car doors start to open until the lift is level at the landing.

NOTES

1 Door pre-opening may compensate for lift levelling, which is the final (slow) approach of the lift to a landing.

2 The pre-opening time is expressed in second (s).

2.3.17 *Incoming Traffic* ð Component of traffic where passengers travel from entrance floors to the populated floors.

2.3.18 *Inter-Floor Traffic* ð Component of traffic where passengers travel between the populated floors.

2.3.19 *Outgoing Traffic* ð Component of traffic where passengers travel from the populated floors to entrance floors.

2.3.20 *Population* (U) ð Maximum population a target building is going to be designed.

2.3.21 *Start Delay Time* (t_{sd}) ð Perion of time from the instant the car doors are close until the lift starts to move.

NOTE ð The start delay time is expressed in second (s).

2.3.22 *Flight Time* (t_f) ð Period of time from the instant the lift starts to move until the lift is level at the next stop floor.

NOTE ð Flight time is usually calculated by assuming ideal lift kinematics based on the rated speed, rated acceleration and jerk.

2.3.23 *Entrance Floor* ð Floor with building entrance or utility floor, that is, restaurant, which attract people from populated floors.

2.3.24 *Entrance Bias* ð Proportion of traffic attributed to a specific entrance floor.

2.3.25 *Transit Time* ð Period of time from when a responding lift begins to open its doors at the boarding floor until the doors begin to open again at the destination floor.

NOTE ð The transit time commences when a passenger arrives, if the responding lift doors are open or opening.

2.4 Terms Relating to Seismic Operation of Lifts

2.4.1 *Design Acceleration* (a_d) ð The horizontal acceleration to be used for calculation of forces (moments acting on lift systems and arising from seismic events).

NOTE ð The value of (a_d) shall be obtained by the lift manufacturer from the building engineer/structural engineer.

2.4.2 *Normal Operation* ð Operation mode in which the lift performs when not in seismic mode or in seismic stand-by mode.

2.4.3 *Retaining Device* ð Mechanical device securely fixed to a structural member of the lift car, counterweight frame designed to retain the lift car and counterweight within its guide rails during seismic activity.

2.4.4 *Seismic Mode* ð Special mode in which the lift operates after detection of seismic trigger level.

2.4.5 *Seismic Stand-By Mode* ð Special mode in which the lift operates after detection of primary earthquake wave without the activation of the seismic detection system.

2.4.6 *Seismic Trigger Level* ð Seismic acceleration which is used to activate a seismic detection system.

2.4.7 *Snag Point* ð The point of interference between flexible elements (for example, ropes, chains, travelling cable, etc) and fixed elements (for example, guide rail brackets, guide rail clip bolts, fishplates, vanes and similar devices).

2.5 Terms Related to Maintenance of Lifts

2.5.1 *Competent Maintenance Person* ð Designated person, suitably trained, qualified by knowledge and practical experience, provided with necessary instructions and supported within their maintenance organization to enable the required maintenance operations to be safely carried out.

2.5.2 *Installation* ð Completely installed passenger lift or good passenger lift or accessible goods only lift or service lift.

2.5.3 *Installer* ð Natural or legal person who takes responsibility for the design, manufacture, installation and placing on the market of lifts.

2.5.4 *Maintenance Organization* ð Company or part of company where competent maintenance person(s) carry out maintenance operation on behalf of the owner of the installation.

2.5.5 *Manufacturer* ð Natural and legal person who takes responsibility for the design, manufacture and placing on the market either of safety components for lifts or complete lift.

2.5.6 *Owner of the Installation* ð Natural or legal person who has the power of disposal of the installation and takes responsibility for its operation and use.

2.5.7 *Inspector* ð Inspector means an inspector of lifts or any other officer appointed and approved by State/Union Government to maintain *Lift Act*/*Rules* or any *other Act*/*Rules* connected with safety of lifts and framed by State/Union Government

2.5.8 *Authorized Person* ð Person with the permission of the natural or legal person who has the responsibility for the operation and use of the lift, to access restricted areas (machinery spaces, pulley rooms and lift well) for maintenance, inspection or rescue operations.

2.5.9 *License* ð A permission granted by competent authority to engage in a business or occupation or in an activity otherwise unlawful.

3 GENERAL

3.1 Conformity with Lifts Act and Rules

3.1.1 The installation shall generally be carried out in conformity with *Lifts Act* and *Rules*, wherever they are in force.

3.1.2 It is the responsibility of the owner of the premises where the lift will be installed, to obtain necessary permission from the Authority before and after the installation of lifts and for subsequent operation of lifts.

3.1.3 A license for public use is a safety provision, issued by state authorities under *Lifts Act* and *Rules*, wherever they are in force and shall be obtained as per the laid down statutory requirement.

3.2 Conformity with *The Electricity Act* and CEA Regulations Thereunder

All electrical work in connection with installation of lifts shall be carried out in accordance with the provisions of the *Electricity Act*, 2003 as amended up-to-date along with the CEA regulations framed thereunder and shall also comply with the other provisions of Part D óBuilding Services, Section 2 Electrical and Allied Installationsô of this NBCS.

3.3 Conformity with Indian Standards

All materials, fittings, appliances, etc, used in electrical installation shall conform to Indian Standard specifications wherever these exist. In case of materials for which Indian Standard specifications do not exist, the materials shall be approved by the competent authority. For detailed specification for lifts, reference shall be made to accepted standards [D-5A(2)].

3.4 Conformity to Accessibility Requirements

All lifts installed for public use shall meet the accessibility requirements in accordance with good practice [D-5A(3)].

3.5 Conformity with Fire Regulations

The installation shall be carried out in conformity with the state fire acts/local fire regulations, wherever they are in force (*see also* Part F óFire and Life Safetyô of this NBCS for guidance purpose).

3.6 Considerations for Selection of Lifts

The considerations for selection of lifts shall be based on the following criteria:

a) *The Intended use of lift* ð The number of lifts and their capacities (that is, load and speed) required for a given building shall be suitably decided to meet the intended requirement. The passenger lifts shall meet the requirements of handling capacity and waiting time for passenger, depending on the liftôs expected usage and building type.

b) *System performance* ð System performance criteria shall be based on building type (residential, commercial, hotel, hospital, etc).

c) *Accessibility requirements* ð *See* **3.4**.

d) *Environmental conditions* ð Lifts directly exposed to atmospheric conditions, that is, weather (for example, those meant for external applications), or any other adverse condition shall be appropriately designed and protected for that particular condition.

e) *Type of main drive for lift* ð Whether electric traction, geared or gearless or hydraulic depending on speed, stops/travel height and capacity requirement.

f) *Civil engineering requirements* ð Machinery location that is, machinery to be located in machine room or machinery to be kept inside lift well thereby eliminating conventional machine room.

g) *Seismic considerations* ð Whether the lift is to be protected against seismic forces or whether the lift is to be rescued to a landing on detection of earthquake or both.

3.7 Maintenance

The considerations relating to maintenance shall be as follows:

a) The lift installation shall receive regular cleaning, lubrication, adjustment and adequate servicing by authorized competent persons at such intervals as per type of equipment and frequency of service demand. It is desirable and normal for the lift supplier to be entrusted with the servicing during the guarantee period of new lift.

b) In order that the lift installation is maintained at all times in a safe condition, a proper maintenance schedule shall be drawn up in consultation with the lift manufacturer and rigidly followed. The provision of a log book to record all items relating to general servicing and inspection is recommended for all lifts.

c) Any accident arising out of operation or maintenance of the lifts shall be duly reported to the authority in accordance with the rules laid down.

d) Lifts are required by statutory regulations to be examined at regular intervals as specified by lift acts, by a competent person.

e) The company entrusted with maintenance contract shall have valid licence to maintain the lifts. The persons assigned for maintenance work shall be appropriately qualified and experienced as required by *lLift Acts* and *Rules*.

3.8 Energy Efficiency and Sustainability

Design options like space restrictions, reliability and safety, riding comfort have been the major market and technological drivers. The following should be encouraged for reducing power consumption and promoting sustainability in buildings:

a) Use of energy efficient a.c. variable voltage variable frequency (VVVF) motor drive or equivalent. Lifts with 1-speed and 2-speed motor control are not recommended for passenger lifts because of high power consumption, poor passenger comfort and tripping hazard;

b) When the lift has answered the last call and stopped at a landing and no further landing call is registered, the car and landing doors shall close. If there is no further landing call after pre-determined period but not less than 90 s, the light and fan inside the car shall both be automatically switched off. Car lights and fan shall switch on automatically before the lift doors start to open or the lift is set in motion;

c) Under normal operating status, at least one lift car of a lift bank shall operate under a standby or sleep mode during off-peak period when the traffic demand on the vertical transportation system is low. During low demand periods, even completely shutting down one or more lifts within a group can be a good energy saving option, without compromising the quality of service;

d) Where a number of lifts are installed together, their controls are interconnected to optimize their operation. By efficiently delivering passengers with the least number of trips, starts and stops, the energy consumed is significantly reduced;

e) Use of energy saving LED lamps for car lighting in place of conventional lamps;

f) Use of gearless type machines to reduce transmission losses;

g) Improvement in total power factor of the motor drive of a lift at the isolator connecting lift to the buildingôs electrical supply circuit;

h) Use of regenerative drives to recycle energy rather than wasting it as heat. The regenerated energy may be used for charging batteries, staircase lighting, lobby lighting, etc;

j) Use of high efficiency motors such as permanent magnet synchronous motors, or induction motors having minimum efficiency class equivalent to IE2 as per accepted standard [D-5A(4)]; and

k) Adoption of materials and practices that are environmentally friendly and sustainable.

4 PLANNING AND DESIGN GUIDELINES

This clause provides guidelines for traffic analysis and minimum vertical transportation requirements; and is not a substitute for detailed understanding of the complex theory and the required practical experience.

4.1 The planning guidelines, design considerations, and precautions to be exercised during design of passenger and goods lifts operated by electric traction are provided hereunder. Manufacturer may be consulted for other types of lifts such as hydraulic, home, automobile lifts, etc.

Design of lifts necessarily calls for coordination among various parties concerned, namely the client, the architect/engineer, the consulting engineers and the lift manufacturer. These guidelines give the information from the stage of planning till the design that should be exchanged between parties. It is essential that all the parties involved in the planning should have a clear understanding of the basis and the theory of planning. All parties involved need to recognize that it is highly impractical to correct badly planned lifts in a building as no changes can be carried out to the building core, if the number of hoist-ways is inadequate or of wrong size or wrongly positioned.

These provisions specify requirements for the architects/engineers, builders/developers and tenderers while finalizing specification of lifts. Two basic considerations, namely, the quantity of service required and the quality of service desired, determine the number and type of lifts to be provided in a particular building. The quantity of service factor, that is, how many people might use the lift system over a defined period of time is represented by the handling capacity. The quality of service factor, that is, how well the lift system deals with its passengers is represented by passenger waiting time and lobby queuing. These factors are interrelated and depend, among other things, on the type of building and its use and on the type of occupier. Both these factors require proper study into the character of the building, extent and duration of peak periods, frequency of service required, type and method of control, type of landing doors, etc.

Figure 1 shows the flow chart to arrive at a reasonable vertical transportation solution for a building.

The adequacy of the lift group in a building is a major contributing factor to the success or failure of a building. Users of lifts would be intolerant of long queues and long waiting times. The planning and selection of the vertical transportation equipment is a specialized activity. Although the basic calculations are relatively simple, the theory on which they are based is complex. The difficulty in planning a lift installation is not only in calculating its probable performance but also in estimating the passenger demand and usage patterns. The architect/engineer doing the planning work should establish the lift system at a very early stage in consultation with the lift manufacturer/consulting engineer and not after the rest of the building has been designed.

This Subsection defines the calculation approach for conventional two button dispatching and does not define calculation methods for destination control systems or hybrid systems. It also does not define an approach to simulation methods as consensus on how to apply simulation has not been established.

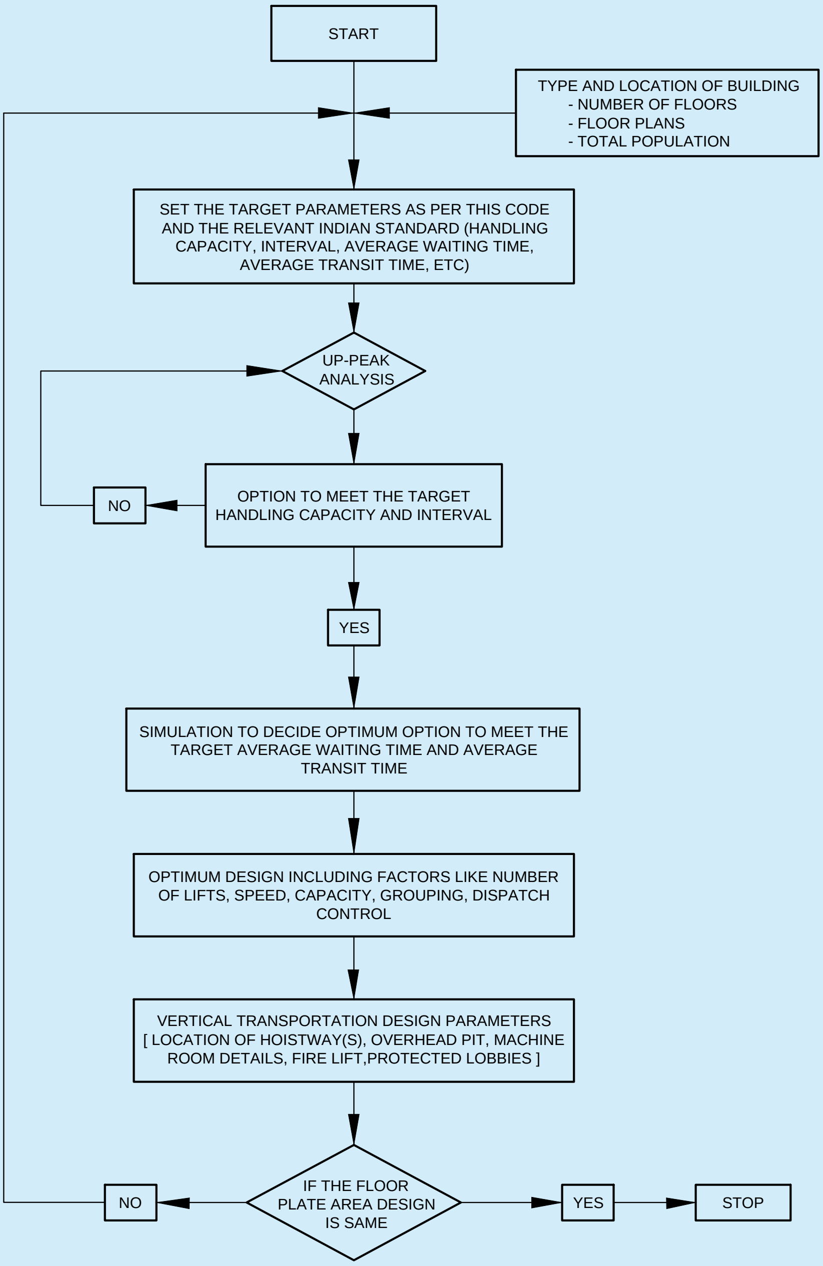

START
TYPE AND LOCATION OF BUILDING
- NUMBER OF FLOORS
- FLOOR PLANS
- TOTAL POPULATION
SET THE TARGET PARAMETERS AS PER THIS CODE AND THE RELEVANT INDIAN STANDARD (HANDLING CAPACITY, INTERVAL, AVERAGE WAITING TIME, AVERAGE TRANSIT TIME, ETC)
UP-PEAK ANALYSIS
NO
OPTION TO MEET THE TARGET HANDLING CAPACITY AND INTERVAL
YES
SIMULATION TO DECIDE OPTIMUM OPTION TO MEET THE TARGET AVERAGE WAITING TIME AND AVERAGE TRANSIT TIME
OPTIMUM DESIGN INCLUDING FACTORS LIKE NUMBER OF LIFTS, SPEED, CAPACITY, GROUPING, DISPATCH CONTROL
VERTICAL TRANSPORTATION DESIGN PARAMETERS [LOCATION OF HOISTWAY(S), OVERHEAD PIT, MACHINE ROOM DETAILS, FIRE LIFT,PROTECTED LOBBIES]
NO
IF THE FLOOR PLATE AREA DESIGN IS SAME
YES
STOP

FIG. 1 TYPICAL FLOWCHART ON PRELIMINARY DESIGN OF LIFTS

4.2 Preliminary Lift Planning

4.2.1 Two models can be used for lift traffic analysis and design:

a) The first model uses a calculation method based on mathematical formulae. This classical model uses the pure up-peak condition as this provides a well-defined, simple traffic pattern amenable to mathematical analysis. These calculations can be carried out manually, using a spreadsheet or by using computer based programme; and

b) The second model is based on discrete digital simulation of the movement of lifts in a building and the passenger dynamics. This simulation model allows very complex situations to be analysed and is generally capable of better evaluations. However, simulation approaches and algorithms vary with software ranging from crude to very sophisticated. With the varied approaches and lack of consensus on simulation approaches and how to apply simulation this standard does not define standards for simulation, however passenger generation for simulation model should be for 120 min and should cover a minimum of 3 intervals (each of 5 min) to co-relate with practical situation.

Generally, if a lift system (using a conventional landing call system) is sized correctly for the up-peak traffic pattern, all other traffic patterns should be adequately served. The notable exceptions to this, are:

1) hotels where check-in/check-out clashes with meal times;
2) hospitals;
3) buildings that open at specified times (example, stock exchanges, movie theatres, stadiums);
4) buildings with 24 Ĭ 7 operation and shift changes (example, BPO/ITES buildings);
5) buildings with amenities located at higher floors (example, roof top restaurant, cafeterias, health clubs);
6) residential buildings (sometimes two-way traffic is considered);
7) buildings with multiple entry levels;
8) parking towers;
9) schools where students change floors or buildings at the beginning and end of classes; and
10) mixed-use buildings.

Methods of calculating the traffic handling capabilities of lifts were first devised for office buildings. In due course detailed modifications were devised to suit other applications without altering the basic principles. The application to office buildings is the most frequently used, and is outlined in **4.2.2** to **4.2.9** as a general approach to lifting.

Subsequently, traffic conditions other than up peak are examined as also building types other than office. It is recommended that calculations based on the classical model should be carried out in order to obtain an understanding of the various factors. A simulation may then be performed in order to cover special situations or to obtain information not provided by the calculation method.

4.2.2 *Population*

4.2.2.1 The first point to be ascertained from the owner/developer or proposed occupier is the total building population. If a definite population figure is not available, then an estimation should be made using floor areas, more specifically, the net usable area (NUA). The NUA excludes circulation areas (stairs, corridors, foyers, etc), structural intrusions (columns, ducts, etc) and facilities (pantry, kitchens, toilets, conference rooms, training rooms, server rooms, storage areas, etc).

4.2.2.2 The number of people occupying the net usable area can vary according to the usage pattern or building type. Because of the criticality of establishing the population, it is recommended that the architect/engineer should prepare a typical test fit to establish an estimate of the population. The test fit estimates can be validated from population counts from buildings with similar usage patterns and types.

4.2.2.3 *Absenteeism*

While the absenteeism is subjected to input from the developer/tenants, studies have shown that in many office buildings it is unlikely that all the total population is present on any one day. Where this is known to be the case the building population to be used in a design may be reduced by 10 percent to 20 percent on account of persons working from home, holiday, sickness, travelling, vacant posts, etc. It would be impractical to consider absenteeism beyond 20 percent of total population. The designer shall note that the absenteeism shall be applied only for office buildings. Absenteeism factor shall not be considered for residential buildings, hotels or hospitals.

People arriving in morning adopts a bell curve arrival pattern. Designers shall not adopt any additional diversity towards people arriving before peak period/after peak period. The designers need to understand the clear circulation and movement pattern of the occupants (and goods) of a building and design to facilitate the circulation and movement. Table 1 gives typical values for the density of population.

Table 1 Occupancy Area Per Person in Office Buildings

(*Clause* 4.2.2.3)

Sl No.	**Building Type**	**Open Plan/ Hall Seating**	**Cellular Plan/Cabins**
(1)	(2)	(3)	(4)
i)	Premium	10 m^2	12 m^2
ii)	Regular	8 m^2	10 m^2
iii)	Low end	5 m^2	8 m^2

For certain specialized building functions such as BPO, areas ranging from 6 m^2 to 10 m^2 per person may be considered.

4.2.3 *Quantity of Service*

It is measured in terms of the total number of passengers handled during the peak 5 min period of the day. This is calculated by determining the number of trips made by the lifts over the peak 5 min period and then multiplying it by the average number of passengers carried in each trip. The target handling capacity as a percentage of the building population is usually the estimated value of passenger arrival rate for the 5 min up-peak period. The minimum recommended quantity of service for office building is given in Table 2.

This would vary depending on various factors like starting time (fixed or flexi-time), nearness to fast access routes like mass rapid transport systems, express ways, major roads, etc.

Table 2 Recommended Quantity of Service in Office Buildings

(*Clause* 4.2.3)

Sl No.	**Type of Occupancy**	**Quantity of Service** Percent
(1)	(2)	(3)
i)	Multi tenancy	10 to 15
ii)	Single tenancy	15 to 25

4.2.4 *Quality of Service*

It is very difficult to get real indications of passenger waiting time and lobby queuing from the classic calculation models. Therefore, interval is considered as the measure. During pure up-peak traffic, the interval or the average time between successive arrivals of the lift cars at the main lobby is generally considered as an indicator of passenger waiting time. Table 3 gives the quality of service based on interval for office buildings.

If interval is used as an indicator of quality of service, it should be noted that passenger average waiting time depends on the car occupancy, the handling capacity *vis-a-vis* the passenger arrival rates, the control systems, etc. The average waiting time approximates 75 percent to 85 percent of the interval for average car occupancy of 80 percent of the actual lift capacity provided the handling capacity is equal to or better than the peak arrival rate. Beyond 80 percent car loading passenger average waiting time increases exponentially and cannot be approximated from interval. Table 4 gives the recommended quality of service measured as average waiting time for office buildings.

Table 3 Recommended Quality of Service in Office Buildings (Based on Interval)

(*Clause* 4.2.4)

Sl No. (1)	Quality of Service (2)	Interval s (3)
i)	Excellent	Less than 25
ii)	Very good	25 to less than 30
iii)	Good	30 to less than 35
iv)	Fair	35 to less than 40
v)	Poor	40 to less than 45
vi)	Unsatisfactory	45 and above

Table 4 Recommended Quality of Service in Office Buildings (Based on Average Waiting Time)

(*Clause* 4.2.4)

Sl No. (1)	Class of Building (2)	Average Waiting Time s (3)
i)	Premium	< 25
ii)	Regular	25 to 35

NOTES

1 The class of building may be as defined by the developer.

2 Service lifts shall be provided in addition to required passenger lifts.

3 Lift designer shall take into consideration the shutdown of lifts for maintenance, especially for office building operating 24 Ĭ 7.

4.2.5 *Traffic Analysis Equations*

The classical method to size a lift installation requires the determination of the time, in second, that it takes for a single lift to make a round trip around the building during the up-peak traffic condition. This is called the round trip time (*RTT*) and is given by:

$$RTT = 2Ht_{\mathrm{v}} + (S+1)(T - t_{\mathrm{v}}) + 2Pt_{\mathrm{p}}$$

where

N = average highest reversal floor = $N - \sum_{i=1}^{N-1}(i/N)^P$;

H = average no of stops = $N\left[1 - \left(1 - \frac{1}{N}\right)^P\right]$;

S = average passengers carried (= 0.8 × maximum actual car capacity);

P = single floor transit time = average inter floor distance/rated speed;

t_v = single floor transit time = average inter floor distance/rated speed;
T = door operating time (t_c+t_o) + single floor flight time t_f (1); and
t_p = passenger transfer time.

The derivation of the round trip time equation assumes the following:

a) Traffic pattern corresponds to a pure up-peak;
b) Passengers arrive according to a rectangular probability distribution;
c) Lifts, on an average, fill to 80 percent of the actual car capacity by numbers irrespective of the weight of each passenger or the space that maybe occupied;
d) All floors are equally populated;
e) Rated speed is achieved in a single floor jump;
f) Inter-floor heights are equal; and
g) Door dwell time does not exceed the calculated passenger transfer time.

Interval, *INT* = *RTT/L*, where *L* is the number of lifts in a single group.

$$\text{5 min handling capacity, } HC = \frac{300 \times P \times L \times 100/Population}{RTT}$$

or

$$\frac{300\ \times P \times 100/Population}{INT}$$

The down peak round trip time is estimated as:

$$RTT_{\text{downpeak}} = Nt_{\text{v}} + (0.5S + 1)(T - t_{\text{v}}) + 2Pt_{\text{p}}$$

The mid-day round trip time is estimated as:

$$RTT_{\text{mid-day}} = 2Ht_{\text{v}} + 2S(T - t_{\text{v}}) + 4Pt_{\text{p}}$$

An estimation of interfloor performance can be obtained using:

$$AWT_{\text{interfloor}} = INT_{\text{uppeak}} + \left(0.22 + 1.78 \frac{A_{\text{interfloor}}}{HC_{\text{uppeak}}} \right)$$

where
$A_{\text{interfloor}}$ = number of passengers arriving during the interfloor period.

4.2.6 *Configuration of Lifts*: *Number*

Determination of number of lifts depends on the required quality and quantity of service. It should be noted here that grouping of lifts and location should be given adequate attention.

If a bank of two lifts or more is required to meet the anticipated traffic requirements, they have to be oriented to facilitate grouping. Individual lifts will not achieve the required quantity and quality of service.

4.2.7 *Configuration of Lifts*: *Capacity*

Determination of car capacity depends on the required quality and quantity of service. A larger car, while improving the handling capacity might adversely impact the quality of service.

4.2.8 *Configuration of Lifts*: *Speed*

In addition to the speeds derived from the calculations for handling capacity and interval, the nominal travel time is used for selecting suitable rated speeds. The higher the building, the faster lifts are needed. The recommended values for nominal travel time in case of an office, commercial or hotel building are given in Table 5.

4.2.9 *Configuration of Lifts: Layout*

The shape and size of a passenger lift car bears a distinct relation to its efficiency in traffic handling. A study of the most suitable proportions for passenger lifts reveals that the width of the lift well entrance is the basic element in the determination of the best proportions. In other words, the width of the car is determined by the width of the entrance and the depth of the car is regulated by the loading per square metre permissible under this standard.

Centre opening doors are the most practicable and the most efficient entrance units for passenger lifts. Given the same door speed, the centre opening is much faster than the side opening type. For passenger lifts, wider cars are preferred as the ingress and egress efficiency is higher. For service/freight/stretcher lifts deeper cars are preferred, so as to easily carry the stretcher/goods.

While sizing the hoist-ways, the possible construction inaccuracies have to be considered. Further, where high speeds lifts are being considered the hoist-ways need to be designed to address the impact of the wind tunnel effect.

Table 5 Recommended Nominal Travel Time for Office, Commercial or Hotel Buildings

(Clause 4.2.8 and Table 11)

Sl No.	**Level**	**Nominal Travel Time** s
(1)	(2)	(3)
i)	Excellent	15 to 25
ii)	Good	> 25 to 35
iii)	Satisfactory	> 35 to 45

4.3 Planning for Specific Building Features

4.3.1 *Special Building Facilities*

Facilities like cafeteria, food courts, restaurants, gymnasium, etc in the building impact the circulation patterns in a building and should be considered for lift traffic design.

It is advisable to have cafeteria on ground floor or lower floor with separate access means other than the main lifts. When the cafeteria/food court is located in mid-way or top of the building, the probable number of trips per person is on higher side, lunch peak needs to be analysed considering multiple trips.

For office buildings having specialty restaurants, clubs on higher levels, it is recommended to have dedicated lifts with separate lobby to avoid conflict between the different constituents.

4.3.2 *Basement Service*

Buildings are sometimes designed with car parks or other facilities at basement levels below the terminal floor. Such floors, if they are served by the main lifts have an adverse impact on the up-peak, down-peak and mid-day traffic patterns. During up-peak conditions, this may cause lifts to arrive at the main terminal already partly full causing confusion. In such a situation people have a tendency to push both up and down buttons resulting into deterioration of the lift service.

If basement floors are served by only a part of a lift group, passengers experience difficulty in selecting the correct lifts out of a group that will serve the basement. It is therefore better to provide basement service to the main lobby by a separate group of óshuttleô lifts so as to avoid compromising the traffic handling capability of the main lift group.

4.3.3 *Multiple Entry Levels*

Some buildings have main entry points at more than one level. The effect of more than one main terminal is disruptive and adversely impacts effective circulation and movement. If there are more than one entrance levels, means should be provided to bring all the routes to a single terminal floor. If this is not possible, then the lift system planning should take into account the extra times incurred in stopping and loading at multiple entry floors. Another difficulty is in deciding whether the building population will use each entrance equally. In the absence of any guidance, the solution is to assume an entrance bias with an additional 10 percent and size the lifts to meet the additional required handling capacity.

The loss of lift efficiency because of multiple entry levels could be as high as 15 percent per additional entry level. Both basement service and multiple entry level buildings with lifts serving all floors can also impact the security of the building.

4.3.4 *Non-Smoking Buildings*

When buildings are defined as non-smoking buildings, designers need to factor in the additional load put on the lifts on account of the additional trips that smokers make to go outside the building. It is appropriate to provide pressurized smoking zones at the floor level rather than require smokers to make additional trips.

4.3.5 *Reserved Lifts*

When lifts have to be reserved for VIP personal movement, designers should not consider these lifts as part of the lift group.

4.3.6 *Zoning (Vertical)/Sky Lobbies in Very Tall Buildings*

As the number of floors served increases, the values of H and S also increase, adversely impacting the round trip time and performance of the lift system. This has led to the concept of zoning in tall buildings. In stacked zoning, a tall building is effectively divided into horizontal layers or stacks. *RTT*, quality and quantity of service can be arrived at separately for each zone. The desired level of service can be attained by adjusting two parameters, in this case ï the number of lifts and the number of floors in the zone. The round trip time for each zone is given by:

$$RTT = 2Ht_{\mathrm{v}} + (S + 1)(T - t_{\mathrm{v}}) + 2Pt_{\mathrm{p}} + 2[t_{\mathrm{express}} - t_{\mathrm{f}}(1)]$$

where

t_{express} = flight time from the main terminal to the express zone terminal/sky lobby.

The round trip time for shuttle lifts serving only 2 floors ï main terminal and sky lobby is given by:

$$RTT = 2T + 2Pt_{\mathrm{p}}$$

4.4 Planning for Specific Building Types

4.4.1 *Residential Buildings*

The peak traffic condition occurs during the morning down-peak when many adults and children are leaving for work and school at the same time. Population assumptions would also need to consider the service staff, drivers of cars, etc. For high rise buildings the delivery of newspapers, milk and disposal of garbage also requires to be considered.

In the luxury housing segment, where the number of ratio of service staff to residents is fairly high, separate service lifts may be required for door deliveries and service staff movement. Typical average daily population for a residential building is given in Table 6.

The passenger handling capacity shall be as given in Table 7. The target handling capacity for residential building is lower as compared to office building with an understanding that the traffic for residential building would be comparatively less. The absenteeism factor shall not apply to residential buildings. The intervals shall be as per values in Table 8. Table 9 gives the recommended quality of service measured as average waiting time for residential buildings and Table 10 gives the nominal travel times.

Sizing of lifts should consider the requirement to shift the stretchers, heavy material, etc and it is recommended that at least one lift in each building should be a deep car which can accommodate a regular ambulance stretcher.

Table 6 Typical Average Population for Residential Buildings

(*Clause* 4.4.1)

Sl No.	**Class of Building**	**Number of Bedrooms Per Apartment**				
		1	2	3	3 With Servant Quarters	4 With or Without Servant Quarters
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	*High end apartments:*					
	a) Residents	2 to 3	3 to 4	5	5	5 to 6
	b) Resident service staff	0	0	0	1	1
	c) Floating service staff	1	2 to 3	3 to 4	3 to 4	4 to 5
ii)	*Mid end apartments:*					
	a) Residents	3	4	5	5	5 to 6
	b) Resident service staff	0	0	0	1	1
	c) Floating service staff	1	1	2 to 3	2 to 3	3 to 4
iii)	*Low end apartments:*					
	a) Residents	4 to 5	5 to 6	NA	NA	NA
	b) Floating service staff	0.5	0.5	NA	NA	NA

NOTE ð Unless separate lifts are provided for service staff, due consideration for service staff shall be given while calculating the required number of lifts. The class of building shall be as defined by the developer.

Table 7 Recommended Handling Capacity for Residential Buildings

(*Clause* 4.4.1)

Sl No.	**Class of Building**	**Handling Capacity** Percent
(1)	(2)	(3)
i)	High end building	> 8
ii)	Mid end building	6 to 8
iii)	Low end building	5 to 7

Table 8 Recommended Quality of Service for Residential Buildings (Based on Time Interval)

(*Clause* 4.4.1)

Sl No. (1)	Class of Building (2)	Interval s (3)
i)	High end building	Ò60
ii)	Mid end building	61 to 80
iii)	Low end building	81 to 100

Table 9 Recommended Quality of Service in Residential Buildings (Based on Average Waiting Time)

(*Clause* 4.4.1)

Sl No. (1)	Class of Building (2)	Average Waiting Time s (3)
i)	High end building	Ò30
ii)	Mid end building	31 to 45
iii)	Low end building	46 to 60

Table 10 Recommended Nominal Travel Time for Residential Buildings

(*Clause* 4.4.1 *and* *Table* 11)

Sl No. (1)	Level (2)	Nominal Travel Time s (3)
i)	High end building	25 to 35
ii)	Mid end building	36 to 45
iii)	Low end building	46 to 60

NOTE — In case of super tall buildings considering limit of lift speed as 10 m/s, the travel time may be longer than specified above.

The class of building shall be as defined by the developer.

4.4.2 *Service Apartments and Hostel*

Average population as 2 person per flat to 3 person per flat/room may be considered. The quantity and quality of service can be considered as per high end residential building, as the peak demand would be during morning hours as maximum of population would be leaving for office, college, etc. The system shall be designed to cater to a peak arrival rate of 8 percent to 10 percent.

4.4.3 *Hospitals*

Factors to be considered include number of staff and shift patterns, number of visitors and visiting hours, location of operation theatres, facilities, delivery of housekeeping supplies, waste disposal, evacuation procedures and segregation of sterile areas. When carrying out traffic analysis for hospitals, designers should consider establishing average car loading by volume rather than by weight. Arrival rates may approximate 10 percent to 15 percent and interval may be 30 s to 50 s.

Lifts shall be taken into consideration according to the evacuation strategy of building. Lifts shall be considered when vertical evacuation is planned for patients who need to be evacuated with stretcher.

The sizing of the lift car and doors should be such that a standard hospital stretcher and attendant can be easily accommodated. Where the hospital bed is likely to be moved the lift car should be able to accommodate the standard hospital bed including the auxiliary support equipment like oxygen cylinders, etc.

In addition to passenger lifts, service lifts is required for the movement of housekeeping staff, catering, etc. Dedicated service lift may be considered for movement of medical waste, garbage, etc.

In large hospitals, it is recommended that the lifts for the patients/hospital beds (or stretchers) should be separated from the lifts for staff/visitors.

NOTE — For hospital buildings, designers should also consider that in an emergency a number of patients would require to be evacuated on stretchers.

4.4.4 *Hotels*

4.4.4.1 The most demanding time is during the check-in and check-out period and two-way traffic occurs during this period with guests going to and from rooms and restaurants and in and out of the hotel. Calculations should be made assuming an equal number of up and down stops during this period. Average room occupancy may range from 1.5 persons to 2 persons and arrival rates from 10 percent to 15 percent.

The following shall also be considered in the calculations:

a) Handling capacity > 12 percent;

b) Interval < 40 s; and

c) Average waiting time : 30 s to 40 s (peak check-in/checkout time).

4.4.4.2 Security considerations need to be taken into account whilst establishing the circulation and lift requirements. Escalators should be employed for heavy short range movements such as from the lobby to banquet/ function level. Adequate number of service lifts need to be provided for service movement of housekeeping and room service staff as well as movement of material. Way finding signage shall be helpful to locate lift lobby for guests.

4.4.4.3 While hotel operator guideline should be the base for lift designing, modern hotels that has public amenities like, roof top restaurants, bars, event spaces, casino, etc. There should be dedicated lifts with separate lift lobby to access these levels, this helps in bifurcating the public traffic from hotel resident guests and thus ensure the security and performance of guest lifts.

4.4.4.4 *Banquets and conventional centre*

Escalators shall be an ideal means for the movement of mass people; however, lifts shall need to be considered to cater specially-abled people. The lifts shall be designed to cater to the minimum arrival rate of 12 percent. When escalators are provided, lift shall be designed for a minimum for 30 percent of total capacity for the factors that all the people may not use escalators. For banquets and conventional centres with higher capacities, lifts shall be designed for a fairly larger capacity as people would travel in groups and expected in special attire. It is recommended that the minimum capacity of lifts shall be 1 360 kg/20 pax with minimum door width of 1 000 mm. Freight lifts may be required depending on the functioning and requirements.

4.4.4.5 Consideration has to be given to valet circulation for vehicle retrieval.

4.4.5 *Retail — Malls with Multiplexes*

Pedestrian movement in retail establishments like malls is generally centred on escalators, and lifts do not play a major part. However, provision should be made for movement of shopping trolleys, wheel chairs, perambulators and persons with limited mobility from one level to another. A commonly applied solution is the installation of inclined moving walks. Where lifts are provided, assumptions of lift car sizing should take into account space occupied by trolleys and shopping bags. Where multiplexes are located on the upper floors, the last movie of the day gets over after the mall is closed at which time the escalators might not be available. In such cases the lift provision has to be adequate to handle the egress of the multiplex population with recommended average waiting time of below 40 s catering to a demand population of minimum 8 percent for 1/3rd of total screens for exiting at different intervals. Staircase factor can be considered for a simulation model.

4.4.6 *Airports/Railway Stations*

While moving walks and escalators greatly improve the building circulation, the use of lifts has to be considered for persons with limited mobility and for movement of baggage trolleys from one level to another. The RTT equation of 4.2.5 may be used, but care may need to be taken in the assumptions of lift car occupancy levels taking into account space occupied by trolleys.

4.4.7 *Multi-Level Car Parking*

Multi-level car parks may be standalone public car parks or attached to office, retail or residential complexes. These car parks may be fully automated where drivers would leave the cars inside or on a trolley at the entry floor and the car is parked and retrieved automatically. The other alternative would be for the use of car lifts and/or ramps.

When the movement of the cars is dependent on car lifts, detailed study has to be carried out to establish the required number of car lifts ensuring that average car retrieval/parking time does not exceed 2 min. The sizing of the car lifts has to be adequate to fit the largest vehicle that is intended to be transported as well as adequate space to enable opening of the doors to enable evacuation of passengers in the eventuality of an entrapment. Designers will also need to take into account the probability of queues developing and provide for holding lanes. For luxury/ high end residential buildings the car parking provision may exceed the total resident count of building. Where there are no separate shuttle lifts for parking floors, designer need to consider the movement of drivers in passenger lifts. When parking count exceeds the count of residents, the entrance bias should be calculated with assumption of certain percentage of total parking from each entry level.

4.4.8 *Multi-Level Car Parking Passenger Traffic*

When car lifts or ramps are the means for parking the cars, then means would need to be provided for the movement of passengers from and to the parking floors. If the main building lifts also serve the parking floors, it is to be noted that, performance will be adversely impacted due to multiple entry floors. Additional entry floors will also affect the security of the building. It is therefore recommended that separate lifts should be considered to move passengers. If separate parking lifts are provided, the basic *RTT* equation of 4.2.5 may be used. Average vehicle occupancy may be considered as 1.5 per car for office car parks, 4 for airports and retail and 2 elsewhere. For high end residential building or private building, usually drivers would be accessing parking level, hence for such luxury building 1 person (driver) per car can be considered.

4.4.9 *Schools and Other Educational Institutions*

In schools and other educational institutions, the traffic flow would consist of peak demand for short duration that would exist just before the start or after finishing of a class or lecture. It is unlikely that an economical solution can be implemented for such high peak requirements. Therefore, the design of the building has to be such that heavy stair usage is facilitated. Mostly for college buildings, demand time would be before and after each lecture/tutorial or seminar; lifts shall be designed to cater to the demand population of 12 percent to 15 percent with an interval of 30 s to 50 s. A higher staircase factor may be considered for traffic analysis.

4.4.10 *Data Centre*

Building population for data centre is usually low, however data centre has requirement of freight lifts. The design of freight lift shall be based on the input from architect/owner on the class of loading, dimension details and weight of equipment to be taken in freight lifts. As the freight lift hoist-way size is very big and usage is not extensive, the lift car size and door should consider all possible designs to reduce hoist-way sizes and increase saleable area.

4.4.11 *Buildings with* 24 Ĭ 7 *Operations*

In buildings operating 24 Ĭ 7 (round the clock), the peak traffic conditions would not be a typical up-peak but will occur during shift changes. The handling capacity should take into account the incoming, outgoing and shift change traffic as well as cafeteria traffic. Calculations shall be made assuming both up and down stops during this period. Particular attention should be paid while designating the drop off points, these should be assigned to a level so as to not increase the burden on the system. Designers need to consider that the lifts in such buildings would have a significantly higher number of starts/stops per hour than a conventional building. Lift designer shall take into consideration the shut-down of lifts for maintenance, especially for office building operating 24 Ĭ 7.

4.4.12 *Observatory*

The height at which the observatory is located and the number of people expected at the observatory level shall decide the speed and the number of lifts. The circulation logic is crucial in locating the observatory lifts. Also, if the observatory is connected with lounge/cafe/souvenir shops, etc, separate service lifts may need to be provided.

4.5 Other Considerations

Designers need to be aware that the door opening and closing times, acceleration and deceleration times, etc would vary between suppliers and equipment types and can impact the overall lift performance. The dispatch algorithms and controller responses would also vary between the suppliers and the equipment types and can impact the actual operational results.

Lifts will breakdown as well as require to be shut-down for regular maintenance and repairs. Lift availability might be hampered during renovation of the building as a lift might be taken up for movement of material and debris. Designers should take into consideration the impact of such non-availability of lifts. The provision of well-located and easily accessible stairs can considerably lessen the demands on the lifts and therefore architect/engineer should consider this aspect in the layout.

4.5.1 *Lift Speed*

For passenger lifts in a building, the general recommendations as given in Table 11 may be followed.

Table 11 Lift Speed

(*Clause* 4.5.1)

Sl No. (1)	No. of Floors (2)	Speed m/s (3)
i)	Up to 6	0.6 to 1.0
ii)	7 to 15	1.0 to 1.5
iii)	16 to 20	1.5 to 1.75
iv)	21 to 30	1.75 to 2.5
v)	31 to 45	3.0 to 4.0
vi)	46 to 60	4.0 to 6.0
vii)	Above 60	6.0 and above

NOTES

1 Above table is considering buildings with average floor height of 3.0 m.

2 For office buildings average floor height is 4.2 m (*see* Table 5 and Table 10).

3 Finalizing the lift speed for any building depends on detailed traffic analysis because number of floors, area per floor, area per person and class of building are crucial factors, which serve as inputs for such traffic analysis.

4 Finalizing the speed for hotel depends on the number of keys per floor and similarly for an observatory depends on the number of expected footfall.

5 For any building, the speed of the lifts will have to be validated against the total population and travel height of the building.

4.5.2 *Quiet Operation of Lifts*

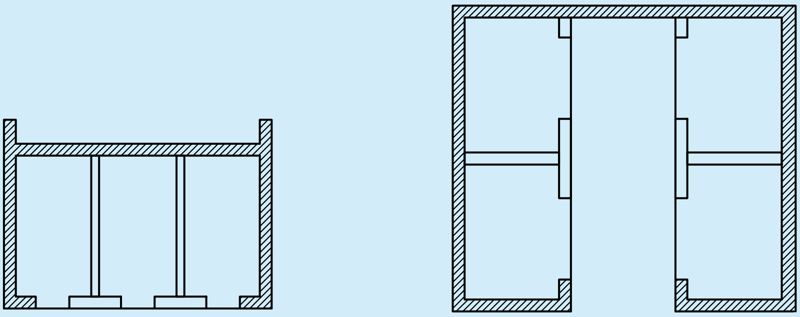
Every precaution should be taken with passenger lifts to ensure quiet operation of the lift doors and machinery. The insulating of the lift machine and any motor generator from the floor by rubber cushions or by a precast concrete slab with rubber cushions, prevents transmission of most of the noise. In this connection, reference may be made to good practice [D-5A(5)] and Part D “Building Services, Section 4 Acoustics, Sound Insulation and Noise Control” of this NBCS for some useful recommendations.

5 LIFT ARRANGEMENTS AND PLANNING DIMENSIONS

The appropriate aspect of lift installation shall be discussed during the preliminary planning of the building with all concerned parties, namely, client, architect, consulting engineer and/or lift manufacturer. This enables the lift manufacturer to furnish the architect and/or consulting engineer with the proposed layout or vice-versa.

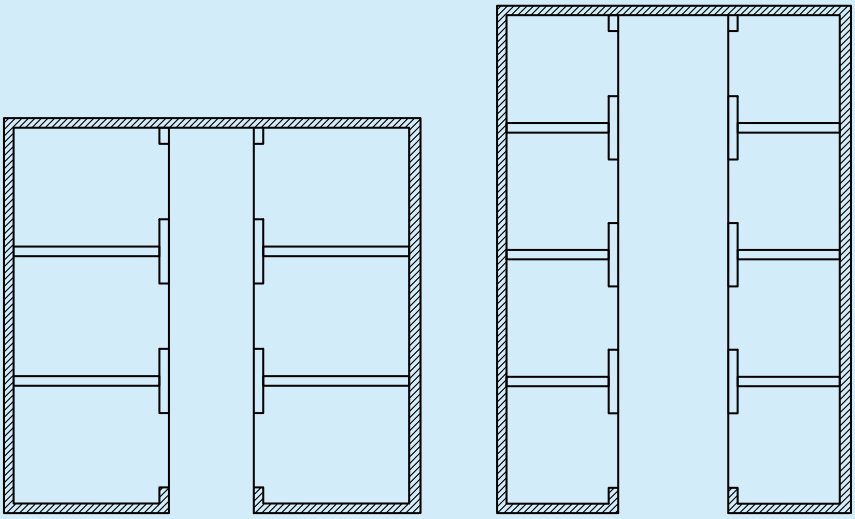
5.1 Exchange of Information

5.1.1 The guidelines laid down together with Fig. 2 will enable the preliminary scheme for the installation to be established. Figure 2 shows only some of the typical arrangements and variations are possible with respect to number of lifts and the layout of lifts especially when destination control system (DCS) is used instead of conventional group control system.



2A STRAIGHT LINE ARRANGEMENT FOR THREE LIFTS

2B ALCOVE ARRANGEMENT FOR FOUR LIFTS



2C ARRANGEMENT FOR SIX LIFTS

2D ARRANGEMENT FOR EIGHT LIFTS

FIG. 2 TYPICAL ARRANGEMENT OF LIFTS

Although the recommended outline for the various classes of lifts enable the general planning details to be determined by the architect/engineer, these should be finally settled at the earliest possible stage by detailed investigation with the purchaser’s representative reaching agreement with the lift manufacturer (where necessary) before an order is finally placed. This will enable a check to be made and information to be exchanged on vital matters such as:

a) number, capacity, speed and disposition of the lifts necessary to give adequate lift service in the proposed building;
b) provision of adequate access to the machine room;
c) loads which the lift will impose on the building structure, and the holes to be left in the machine room floor and cut-outs for wall boxes for push-buttons and signals;
d) necessity for and type of insulation to minimize the transmission of vibration and noise to other parts of the building;
e) special requirements of local authorities and other requirements set out in the 'planning permit';
f) need for the builder to maintain accuracy of building as to dimensions and in-plumb;
g) periods of time required for preparation and approval of relevant drawings for manufacturing and the installation of the lift equipment;
h) requirements for fixing guide brackets to the building structure;
j) time at which electric power will be required before completion to allow for testing;
k) requirements for electrical supply feeders, etc;
m) requirements for scaffolding in the lift well and protection of the lift well prior to and during installation of equipment; and
n) delivery and storage of equipment.

5.1.2 *Information to be provided by Architect or Engineer*

As a result of preliminary discussions, the drawings of the building should give the following particulars and finished sizes:

a) number, type and size of lifts and position of lift well;
b) particulars of lift well enclosure;
c) size, position, number and type of landing doors;
d) number of floors served by the lift;
e) height between floor levels;
f) number of entrances;
g) total headroom;
h) provision of access to machine room;
j) provision of ventilation and, if possible, natural lighting of machine room;
k) height of machine room;
m) depth of lift pit;
n) position of lift machine, above or below lift well;
p) size and position of any trimmer joists or stanchions adjacent to the lift well at each floor;
q) size and position or supporting steel work at roof levels;
r) size and position of any footings or grillage foundations, if these are adjacent to the lift pit; and
s) in the case of passenger lifts whether the lift cage is required to carry household luggage, such as refrigerator, steel almirah, etc.

5.2 The lift lobby should be designed appropriately since this has bearing on the traffic handling especially when more number of lifts are involved. In a dual line arrangement (lifts opposite to each other) the lobby should be between 1.5 times and 2.5 times the depth of one car. Typically, the greater the number of lifts, the bigger the multiplier to be used. As an example, a quadruplex may use 1.5 to 2, where as an octuplet will need 2 to 2.5. For in-line (single line) arrangements, the lobby can be typically half of the above recommendations.

5.3 The architect/engineer should advise the lift manufacturer, if the authority has any special requirements regarding lifts in buildings in the administrative area concerned.

5.4 The architect/engineer should inform the lift manufacturer of the dates when the erection of the lift may be commenced and is to be completed so that sufficient time is allowed for the manufacture and erection of the lift.

5.5 When submitting application for a building permit to the local Authority, the building plans shall include the details of lifts (number of lifts duly numbered, location, type, type of doors, passenger capacity and speed).

5.6 Positioning of Lifts

A thorough investigation should be made for assessing the most suitable position for lift(s) while planning the building. It should take into account future expansions, if any. Though each building has to be considered individually for purposes of location of lifts, factors influencing the locations of passenger and goods lifts are given in **5.6.2** to **5.6.4**.

5.6.1 *Arrangement of Lifts*

The lifts should be easily accessible from all entrances to the building. For maximum efficiency, they should be grouped near the centre of the building. It is preferable not to have all the lifts out in straight line and, if possible, not more than four lifts should be arranged in this manner. If more than 4 lifts have to be grouped together in a straight line, then destination control systems would require to adopt. Further, the corridor should be wide enough to allow sufficient space for waiting passengers as well as for through passengers.

In some cases, when there are more than three lifts, the alcove arrangement is recommended. With this arrangement, the lift alcove leads off the main corridor so that there is no interference by traffic to other groups or to other parts of the ground floor. This arrangement permits the narrowest possible corridors and saves space on the upper floors. Walking distance to the individual lift is reduced and passenger standing in the centre of the group can readily see all the lift doors and landing indicators. The ideal arrangement of the lifts depends upon the particular layout of the respective building and should be determined in every individual case. Some typical recommended arrangements are given in Fig. 2.

5.6.2 *Passenger Lifts*

5.6.2.1 *Low and medium class flats*

Where a lift is arranged to serve two, three or four flats per floor, the lift may be placed adjoining a staircase, with the lift entrances serving direct on to the landings. Where the lift is to serve a considerable number of flats having access to balconies or corridors, it may be conveniently placed in a well-ventilated tower adjoining the building.

5.6.2.2 *Office buildings, hotels and high class flats*

In general, the arrangement as recommended in **5.6.1** should be followed. However, in case that is not possible, it is desirable to have at least a battery of two lifts at two or more convenient points of a building. If this is not possible, it is advisable to have at least two lifts side by side at the main entrance and one lift each at different sections of the building for inter-communication. When two lifts are installed side by side, the machine room shall be suitably planned with sufficient space for housing the machine equipment. The positioning of lifts side by side gives the following advantages:

a) All machines and switch gear may be housed in one machine room;

b) Lifts can be inter-connected more conveniently from an installation point of view; and

c) Greater convenience in service owing to the landing openings and each floor being adjacent.

5.6.2.3 *Shops and departmental stores*

Lifts in shops and stores should be situated so as to secure convenient and easy access at each floor.

5.6.2.4 For buildings with more than 12 floors, where passenger and service lifts are provided in one lobby, it is recommended to have group control for all the lifts.

5.6.3 *Goods Lifts*

The location of lifts in factories, warehouses and similar buildings should be planned to suit the progressive movement of goods throughout the buildings, having regard to the nature of position of the loading platforms, railway sidings, etc. The placing of a lift in a fume or dust laden atmosphere or where it may be exposed to extreme temperatures, should be avoided, wherever possible. Where it is impossible to avoid installing a lift in an adverse atmosphere, the electrical equipment should be of suitable design and construction to meet the conditions involved.

Normally goods lifts have lower speeds than passenger lifts for the same travel because traffic conditions are less demanding, and more time is required for loading and unloading. As loads for goods lifts increase in size and weight, so the operation of loading and unloading becomes more difficult. Therefore, it is usual to require greater accuracy of levelling as the capacity of the goods lift increases.

A large capacity goods lift operating at high speed is often a very uneconomical solution. The inherent high cost is enhanced due to the very small demand for such equipment, much of which is custom made. The high capital cost of the lift, building work and electrical supply equipment usually shows a much smaller return as an investment than more normal size of lifts.

5.6.4 *Hospital Bed Lifts*

Hospital bed lifts should be situated conveniently near the ward and operating at the entrances. There shall be sufficient space near the landing door for easy movement of stretcher/bed. It is convenient to place the passenger lifts in a hospital, near the staircases.

5.7 General Arrangement Drawings (GAD)

The general arrangement drawings should be prepared by the lift manufacturer. The lift manufacturer requires sufficient information for the preparation of working drawings and is usually obtained from architectôs drawings supplemented by any information obtained from the site and by collaboration with the other contractors.

General arrangement drawings showing the layout of lifts duly numbered, details of builders work, for example, holes in walls for guide fixing, holes in machine room floor for ropes and conduits, recesses for landing sills, supports for lift machine and loads imposed on the building should be submitted by the lift manufacturer to the architect/engineer for written approval.

5.8 Additional Requirements for Passenger, Goods and Service Lifts

5.8.1 *Refuge Spaces and Clearances in the Pit or Bottom Car Clearances*

When the car is at its lowest position, at least one clear area where a refuge space can be accommodated as per Table 12 shall be provided on the pit floor having a vertical clearance as specified.

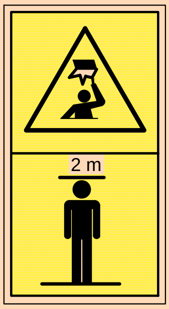
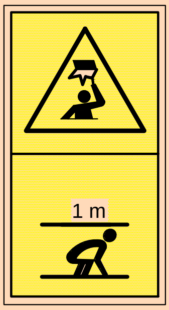
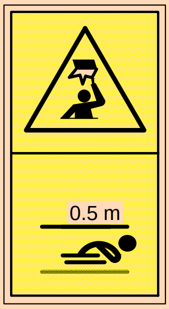
When the car is at the lowest position the following conditions shall also be satisfied:

a) The free vertical distance between the bottom of the pit and the lowest parts of the car shall be at least 0.50 m. This distance may be reduced for any part of the apron or parts of the vertically sliding car door(s) to a minimum of 0.10 m within a horizontal distance of 0.15 m to the adjacent wall(s).

b) The free vertical distance between the highest parts fixed in the pit, for instance a tensioning device for compensation means being in its highest position, jack supports, pipes and other fittings and the lowest parts of the car, shall be at least 0.30 m.

Table 12 Dimensional Requirements of Designated Area in the Pit

(*Clause* 5.8.1)

Sl No.	Type	Posture	Pictogram	Horizontal Dimensions of the Refuge Space mm Ĭ mm	Height of the Refuge Space mm
(1)	(2)	(3)	(4)	(5)	(6)
i)	1	Upright posture		400 I 500	2 000
ii)	2	Crouching		500 I 700	1 000
iii)	3	Laying		700 I 1 000	500

The following conditions shall also apply:

1) When the car is at its lowest position at least one clear area where a refuge space can be accommodated shall be provided on the pit floor.

2) If more than one person is necessary in the pit to carry out inspection and maintenance work, an additional refuge space shall be provided for each additional person.

3) In the case of more than one refuge space, they shall be of the same type and not interfering with each other.

4) A sign in the pit readable from the entrance(s) shall clearly indicate the allowed number of persons and the type of posture considered for the refuge spaces(s) accommodation.

NOTES

1 Dimensional requirements of designated area in the pit may vary depending upon manufacturer.

2 Designated manufacturer shall coordinate and upgrade the requirements on order specific.

3 Table 17 shall be referred for the recommended dimensions of pit depth.

5.8.2 *Refuge Spaces on Car Roof and Clearances in Headroom or Car Top Clearances*

When the car is at its highest position, at least one clear area where a refuge space can be accommodated as per Table 13 shall be provided on the car roof having a vertical clearance as specified.

When the car is at its highest position, the clear distance between the lowest parts of the ceiling of the well (including beams and parts situated under the ceiling) and:

a) the highest pieces of equipment fixed on the roof, except for those covered in (b) and (c) below, shall be at least 0.50 m in any vertical or inclined direction within the projection of the car;

b) the highest part of the guide shoes or rollers, of the compensation means terminations and of the header or parts of vertically sliding doors, if any, shall be at least 0.10 m in any vertical direction within a horizontal distance of 0.40 m within the projection of the car; and

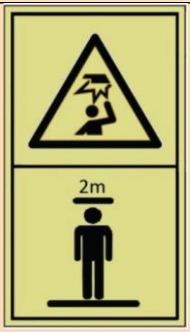
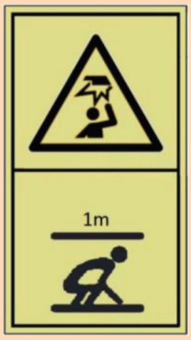
c) the highest part of the balustrade shall be at least:

   1) 0.30 m within a horizontal distance of 0.40 m within the projection of the car and 0.10 m on the outside of the balustrade; and

   2) 0.50 m in any inclined distance beyond 0.40 m within the projection of the car.

Table 13 Dimensional Requirements of Designated Area on Car Roof and Clearance on Head Room

(*Clause* 5.8.2)

Sl No. (1)	Type (2)	Posture (3)	Pictogram (4)	Horizontal Dimensions of the Refuge Space mm Ĭ mm (5)	Height of the Refuge Space mm (6)
i)	1	Upright posture	 	400 Ĭ 500	2 000
ii)	2	Crouching	 	500 Ĭ 700	1 000

The following conditions shall also apply:

1) At least one clear area where a refuge space can be accommodated shall be provided on the car roof;

2) If more than one person is necessary in the car roof to carry out inspection and maintenance work, an additional designated area shall be provided for each additional person;

3) In the case of more than one refuge space, they shall be of the same type and not interfering with each other; and

4) A sign on the car roof readable from the landings giving access to the car roof shall clearly indicate the allowed number of persons and the type of posture considered for the refuge space(s) accommodation.

NOTES

1 Dimensional requirements of designated area in the pit may vary depending upon manufacturer.

2 Designated manufacturer shall coordinate and upgrade the requirements on order specific.

3 Table 17 shall be referred for the recommended dimensions of pit depth.

5.9 Additional Requirements for Dumb Waiters

5.9.1 *Top Car Clearance*

The top car clearance shall be sufficient to avoid any protruding part fixed on the top of the car coming in direct contact with the ceiling or diverting sheave.

The clearance shall be calculated taking into account the following and shall not be less than the sum of the following four items:

a) bottom counterweight run-by;

b) stroke of the counterweight buffer used;

c) dimensions of the portion of the diverting sheave hanging underneath the ceiling in the lift well; and

d) 150 mm for compensating for gravity stopping distance and future repairs to the rope connections at counterweight and at the car or at the suspension points.

5.9.2 *Bottom Car Clearance*

The bottom car clearance shall be maintained in such a way that the counterweight shall not come in contact with the ceiling or any part hanging underneath the ceiling, when the car completely rests on fully compressed buffers, provided the buffers are spring type mounted on solid concrete or steel bed.

In case of wooden buffers the bottom car clearance shall be maintained in such a way that the total downward travel of the car from the service level of the immediate floor near the pit, shall not be more than the top counterweight clearance, when the wooden buffers are completely crushed.

5.9.3 *Top Counterweight Clearance*

The top clearance for the counterweight can be calculated taking into account the following and shall not be less than the sum of the following three items:

a) car run-by;

b) compression of the buffer spring or height of the wooden block used as buffer; and

c) 150 mm to compensate for gravity stopping distance for counterweight and any future repairs to rope connections at the counterweight at the car ends or at the suspension points.

5.9.4 *Run-by for Cars and Counterweights*

a) *Minimum bottom run-by* ð The bottom run-by for cars and counterweights shall not be less than 150 mm; and

b) *Maximum bottom run-by* ð In no case shall the maximum bottom run-by exceeds 300 mm.

5.10 Planning for Dimensions

5.10.1 *General*

The dimensions of lift well shall be chosen to accommodate the doors inside the well which is the normal practice. In special cases, the door may be accommodated in a recess in the front wall, for which prior consultation shall be made with the lift manufacturer.

5.10.2 *Plan Dimensions*

All plan dimensions of lift well given hereunder, are the minimum clear plumb sizes. The architect/engineer, in conjunction with the builder, shall ensure that adequate tolerances are included in the building design so that the specified minimum clear plumb dimensions are obtained in the finished work.

NOTE ð The words 'clear plumb dimensions' should be noted particularly in case of high rise buildings.

Rough opening in concrete or brick walls to accommodate landing doors depend on design of architrave. It is advisable to provide sufficient allowances in rough opening width to allow for alignment errors of opening at various landings. When more than one lift is located in a common well, a minimum allowance of 150 mm for separator beams shall be made in the widths.

Where the governor operated counterweight safety is required under conditions stipulated in good practice [D-5A(1)], the tabular values under 5.10.3.1 should be revised in consultation with the lift manufacturer.

For outline dimensions of lifts having more than one car entrance, lift manufacturers shall be consulted.

5.10.3 *Outline Dimensions*

5.10.3.1 The outline dimensions of lift shaft, machine-room and machine room less lifts, pit depth, overhead height and raw door opening size for lifts to which this Subsection applies are specified in Table 14 to Table 32 as indicated below:

a)	Machine room lifts:		
	1)	Recommended dimensions of passenger lifts and service lifts	Table 14
	2)	Recommended dimensions of stretcher/hospital bed lifts	Table 15
	3)	Recommended dimensions of goods lifts with machine room	Table 16
	4)	Recommended dimensions of machine room height, overhead, pit depth for passenger, goods, stretcher/hospital lifts with machine room	Table 17
	5)	Recommended dimensions of automobile lifts with machine room ð Through type car	Table 18
	6)	Recommended dimensions of dumbwaiter lifts	Table 19
	7)	Entrance type for horizontal and vertical sliding doors	Table 20
	8)	Recommended dimension of goods lifts with machine room ð Series A : Vertical sliding door (entrance Type 4 and 5)	Table 21
	9)	Recommended dimension of goods lifts with machine room ð Series A : Vertical sliding door (entrance Type 6)	Table 22
	10)	Recommended dimension of goods lifts with machine room ð Series B : Horizontal sliding doors (entrance Type 3)	Table 23
	11)	Recommended dimension of goods lifts with machine room ð Series B : Vertical sliding doors (entrance, Type 4 and 5)	Table 24
	12)	Recommended dimension of goods lifts with machine room ð Series B : Vertical sliding doors (entrance Type 6)	Table 25
	13)	Recommended dimension of automobile lifts with machine room ð Trough type car ð Series B : Vertical sliding Door (entrance Type 4)	Table 26
b)	Machine room-less lifts:		
	1)	Recommended dimensions of passenger lifts MRL	Table 27
	2)	Recommended dimensions of stretcher/hospital lifts MRL	Table 28
	3)	Pit depth for passenger/stretcher/hospital lifts MRL	Table 29
	4)	Overhead height for passenger and stretcher/hospital lifts MRL	Table 30
	5)	Recommended dimensions of goods lifts MRL	Table 31
	6)	Recommended dimensions of automobile lifts MRL	Table 32

Typical car and landing dimensions for horizontal sliding doors and vertical sliding doors for Series A and Series B are as shown in Fig. 8 and Fig. 9 respectively.

5.10.3.2 *Minimum floor to floor height*

Minimum floor to floor height for landings on same side for horizontally sliding door is *f* + 750 mm and for vertically bi-parting doors is 1.5 *f* + 250 mm, where ớ*f* ôis clear entrance height in mm.

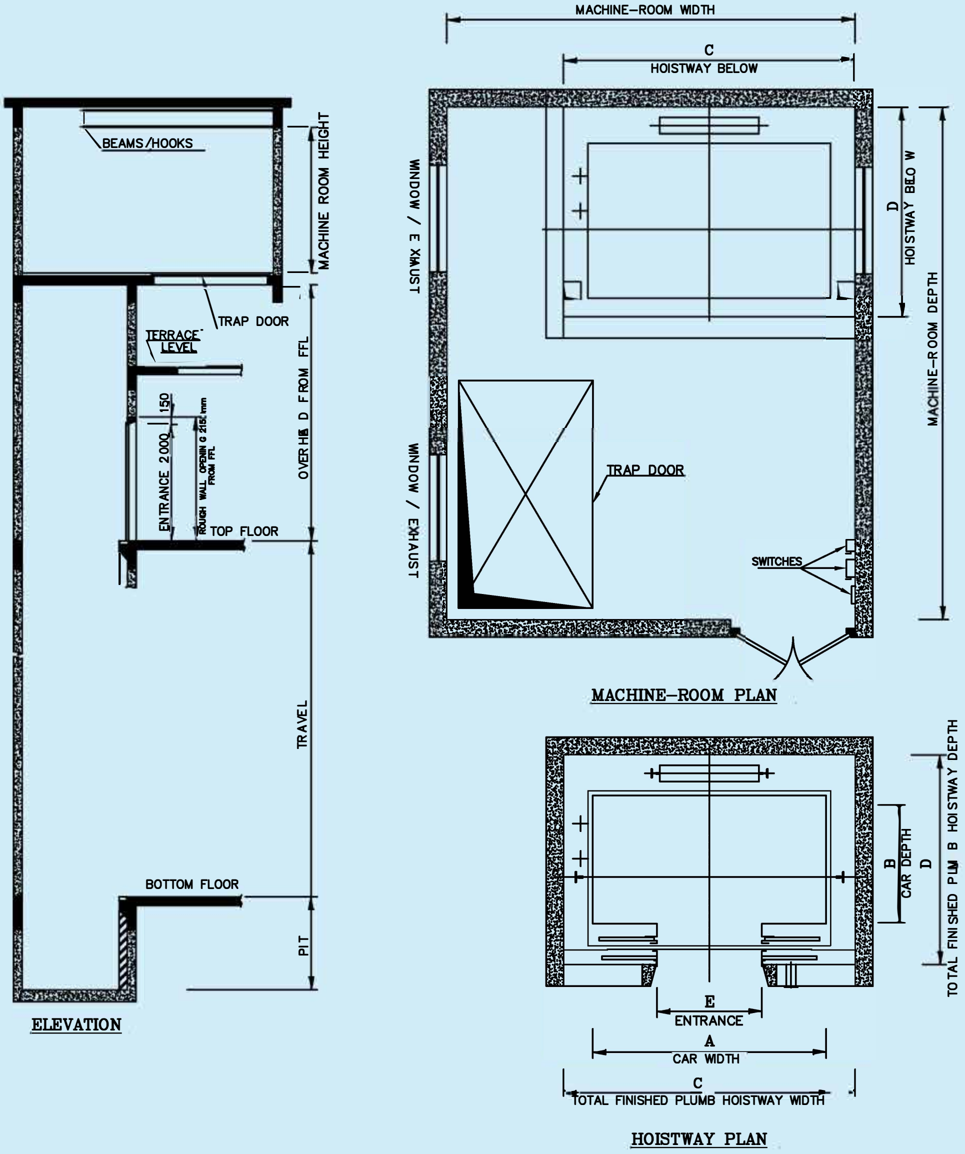

MACHINE–ROOM WIDTH
C
HOISTWAY BELOW
BEAMS/HOOKS
MACHINE ROOM HEIGHT
TRAP DOOR
TERRACE LEVEL
150
ENTRANCE 2000
ROUGH WALL OPENIN G 2150 mm FROM FFL
TOP FLOOR
OVERHEAD FROM FFL
TRAVEL
BOTTOM FLOOR
PIT
ELEVATION
WINDOW / EXHAUST
WINDOW / EXHAUST
D
HOISTWAY BELOW
MACHINE–ROOM DEPTH
TRAP DOOR
SWITCHES
MACHINE–ROOM PLAN
B
CAR DEPTH
D
TOTAL FINISHED PLUMB HOISTWAY DEPTH
E
ENTRANCE
A
CAR WIDTH
C
TOTAL FINISHED PLUMB HOISTWAY WIDTH
HOISTWAY PLAN

FIG. 3 FOR PASSENGER LIFTS AND SERVICE LIFT

Table 14 Recommended Dimensions of Passenger Lifts and Service Lifts

(*Clause* 5.10.3.1)

All dimensions in millimetres.

Sl No.	**No. of Passengers**	**Rated Load**	**Car Size**		**COPD Door**	**Passenger and Service Lifts with Machine Room: Shaft Sizes**													
						Rated speed < 1 m/s		1.0 m/s Ò Rated Speed Ò2.5 m/s		3.0 m/s Ò Rated Speed Ò3.5 m/s		4.0 m/s Ò Rated Speed Ò5.0 m/s		Rated Speed = 6.0 m/s		7.0 m/s Ò Rated Speed Ò8.0 m/s		9.0 m/s ÒRated Speed Ò10.0 m/s	
						Shaft Size		Shaft Size		Shaft Size		Shaft Size		Shaft Size		Shaft Size		Shaft Size	
		kg	Width	Depth	Width	Width	Depth	Width	Depth	Width	Depth	Width	Depth	Width	Depth	Width	Depth	Width	Depth
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
i)	4	272	1 100	700	800	1 900	1 300	1 900	1 300	ï	ï	ï	ï	ï	ï	ï	ï	ï	ï
ii)	6	408	1 100	1 000	800	1 900	1 700	1 900	1 700	ï	ï	ï	ï	ï	ï	ï	ï	ï	ï
iii)	8	544	1 400	1 100	800	1 900	1 750	1 900	1 900	ï	ï	ï	ï	ï	ï	ï	ï	ï	ï
iv)	10	680	1 300	1 350	800	1 900	2 150	1 900	2 150	ï	ï	ï	ï	ï	ï	ï	ï	ï	ï
v)	13	884	2 000	1 100	900	2 600	1 900	2 600	1 900	2 800	2 200	ï	ï	ï	ï	ï	ï	ï	ï
vi)	14	952	1 600	1 400	900	2200	2100	2200	2100	2 400	2 400	ï	ï	ï	ï	ï	ï	ï	ï
vii)	15	1020	1450	1 650	1000	2 600	2 000	2 600	2 000	2 250	2 650	2 600	2 150	2 600	2 250	2 600	2 300	2 600	2450
viii)	16	1 088	1 600	1 600	1 000	2 450	1 900	2 600	2 100	2 400	2 600	2 600	2 350	2 600	2 450	2 600	2 500	2 600	2650
ix)	18	1 224	2 000	1 400	1 000	ï	ï	2 600	2 350	2 800	2 400	2 600	2 350	2 600	2 350	2 700	2 300	2 700	2450
x)	20	1 360	2 000	1 500	1 000	ï	ï	2 600	2 350	2 800	2 500	2 600	2 350	2 600	2 350	2 700	2 400	2 700	2550
xi)	22	1 496	2 100	1 600	1 100	ï	ï	2 700	2 300	2 900	2 600	2 700	2 350	2 700	2 450	2 800	2 500	2 800	2550

Table 14 (*Concluded*)

Sl No.	**No. of Passengers**	**Rated Load**	**Car Size**		**COPD Door**	**Passenger and Service Lifts with Machine Room: Shaft Sizes**													
						Rated speed < 1 m/s		1.0 m/s Ò Rated Speed Ò2.5 m/s		3.0 m/s Ò Rated Speed Ò3.5 m/s		4.0 m/s Ò Rated Speed Ò5.0 m/s		Rated Speed = 6.0 m/s		7.0 m/s Ò Rated Speed Ò8.0 m/s		9.0 m/s ÒRated Speed Ò10.0 m/s	
						Shaft Size		Shaft Size		Shaft Size		Shaft Size		Shaft Size		Shaft Size		Shaft Size	
		kg	Width	Depth	Width	Width	Depth	Width	Depth	Width	Depth	Width	Depth	Width	Depth	Width	Depth	Width	Depth
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
xii)	24	1 632	1 800	2 000	1 100	ï	ï	2 600	2 600	2 600	3 000	3 000	2 350	3 000	2 450	3 050	2 550	3 050	2550
xiii)	26	1 768	2 350	1 600	1 200	ï	ï	2 600	2 700	3 150	2 600	2 600	2 350	2 600	2 450	2 650	2 550	2 650	2550
xiv)	29	1 972	2 350	1 700	1 200	ï	ï	ï	ï	3 150	2 700	3 000	2 500	3 000	2 550	3 050	2 600	3 050	2700

NOTES

1 All dimensions given above for lifts having centre opening power operated doors (COPD) with counterweight at rear, are recommended dimensions primarily for architects and building planners. Any variations mutually agreed between the manufacturer and the purchaser is permitted. However, variation in:

a) Car inside dimensions shall be within the minimum and maximum area limits specified in accordance with Table 37;

b) Entrance width on higher side is permitted; and

c) Entrance width on lower side is permitted up to 100 mm subject to minimum of 700 mm.

2 The minimum size of the lift car and all other requirements relating to accessibility, in all public buildings shall be in accordance with good practice [D-5A(3)].

Table 15 Recommended Dimensions of Stretcher/Hospital Lifts

(*Clause* 5.10.3.1)

All dimensions in millimetres.

Sl. No	**No. of Passengers**	**Rated Load**	**Rounded off Rated Load**	**Car Size**		**2P TSPD Door**	**Hospital Bed / Stretcher Lifts with Machine Room: Shaft Sizes**													
							Rated Speed Ò1 m/s		0.6 m/s Ò Rated Speed Ò2.5 m/s		3.0 m/s Ò Rated Speed Ò3.5 m/s		4.0 m/s Ò Rated Speed Ò5.0 m/s		Rated Speed = 6.0 m/s		7.0 m/s Ò Rated Speed Ò 8.0 m/s		9.0 m/s Ò Rated Speed Ò10.0 m/s	
							Shaft Size		Shaft Size		Shaft Size		Shaft Size		Shaft Size		Shaft Size		Shaft Size	
		kg	kg	Width	Depth	Width	Width	Depth	Width	Depth	Width	Depth	Width	Depth	Width	Depth	Width	Depth	Width	Depth
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)
i)	15	1 020		1 000	2 400	800	1 800	3 000	1 800	3 000	2 100	3 400								
ii)	20	1 360		1 300	2 400	1 200			2 300	3 000	2 650	3 400	2 350	3 000	2 350	3 000	2 500	3 000	2 500	3 000
iii)	26	1 768	1 800	1 400	2 550	1 200			2 650	3 050	2 650	3 550	2 500	3 050	2 500	3 050	2 600	3 150	2 650	3 150
iv)	29	1 972	1 500	1500	2 700	1 400			2 650	3 200	3 100	3 700	2 600	3 200	2 600	3 200	2 700	3 200	2 700	3 200
v)	36	2 448	2 500	1 800	2 700	1 400			2 800	3 150	2 900	3 200	2 900	3 200	2 900	3 200	3 000	3 200	3 000	3 200

NOTES

1 All dimensions given above for lifts having two panel telescopic doors (2P TSPD) with counterweight at side, are recommended dimensions primarily for architects and building planners. Any variations mutually agreed to between the manufacturer and the purchaser is permitted. However, variation in:

a) Car inside dimensions shall be within the maximum area limits specified in accordance with Table 37;

b) Entrance width on higher side is permitted; and

c) Entrance width on lower side is permitted up to 100 mm subject to minimum of 700 mm.

2 Car depth of 2 100 mm may be considered in residential/commercial buildings, where use of only ambulance stretcher is envisaged. The hoist-way depth maybe reduced accordingly.

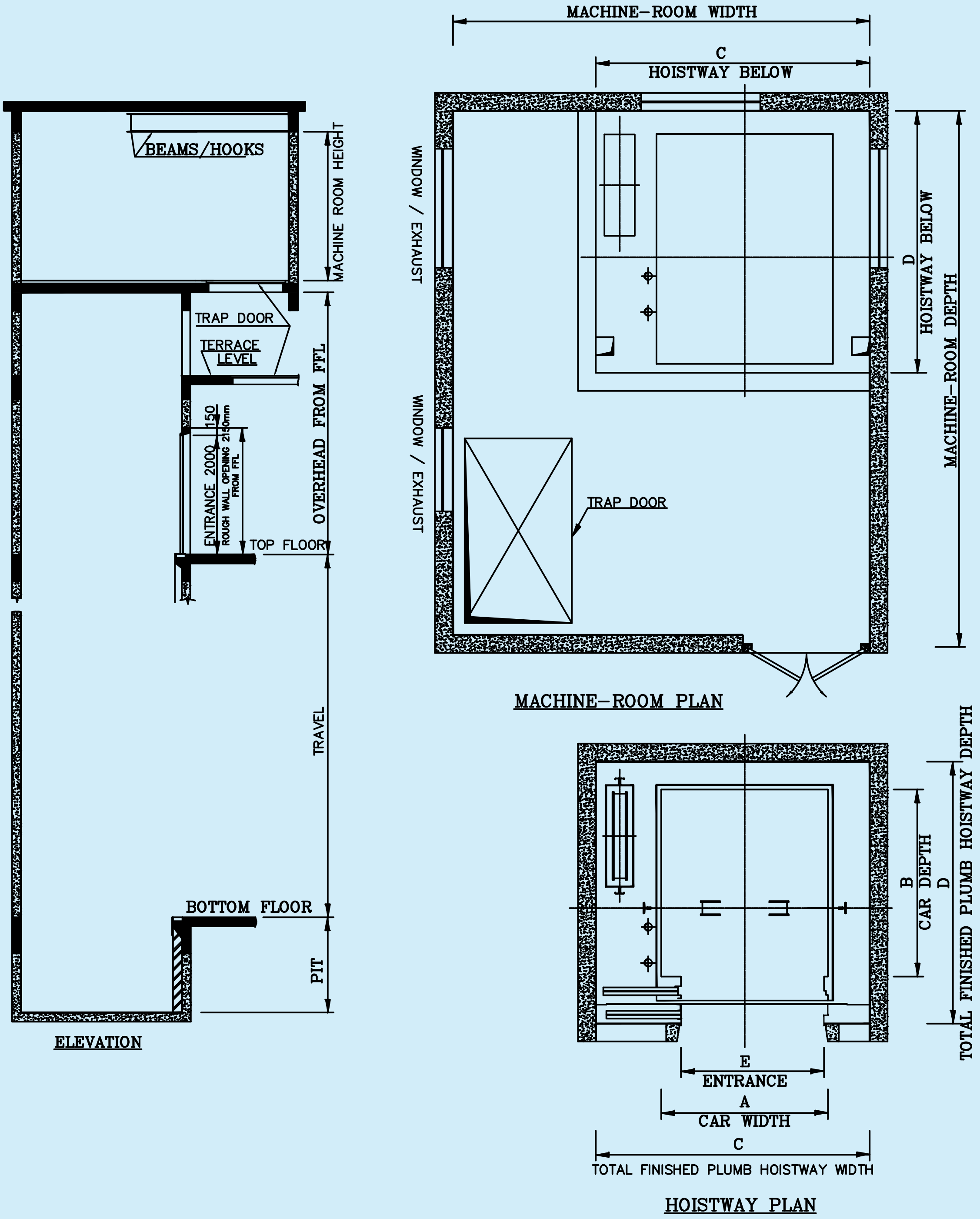

BEAMS/HOOKS
MACHINE ROOM HEIGHT
TRAP DOOR
TERRACE LEVEL
OVERHEAD FROM FFL
150
ENTRANCE 2000
ROUGH WALL OPENING 2150mm FROM FFL
TOP FLOOR
TRAVEL
BOTTOM FLOOR
PIT
ELEVATION
MACHINE-ROOM WIDTH
C
HOISTWAY BELOW
WINDOW / EXHAUST
WINDOW / EXHAUST
D
HOISTWAY BELOW
MACHINE-ROOM DEPTH
TRAP DOOR
MACHINE-ROOM PLAN
B
CAR DEPTH
D
TOTAL FINISHED PLUMB HOISTWAY DEPTH
E
ENTRANCE
A
CAR WIDTH
C
TOTAL FINISHED PLUMB HOISTWAY WIDTH
HOISTWAY PLAN

FIG. 4 (TABLE 15) FOR STRETCHER/HOSPITAL LIFTS

Table 16 Recommended Dimensions of Goods Lifts with Machine Room

(*Clause* 5.10.3.1)

All dimensions are in millimetres.

Sl No.	**Rated Load**	**Car Size**		**COPD Door**	**0.6 m/s Ò Rated Speed Ò2.5 m/s**		**3.0 m/s Ò Rated Speed Ò3.5 m/s**		**4.0 m/s Ò Rated Speed Ò 5.0 m/s**		**Rated Speed = 6.0 m/s**		**7.0 m/s Ò Rated Speed Ò 8.0 m/s**		**9.0 m/s ÒRated Speed Ò10.0 m/s**	
					Shaft Size		Shaft Size		Shaft Size		Shaft Size		Shaft Size		Shaft Size	
	kg	Width	Depth	Width	Width	Depth	Width	Depth	Width	Depth	Width	Depth	Width	Depth	Width	Depth
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
i)	1 000	1 400	1 800	2P-tel-1 200	2 550	2 200	ï	ï	ï	ï	ï	ï	ï	ï	ï	ï
ii)	1 500	1 700	2 000	4P-1 500	2 750	2 550	ï	ï	ï	ï	ï	ï	ï	ï	ï	ï
iii)	2 000	1 700	2 500	4P-1 500	2 800	3 050	2 800	3 050	2 900	3 050	3 000	3 050	3 000	3 050	3 000	3 050
iv)	2 500	2 000	2 500	4P-1 800	3 100	3000	3 000	3 050	3 100	3 050	3 200	3 050	3 200	3 050	3 200	3 050
v)	3 000	2 000	3 000	4P-1 800	3 100	3 550	3 000	3 550	3 100	3 550	3 200	3 550	3 200	3 550	3 200	3 550
vi)	4 000	2 500	3 000	4P-2 100/ 6P-2 100	3 700	4 000	3 700	3 650	ï	ï	ï	ï	ï	ï	ï	ï
vii)	5 000	2 500	3 600	4P-2 100/ 6P-2 100	3 850	4 250	3 850	4 250	ï	ï	ï	ï	ï	ï	ï	ï

NOTES

1 All dimensions given above for lifts having centre opening power operated doors (COPD) with counterweight at side, are recommended dimensions primarily for architects and building planners. Any variations mutually agreed to between the manufacturer and the purchaser are permitted. However, the minimum rated load for the goods lift shall be based on a load of not less than 3.45 kN/m^2 of the net inside car area.

2 Car inside dimensions shall be within the maximum area limits specified in accordance with Table 32.

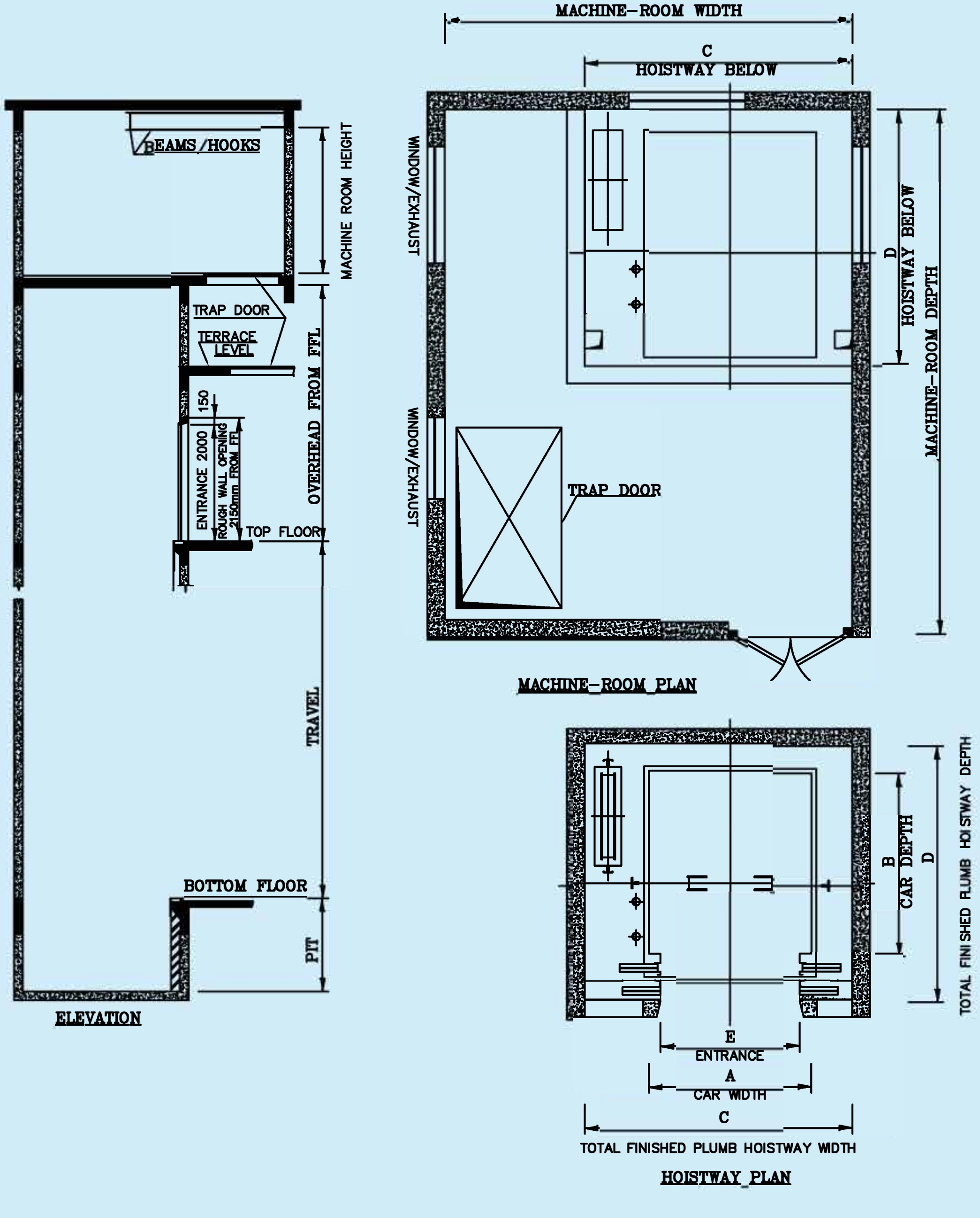

BEAMS/HOOKS
MACHINE ROOM HEIGHT
TRAP DOOR
TERRACE LEVEL
150
ENTRANCE 2000
ROUGH WALL OPENING 2150mm FROM FFL
TOP FLOOR
OVERHEAD FROM FFL
TRAVEL
BOTTOM FLOOR
PIT
ELEVATION
MACHINE-ROOM WIDTH
C
HOISTWAY BELOW
WINDOW/EXHAUST
WINDOW/EXHAUST
D
HOISTWAY BELOW
MACHINE-ROOM DEPTH
TRAP DOOR
MACHINE-ROOM PLAN
B
CAR DEPTH
D
TOTAL FINISHED PLUMB HOISTWAY DEPTH
E
ENTRANCE
A
CAR WIDTH
C
TOTAL FINISHED PLUMB HOISTWAY WIDTH
HOISTWAY PLAN

FIG. 5 (TABLE 16) FOR GOODS LIFTS

Table 17 Recommended Dimensions of Machine Room Height, Overhead, Pit Depth for Passenger, Goods, and Stretcher/Hospital Lifts with Machine Room

(*Clauses* 5.8.1, 5.8.2 *and* 5.10.3.1)

All dimensions are in millimetres.

For Speed up to 3.5 m/s

Sl No.	**No. of Passengers**	**Rated Load** kg	**Dimensions of Pit Depth, Overhead Height (HR) and Machine Room Height(MR)**																				
			0.7 m/s			1.0 m/s			1.6 m/s			2 m/s			2.5 m/s			3 m/s			3.5 m/s		
			Pit Depth	HR	MR	Pit Depth	HR	MR	Pit Depth	HR	MR	Pit Depth	HR	MR	Pit Depth	HR	MR	Pit Depth	HR	MR	Pit Depth	HR	MR
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)
i)	4	272	1 350	CH + 1 900	2 500	1 500	CH + 1 950	2 500	1 600	CH + 2 400	2 500	2 200	CH + 2 800	2 500	ï	ï	ï	ï	ï	ï	ï	ï	ï
ii)	6	408	1 350	CH + 1 900	2 500	1500	CH +1950	2500	1 600	CH + 2 400	2 500	2 200	CH + 2 800	2 500	ï	ï	ï	ï	ï	ï	ï	ï	ï
iii)	8	544	1 350	CH + 1 900	2 500	1500	CH +1950	2500	1 600	CH + 2 400	2 500	2 200	CH + 2 800	2 500	ï	ï	ï	ï	ï	ï	ï	ï	ï
iv)	10	680	1 350	CH + 1 900	2 500	1500	CH + 1950	2500	1 600	CH +2 400	2 500	2 200	CH + 2 800	2 500	2 250	CH + 2 800	2 500	ï	ï	ï	ï	ï	ï
v)	13	884	1 350	CH + 1 900	2 500	1500	CH +1950	2500	1 600	CH +2 400	2 500	2 200	CH + 2 800	2 500	2 500	CH + 3 000	2 500	3 200	CH + 3 250	3 500	4 500	CH + 3 550	3 500
vi)	14	952	1 350	CH + 1 900	2 500	1500	CH +1950	2500	1 800	CH + 2 400	2 500	2 200	CH + 2 800	2 500	2 500	CH + 3 000	2 500	3 200	CH + 3 250	3 500	4 500	CH + 3 550	3 500
vii)	16	1 088/ 1 000	1500	CH+ 1 900	2 500	1500	CH +1950	2500	1 800	CH + 2 400	2 500	2 200	CH + 2 800	2 500	2 500	CH + 3 000	2 500	3 200	CH + 3 250	3 500	4 500	CH + 3 550	3 500
viii)	18	1 224	ï	ï	ï	1 500	CH + 1950	2500	1 800	CH + 2 400	2 500	2 200	CH + 2 800	2 500	2 500	CH + 3 000	2 500	3 200	CH + 3 250	3 500	4 500	CH + 3 550	3 500
ix)	20	1 360	ï	ï	ï	1 500	CH + 1 950	2500	1 800	CH + 2 400	2 500	2 200	CH +2 800	2 500	2 500	CH + 3 000	3 000	3 200	CH+ 3 250	3 500	4 500	CH+ 3 550	3 500
x)	22	1 496/ 1 500	ï	ï	ï	1 500	CH + 1 950	2500	1 800	CH + 2 400	3 000	2 200	CH + 2 800	3 000	2 500	CH + 3 000	3 000	3 200	CH+ 3 250	3 500	4 500	CH+ 3 550	3 500
xi)	24	1 632	ï	ï	ï	1500	CH + 1950	2500	1 800	CH + 2 400	3 000	2 200	CH + 2 800	3 000	2 500	CH + 3 000	3 000	3 200	CH+ 3 250	3 500	4 500	CH+ 3 550	3 500
xii)	26	1 768	ï	ï	ï	1 500	CH + 1 950	3000	1 800	CH + 2 400	3 000	2 200	CH + 2 800	3 000	2 500	CH + 3 000	3 000	3 200	CH+ 3 450	3 500	4 500	CH+ 3 550	3 500
xiii)	29	1 972/ 2 000	ï	ï	ï	1 600	CH + 1 950	3000	1 800	CH + 2 400	3 000	2 200	CH + 2 800	3 000	2 500	CH + 3 000	3 000	3 200	CH+ 3 450	3 500	4 600	CH+ 3 550	3 500
xiv)	ï	2 500	ï	ï	ï	1 800	CH + 1 950	4000	1 800	CH + 2 400	4 000	2 200	CH + 2 800	4 000	2 500	CH + 3 000	4 000	3 200	CH+ 3 450	4 000	4 600	CH+ 3 550	4 000
xv)	ï	3 000	ï	ï	ï	1 800	CH + 1 950	4000	1 800	CH + 2 400	4 000	2 200	CH + 2 800	4 000	2 500	CH + 3 000	4 000	3 200	CH+ 3 450	4 300	4 600	CH+ 3 600	4 300
xvi)	ï	4 000	ï	ï	ï	1 800	CH + 2200	4300	1 800	CH + 2 400	4 300	2 200	CH + 2 800	4 300	2 500	CH + 3 000	4 300	3 200	CH+ 3 450	4 300	4 600	CH+ 3 600	4 300
xvii)	ï	5 000	ï	ï	ï	1 800	CH + 2200	4500	1 800	CH + 2 400	4 500	2 200	CH + 2 800	4 500	2 500	CH + 3 000	5 000	3 200	CH+ 3 450	5 000	4 600	CH+ 3 600	5 000

Table 17 (*Concluded*)

Sl No.	**No. of Passengers**	**Rated Load** kg	**Passenger, Goods, Stretcher/Hospital Lifts with Machine Room: Dimensions of Pit Depth, Overhead Height (HR) and Machine Room Height(MR)**																				
			4 m/s			5 m/s			6 m/s			7 m/s			8 m/s			9 m/s			10 m/s		
			Pit Depth	HR	MR	Pit Depth	HR	MR	Pit Depth	HR	MR	Pit Depth	HR	MR	Pit Depth	HR	MR	Pit Depth	HR	MR	Pit Depth	HR	MR
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)
i)	14	952	4 600	CH + 3 450	4 000	4 700	CH + 3 450	4 000	5 500	CH + 3 800	4 300	5 900	CH + 5 000	4 300	6 500	CH + 5 800	4 300	7 100	CH + 6 500	5 000	7 500	CH + 6 900	5 000
ii)	16	1 088/ 1 000	4 600	CH + 3 450	4 000	4 700	CH + 3 450	4 000	5 500	CH + 3 800	4 300	5 900	CH + 5 000	4 300	6 500	CH + 5 800	4 300	7 100	CH + 6 500	5 000	7 500	CH + 6 900	5 000
iii)	18	1 224	4 600	CH + 3 450	4 000	4 700	CH + 3 450	4 000	5 500	CH + 3 800	4 300	5 900	CH + 5 000	4 300	6 500	CH + 5 800	4 300	7 100	CH + 6 500	5 000	7 500	CH + 6 900	5 000
iv)	20	1 360	4 600	CH + 3 450	4 000	4 700	CH + 3 450	4 000	5 500	CH + 3 800	4 300	5 900	CH + 5 000	4 300	6 500	CH + 5 800	4 300	7 100	CH + 6 500	5 000	7 500	CH + 6 900	5 000
v)	22	1 496/ 1 500	4 600	CH + 3 450	4 000	4 700	CH + 3 450	4 000	5 500	CH + 3 800	4 300	5 900	CH + 5 000	4 300	6 500	CH + 5 800	4 300	7 100	CH + 6 500	5 000	7 500	CH + 6 900	5 000
vi)	26	1 768	4 600	CH + 3 450	4 000	4 700	CH + 3 450	4 300	5 500	CH + 3 800	4 300	5 900	CH + 5 000	4 300	6 500	CH + 5 800	4 300	7 100	CH + 6 500	5 000	7 500	CH + 6 900	5 000
vii)	29	1 972/ 2 000	4 600	CH + 3 450	4 000	4 700	CH + 3 450	4 300	5 500	CH + 3 800	4 300	5 900	CH + 5 000	5 000	6 500	CH + 5 800	5 000	7 100	CH + 6 500	5 000	7 500	CH + 6 900	5 000
viii)	ï	2 500	4 600	CH + 3 450	4 300	4 700	CH + 3 450	5 000	5 500	CH + 3 800	5000	5 900	CH + 5 500	5 000	6 500	CH + 6 300	5 000	7 100	CH + 7 000	5 000	7 500	CH + 7 500	5 000
ix)	ï	3 000	4 600	CH + 3 600	4 300	4 700	CH + 3 600	5 000	5 500	CH + 4 000	5 000	5 900	CH + 5 500	5 000	6 500	CH + 6 300	5 000	7 100	CH + 7 000	5 000	7 500	CH + 7 500	5 000

CH ï Car clear inside height measured from car finished floor level to false ceiling.

NOTES

1 Recommended dimensions for pit depth, overhead and machine-room for different lift speeds are given in the table above. These dimensions may differ in practice as per individual manufacturerôs design depending upon load, speed and drive. However, the pit depth and overhead shall be such as to conform to the requirements of bottom clearance and top clearance in accordance with the accepted standards [D-5A(1)].

2 In case of goods lifts minimum pit depth required is 1 600 mm.

3 In case of lift speeds 3.5 m/s and 4 m/s with rear counterweight the pit depth requirement could be less by about 500 mm to 1 000 mm.

Table 18 Recommended Dimensions of Automobile Lifts with Machine Room-Through Type Car

(Rated Speed = 0.6 m/s or 1.0 m/s)

(*Clause* 5.10.3.1)

All dimensions in millimetres.

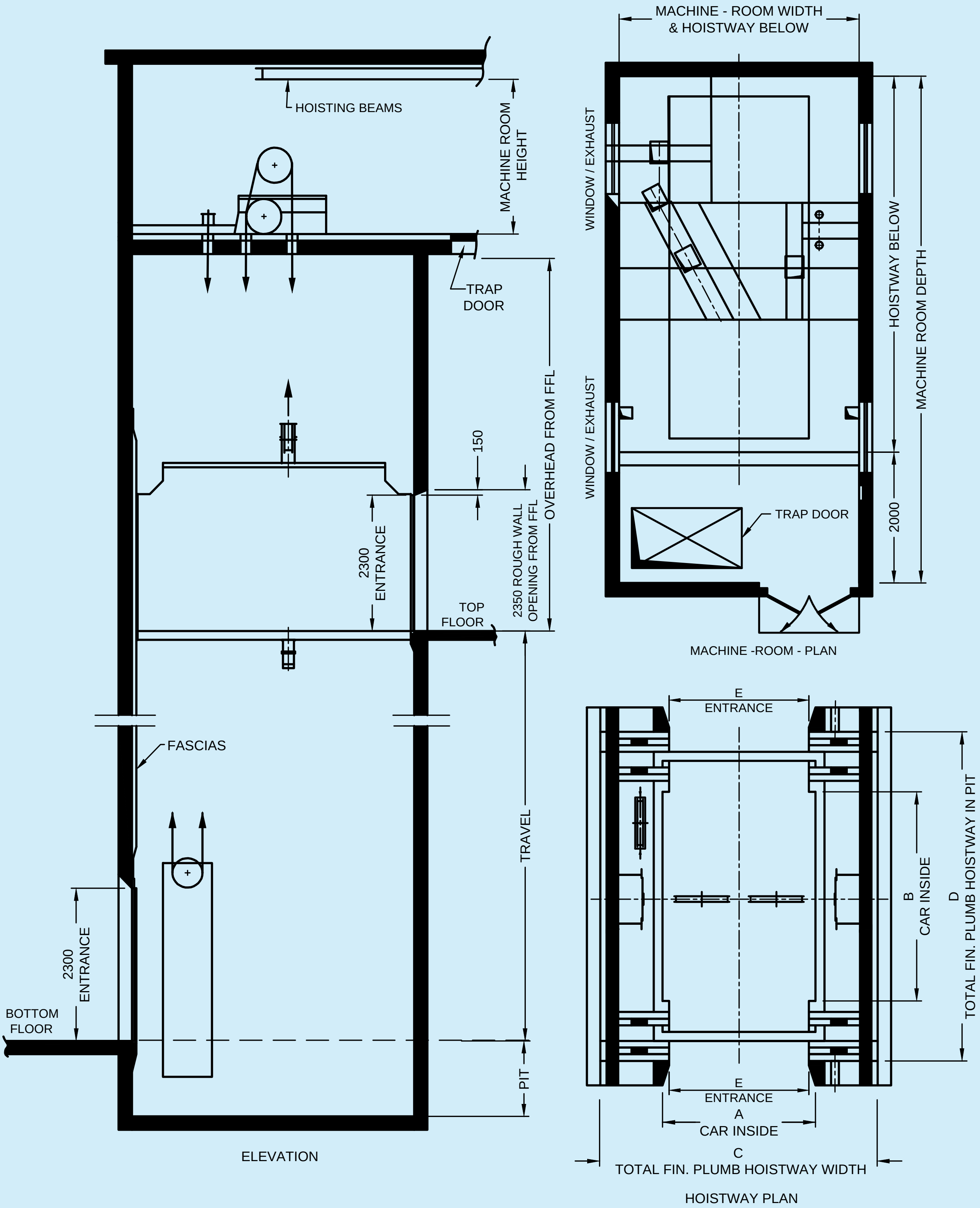
Sl No.	**Rated Load**	**Car Size**		**COPD Door**	**Shaft Size**		**Car Height**	**Overhead Height**	**Pit Depth**	**Machine Room Height**
	Kg	Width	Depth	Width	Width	Depth	CH	HR	PH	MR
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
i)	2 500	2 500	5 000	4P - 2 400	4 000	5 780	2 200	5 200	1 800	4 000
ii)	3 000	2 700	5 400	4P - 2 400	4 000	5 880				
iii)	4 000	3 000	5 800	6P - 3 000	4 300	6 700			2 000	4 500
iv)	5 000	3 000	6 000	6P - 3 000	4 300	6 900				

NOTES

1 All dimensions given above for lifts having centre opening power operated doors (COPD) with counterweight at side, are recommended dimensions primarily for architects and building planners. Any variations mutually agreed to between the manufacturer and the purchaser are permitted. However, the minimum rated load for the automobile lift shall be based on a load of not less than 1.45 kN/m^2 of the net inside car area.

2 Dimensions of machine room height, pit depth and overhead may differ in practice as per individual manufacturer's design depending upon load, speed and drive. However, the pit depth and overhead shall be such as to conform to the requirements of bottom clearance and top clearance in accordance with the accepted standards [D-5A(6)].

3 The lift car width should be selected such that in case of emergency while the automobile is in the car-lift the driver should be able to open the automobile door and come out of the automobile.


MACHINE - ROOM WIDTH & HOISTWAY BELOW
HOISTING BEAMS
MACHINE ROOM HEIGHT
TRAP DOOR
150
OVERHEAD FROM FFL
2300 ENTRANCE
2350 ROUGH WALL OPENING FROM FFL
TOP FLOOR
FASCIAS
TRAVEL
2300 ENTRANCE
BOTTOM FLOOR
PIT
ELEVATION
WINDOW / EXHAUST
WINDOW / EXHAUST
HOISTWAY BELOW
MACHINE ROOM DEPTH
TRAP DOOR
2000
MACHINE -ROOM - PLAN
E ENTRANCE
B CAR INSIDE
D TOTAL FIN. PLUMB HOISTWAY IN PIT
E ENTRANCE
A CAR INSIDE
C TOTAL FIN. PLUMB HOISTWAY WIDTH
HOISTWAY PLAN

All dimensions in mm.

FIG. 6 (TABLE 18) FOR RECOMMENDED DIMENSIONS OF AUTOMOBILE LIFTS

Table 19 Recommended Dimensions of Dumbwaiter Lifts

(*Clause* 5.10.3.1)

All dimensions in millimetres.

Sl No.	Load	Car Inside			Lift Well		Entrance	Machine Room Extension
	kg	*A*	*B*	*H*	*C*	*D*	*E*	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
i)	100	700	700	800	1 200	900	700	D + 1 000
ii)	150	800	800	900	1 300	1 000	800	D + 1 000
iii)	200	900	900	1 000	1 400	1 100	900	D + 1 000
iv)	250	1 000	1 000	1 200	1 500	1 200	1 000	D + 1 000

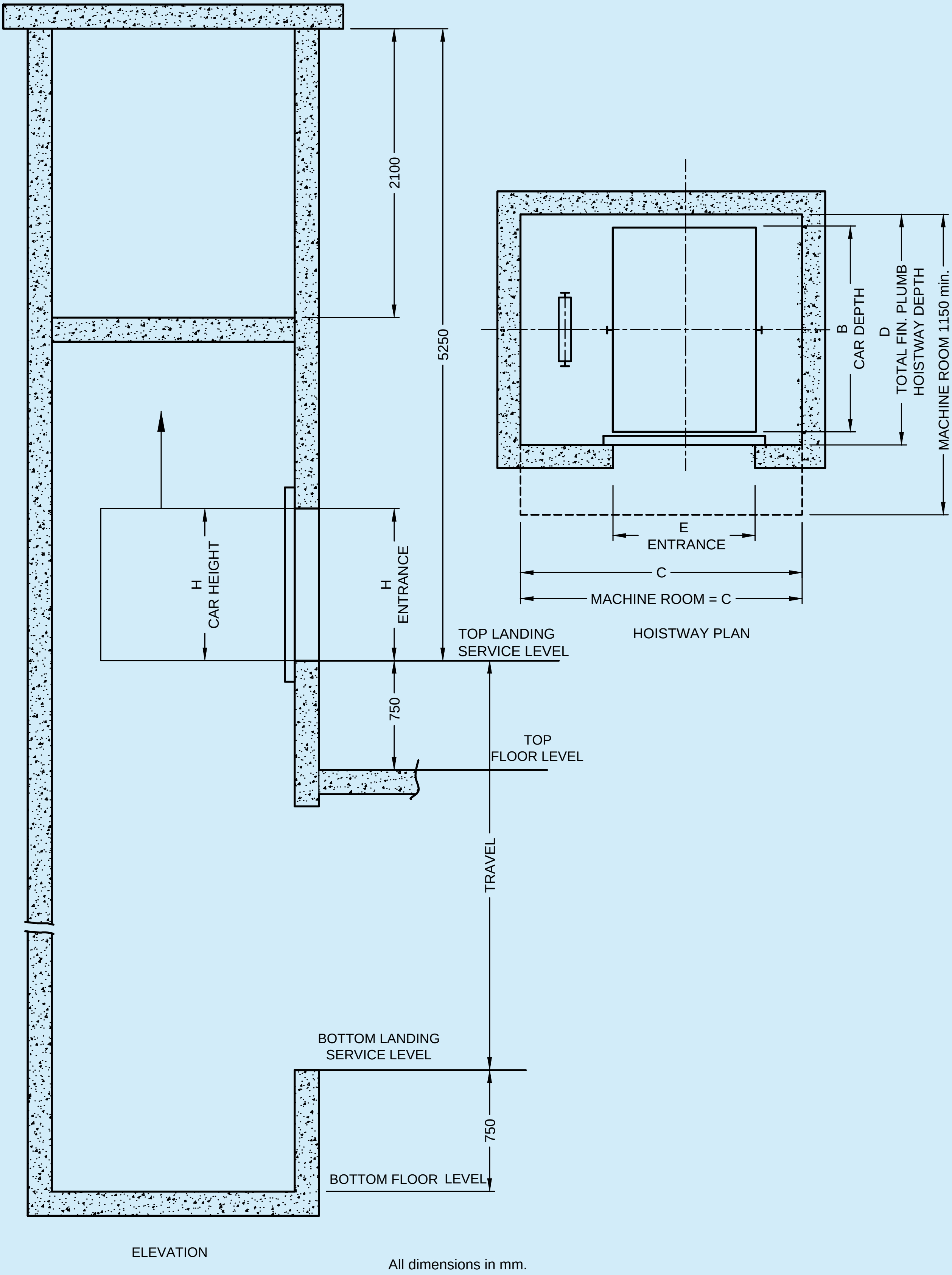
NOTES

1 Entrance width ó*E*ô is based on assumption of provision of vertical bi-parting doors (no car door is normally provided).

2 D + 1000, where óDô is shaft depth.

3 Head room ï 3 000 (with M/C Room) *Max* speed 0.34 m/s.

4 Head room MRL ï 4 050 to 4 450 (*Max* speed 0.34 m/s).



2100
5250
H
CAR HEIGHT
H
ENTRANCE
TOP LANDING
SERVICE LEVEL
750
TOP
FLOOR LEVEL
TRAVEL
BOTTOM LANDING
SERVICE LEVEL
750
BOTTOM FLOOR LEVEL
ELEVATION
B
CAR DEPTH
D
TOTAL FIN. PLUMB
HOISTWAY DEPTH
MACHINE ROOM 1150 min.
E
ENTRANCE
C
MACHINE ROOM = C
HOISTWAY PLAN

All dimensions in mm.

FIG. 7 (TABLE 19) FOR DUMBWAITER LIFTS

Table 20 Entrance Type: Horizontal and Vertical Sliding Doors

(*Clause* 5.10.3.1, *Table* 21, *Table* 22, *Table* 24, *Table* 25 *and Table* 26)

Sl No.	**Type**	**Horizontal Sliding Doors**		**Vertical Sliding Doors**	
		Landing Door	Car Door	Landing Door	Car Door
(1)	(2)	(3)	(4)	(5)	(6)
i)	Type 1	Telescopic door (side opening)	Telescopic door (side opening)	ï	ï
ii)	Type 2	Centre opening door	Centre opening door	ï	ï
iii)	Type 3	Centre telescopic door	Centre telescopic door	ï	ï
iv)	Type 4	ï	ï	Bi-parting (central opening)	Telescopic upwards
v)	Type 5	ï	ï	Bi-parting pass type (central opening, overlapping)	Telescopic upwards
vi)	Type 6	ï	ï	Telescopic upwards	Telescopic upwards

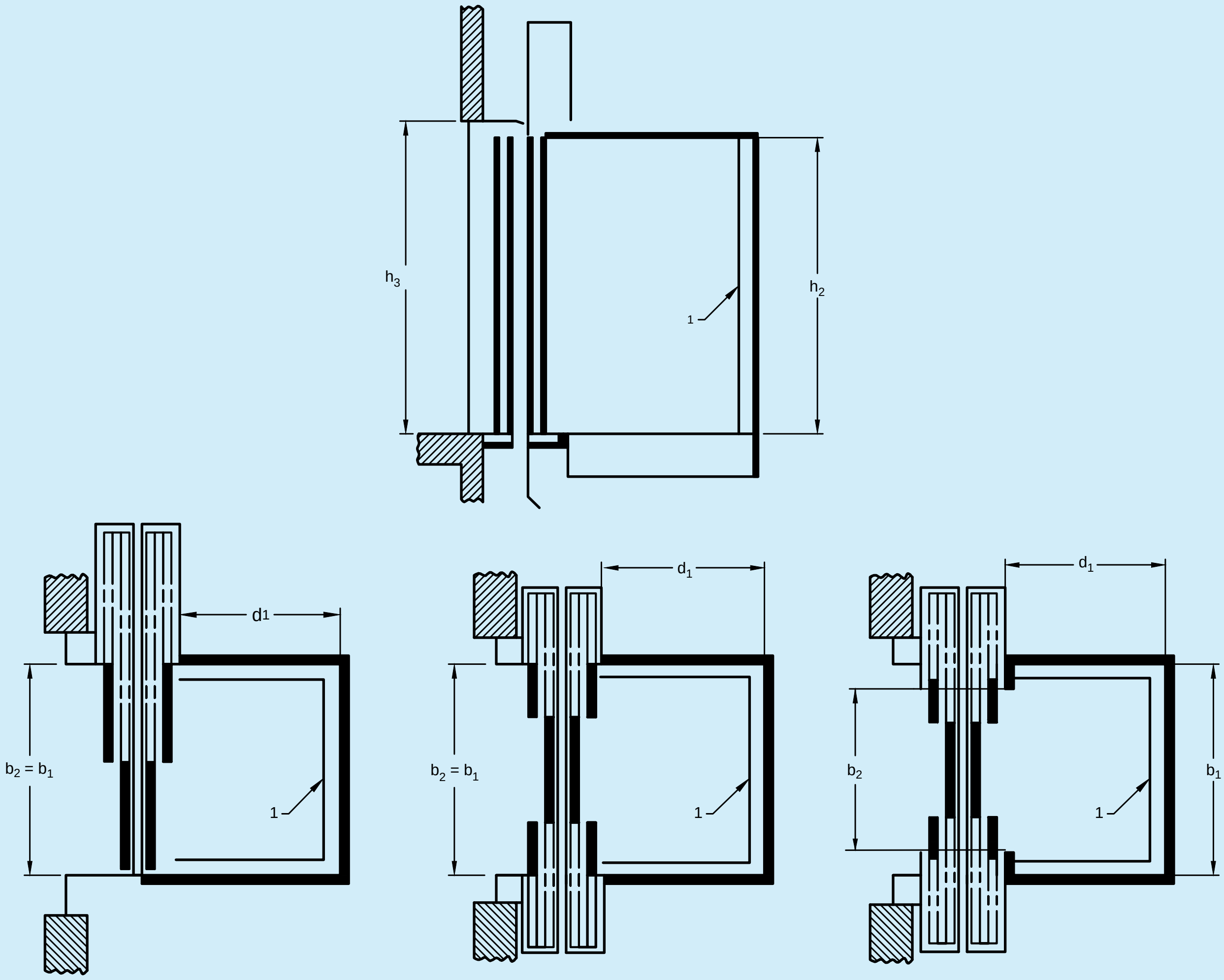
Two types of loading (load per unit area) are addressed:

Series A ð Passenger and goods (freight) lifts with loading conforming to Table 6 and Table 7 of accepted standard [D-5A(1)].

Series B ð Goods (freight) and automobiles lifts which have lesser loading as compared to that for Series A.

The lift well and machine room dimensions of electric lift for Series A and Series B are as shown in Fig. 10, and lift well and machine room dimensions of hydraulic lift for Series A and Series B are as shown in Fig. 11.

Automobile lifts with machine room for through type car Series B with vertical sliding door is shown in Fig. 12.

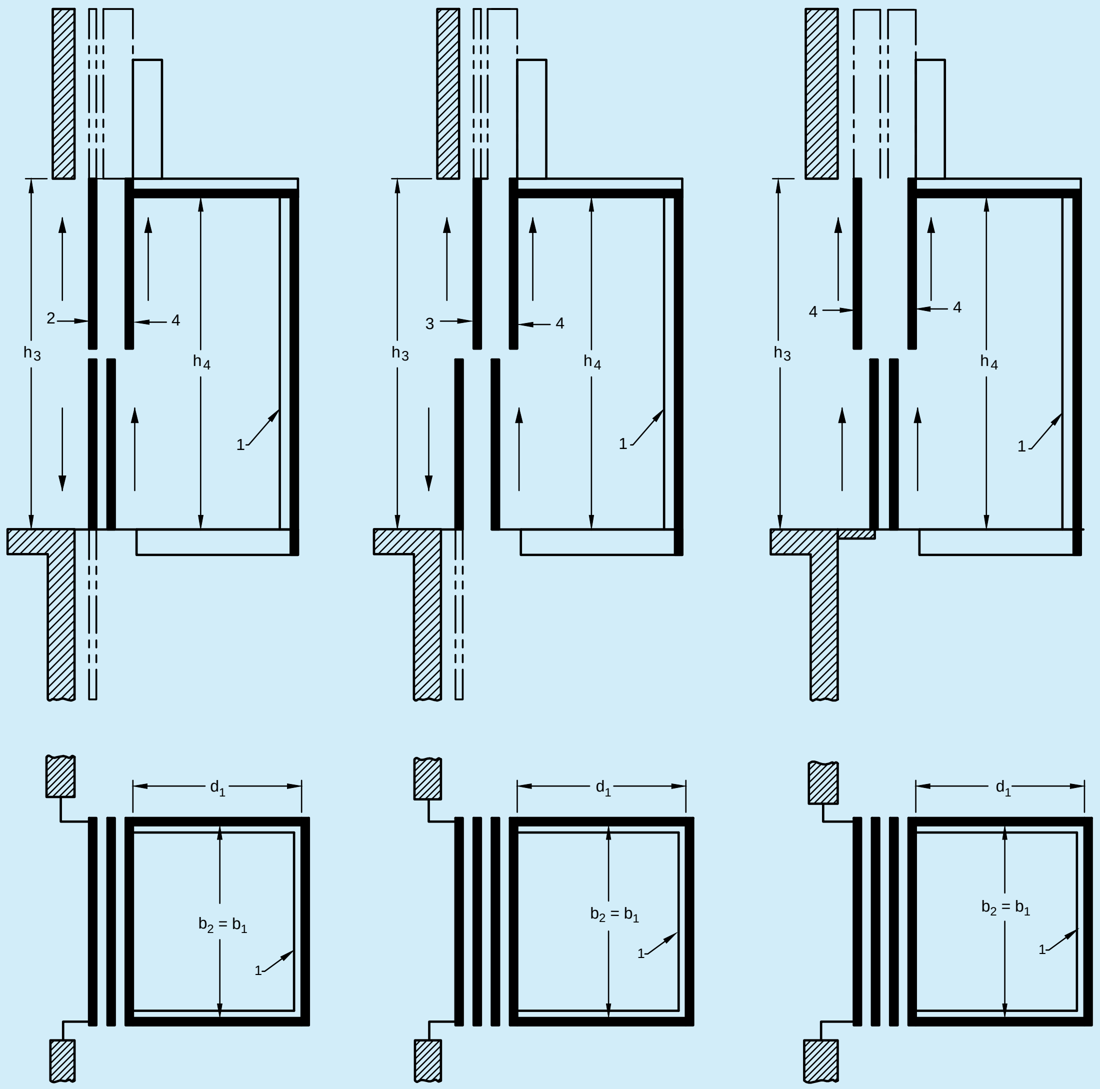


Key

1	Protective elements
b_1	Car width
b_2	Entrance width
d_1	Car depth
h_3	Entrance height
h_4	Car height

Entrance	:	Type 1	Type 2	Type 3
Landing door	:	Telescopic door (side opening)	Centre opening door	Centre telescopic door
Car door	:	Telescopic door (side opening)	Centre opening door	Centre telescopic door

FIG. 8 CAR AND LANDING DIMENSIONS FOR HORIZONTAL SLIDING DOORS FOR SERIES A AND SERIES B



Key

1 Protective elements

2 Bi-parting (central opening)

3 Bi-parting , pass type (central opening, overlapping)

4 Telescopic upwards

b_1 Car width

b_2 Entrance width

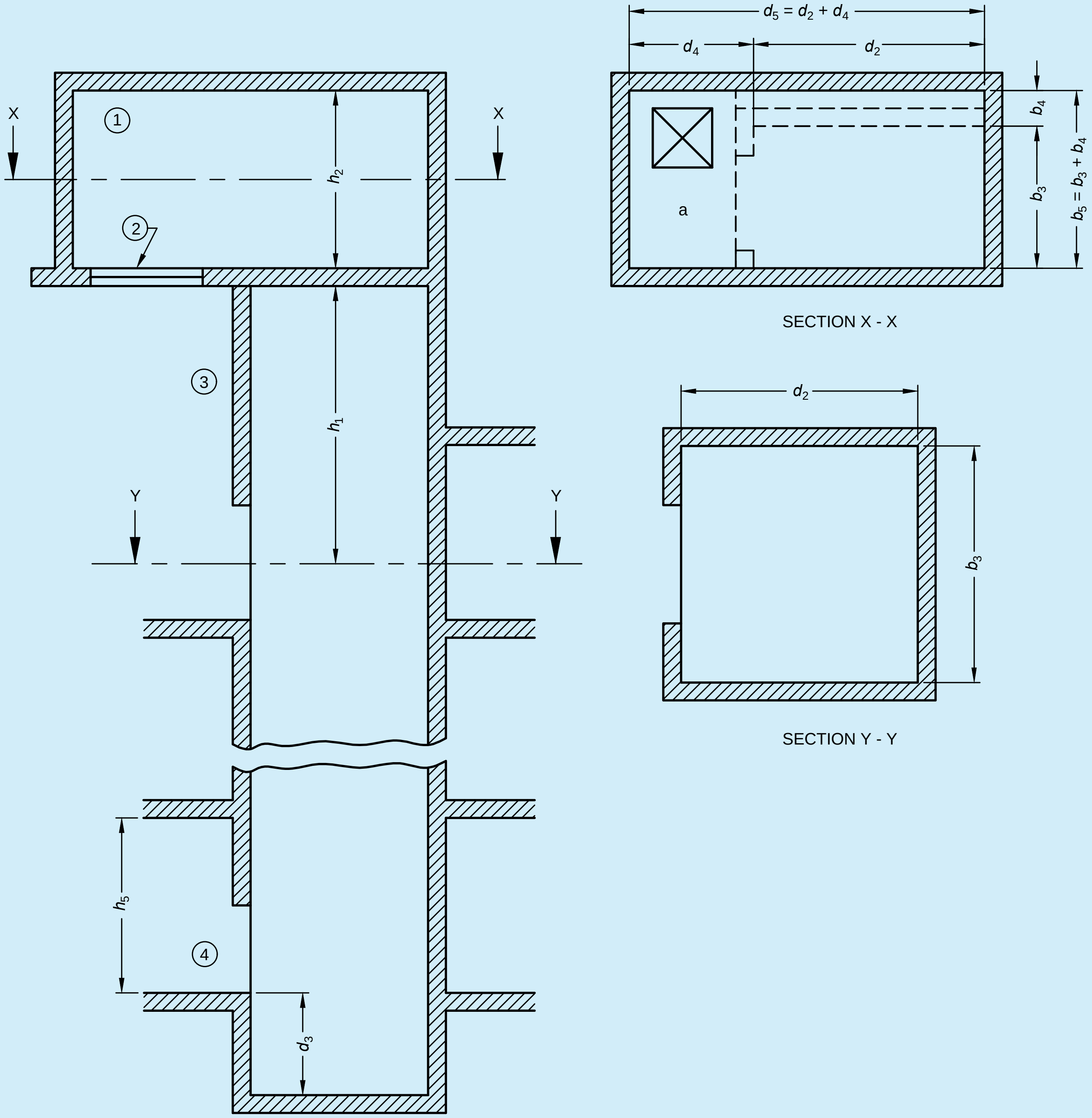
d_1 Car depth

h_3 Entrance height

h_4 Car height

Entrance	:	Type 4	Type 5	Type 6
Landing door	:	Bi-parting (centre opening)	Bi-parting , pass type (centre opening, overlapping)	Telescopic upwards
Car door	:	Telescopic upwards	Telescopic upwards	Telescopic upwards

FIG. 9 CAR AND LANDING DIMENSIONS FOR VERTICAL SLIDING DOORS FOR SERIES A AND SERIES B



SECTION X - X

SECTION Y - Y

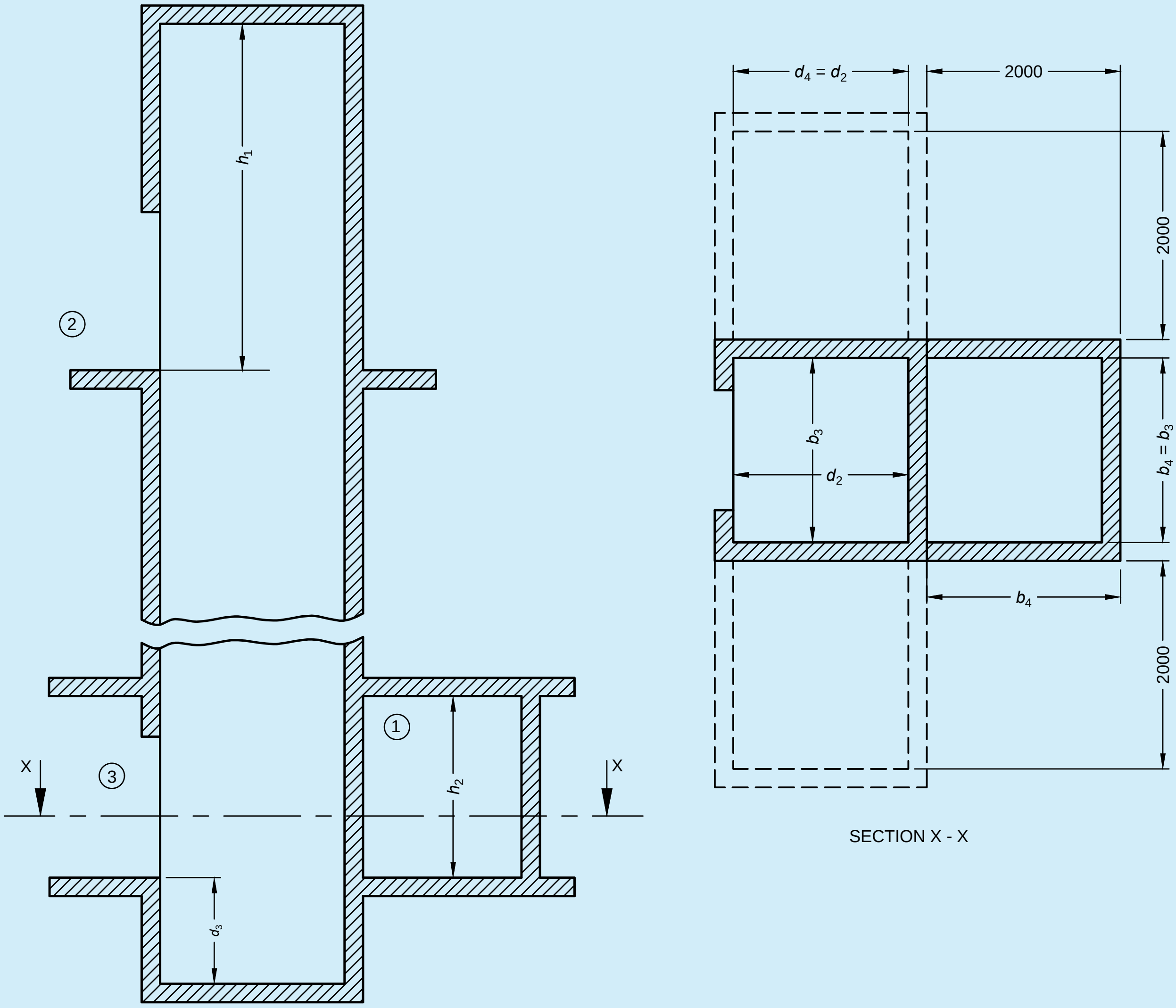
KEY :

1 - MACHINE ROOM
2 - TRAP DOOR
3 - HIGHEST LEVEL SERVE
4 - LOWEST LEVEL SERVED
5 - TELESCOPIC UPWARDS
6 - BI-PARTING (CENTER OPENING)
b_3 - WELL WIDTH
b_4 - MACHINE ROOM EXTENSION WIDTH

b_5 - MACHINE ROOM WIDTH
d_2 - WELL DEPTH
d_3 - PIT DEPTH
d_4 - MACHINE ROOM EXTENSION DEPTH
d_5 - MACHINE ROOM DEPTH
h_1 - OVERHEAD HEIGHT
h_2 - MACHINE ROOM HEIGHT

IT IS NECESSARY TO HAVE AN ACCESS DOOR TO THE MACHINE ROOM ALTHOUGH THIS IS NOT INDICATED ON THE SKETCH

FIG. 10 LIFT WELL AND MACHINE ROOM DIMENSIONS: ELECTRIC LIFTS FOR SERIES A AND SERIES B



SECTION X - X

1 - MACHINE ROOM
2 - HIGHEST LEVEL SERVED
3 - LOWEST LEVEL SERVED
b_3 - WELL WIDTH
b_4 - MACHINE ROOM WIDTH
d_2 - WELL DEPTH
d_3 - PIT DEPTH
d_4 - MACHINE ROOM DEPTH
h_1 - HEADROOM HEIGHT
h_2 - MACHINE ROOM HEIGHT

IT IS NECESSARY TO HAVE AN ACCESS DOOR TO THE MACHINE ROOM ALTHOUGH THIS IS NOT INDICATED ON THE SKETCH

FIG. 11 LIFT WELL AND MACHINE ROOM DIMENSIONS: HYDRAULIC LIFTS FOR SERIES A AND SERIES B

Table 21 Recommended Dimensions of Goods Lifts with Machine Room Series A Cars ð Vertical Sliding Door (Entrance Type 4 and 5)

(*Clause* 5.10.3.1)

All dimensions are in millimetres.

Series A Car with Vertical Sliding Door															
Sl No.	**Rated Load**	**Rated Speed**	**Car Size**		**Door**	**Shaft Size**		**Car Height**	**Entrance Height**	**Overhead Height**	**Pit Depth**	**Machine Room Size**		**Machine Room Height**	**Min Floor to Floor Height**
	kg	m/s	Width (b_1)	Depth (d_1)	Width (b_2)	Width (b_3)	Depth (d_2)	CH (h_4)	EH (h_3)	HR (h_1)	PH (d_3)	Width (b_5)	Depth (d_5)	MR (h_2)	MM (h_5)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
i)	1 000	0.5 to 1.0	1 400	1 800	1 400	2 350	2 300	2 200	2 000	4 800	1 600	(b_3 + 1 000)	(d_2 + 2 500)	2 500	(h_3+f)
ii)	1 500		1 700	2 000	1 700	2 650	2 500	2 200	2 000	4 800	1 600			2 500	
iii)	1 600		1 700	2 100	1 700	2 650	2 600	2 200	2 000	4 800	1 600			2 500	
iv)	2 000		1 700	2 500	1 700	2 800	3 000	2 200	2 000	4 800	1 600			2 500	
v)	2 500		2 000	2 500	2 000	3 050	3 000	2 200	2 000	4 800	1 600			2 500	
vi)	3 000	0.5	2 000	3 000	2 000	3 100	3 600	2 200	2 000	4 800	1 800			3 000	
vii)	3 500		2 500	2 550	2 500	3 700	3 100	2 200	2 000	4 800	1 800			3 000	
viii)	4 000		2 500	3 000	2 500	3 700	3 600	2 200	2 000	4 800	1 800			3 000	
ix)	5 000		2 500	3 600	2 500	3 700	4 100	2 200	2 000	4 800	1 800			3 000	

NOTES

1 For width and depth of machine room and minimum floor to floor height requirement refer below:

a) Machine room width is (b_3+b_4), where b_3 is width of shaft size and b_4 as 1000 mm to be considered;

b) Machine room depth is (d_2+d_4), where d_2 is depth of shaft size and d_4 as 2500mm to be considered; and

c) Minimum floor to floor height (h_5) for landings for vertical sliding door is (h_3 + f), where óh_3ô is clear entrance height and dimension ófô depends upon the type of door. Refer Table 20 for vertical sliding door types.

2 In case counterweight safety is applicable check for dimensions with lift manufacturer.

3 Recommended dimensions for pit depth, overhead and machine-room for different lift speeds are given in the table above. These dimensions may differ in practice as per individual manufacturerôs design depending upon load, speed and drive. However, the pit depth and overhead shall be such as to conform to the requirements of bottom clearance and top clearance in accordance with the accepted standards [D-5A(1)].

4 All dimensions given above for machine room lifts are recommended dimensions for architects and building planners. Any variations mutually agreed to between the manufacturer and the purchasers are permitted. However, the minimum rated load for the goods lift shall be based on Class of loading for the net inside car area. Refer 8.3.1.1 for class of loading.

Table 22 Recommended Dimensions of Goods Lifts with Machine Room ð Series A cars ð Vertical Sliding Door (Entrance Type 6)

(*Clause* 5.10.3.1)

All dimensions are in mm.

Series A Car with Vertical Sliding Door

Sl No.	Rated Load	Rated Speed	Car Size		Door	Shaft Size		Car Height	Entrance Height	Overhead Height	Pit Depth	Machine Room Size		Machine Room Height	Min Floor to Floor Height
	kg	m/s	Width (b_1)	Depth (d_1)	Width (b_2)	Width (b_3)	Depth (d_2)	CH (h_4)	EH (h_3)	HR (h_1)	PH (d_3)	Width (b_5)	Depth (d_5)	MR (h_2)	MM (h_5)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(8)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
i)	1 000	0.5 to 1.0	1 400	1 800	1 400	2 400	2 300	2 200	2 000	4 800	1 600	(b_3 + 1 000)	(d_2 + 2 500)	2 500	(h_3+ f)
ii)	1 500		1 700	2 000	1 700	2 700	2 500	2 200	2 000	4 800	1 600			2 500	
iii)	1 600		1 700	2 100	1 700	2 700	2 600	2 200	2 000	4 800	1 600			2 500	
iv)	2 000		1 700	2 500	1 700	2 850	3 000	2 200	2 000	4 800	1 600			2 500	
v)	2 500		2 000	2 500	2 000	3 100	3 000	2 200	2 000	4 800	1 600			2 500	
vi)	3 000	0.5	2 000	3 000	2 000	3 150	3 600	2 200	2 000	4 800	1 800			3 000	
vii)	3 500		2 500	2 550	2 500	3 750	3 100	2 200	2 000	4 800	1 800			3 000	
viii)	4 000		2 500	3 000	2 500	3 750	3 600	2 200	2 000	4 800	1 800			3 000	
ix)	5 000		2 500	3 600	2 500	3 750	4 100	2 200	2 000	4 800	1 800			3 000	

NOTES

1 For width and depth of Machine size dimensions and minimum floor to floor height requirement refer below:

a) Machine room Width is (b_3 +b_4), where b_3 is width of shaft size and b_4 as 1000 mm to be considered;

b) Machine room Depth is (d_2 +d_4), where d_2 is depth of shaft size and d_4 as 2500mm to be considered; and

c) Minimum floor to floor height (h_5) for landings for vertical sliding door is (h_3 + f), where ó$h_3$ôis clear entrance height and dimension ó$f$ôdepends upon the type of door. Refer Table 20 for vertical sliding door types.

2 In case counterweight safety is applicable check for dimensions with lift manufacturer.

3 Recommended dimensions for pit depth, overhead and machine-room for different lift speeds are given in the table above. These dimensions may differ in practice as per individual manufacturerôs design depending upon load, speed and drive. However, the pit depth and overhead shall be such as to conform to the requirements of bottom clearance and top clearance in accordance with the accepted standards [D-5A(1)].

4 All dimensions given above for machine room lifts are recommended dimensions for architects and building planners. Any variations mutually agreed to between the manufacturer and the purchasers are permitted. However, the minimum rated load for the goods lift shall be based on Class of loading for the net inside car area. Refer **8.3.1.1** for Class of loading.

Table 23 Recommended Dimensions of Goods Lifts with Machine Room Series B Horizontal Sliding Doors (Entrance, Type 3)

(*Clause* 5.10.3.1)

All dimensions are in millimetres.

Series B Car with Horizontal Sliding Door

Sl No.	**Rated Load**	**Rated Speed**	**Car Size**		**Door**	**Shaft Size**		**Car Height**	**Entrance Height**	**Overhead Height**	**Pit Depth**	**Machine Room Size**		**Machine Room Height**	**Min Floor to Floor height**
	kg	m/s	Width	Depth	Width	Width	Depth	CH	EH	HR	PH	Width	Depth	MR	MM
			(b_1)	(d_1)	(b_2)	(b_3)	(d_2)	(h_4)	(h_3)	(h_1)	(d_3)	(b_5)	(d_5)	(h_2)	(h_5)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
i)	2 000	0.5 to 1.0	1 800	3 100	1 250	2 700	3 750	2 500	2 100	4 800	1 800	b_3 + 1 200	d_2 + 2 000	3 000	(h_3 + 750)
ii)	2 500		2 100	3 300	1 500	3 000	3 950	2 500	2 100	4 800	1 800	b_3 + 1 200	d_2 + 2 000	3 000	
iii)	3 500	0.25 to 0.5	2 400	3 600	1 750	3 300	4 250	2 500	2 100	5 000	2 000	b_3 + 1 200	d_2 + 2 000	3 000	
iv)	5 000		3 000	3 600	2 200	4 000	4 250	2 500	2 100	5 000	2 000	b_3 + 1 200	d_2 + 2 000	3 000	

NOTES

1 Minimum floor to floor height (h_5) for landings on same side for horizontal sliding door is (h_3 + 750), where óh_3ô is clear entrance height.

2 In case counterweight safety is applicable check for dimensions with lift manufacturer.

3 Recommended dimensions for pit depth, overhead and machine-room for different lift speeds are given in the table above. These dimensions may differ in practice as per individual manufacturerôs design depending upon load, speed and drive. However, the pit depth and overhead shall be such as to conform to the requirements of bottom clearance and top clearance in accordance with the accepted standards [D-5A(1)].

4 All dimensions given above for machine room lifts are recommended dimensions for architects and building planners. Any variations mutually agreed to between the manufacturer and the purchasers are permitted. However, the minimum rated load for the goods lift shall be based on class of loading for the net inside car area. Refer **8.3.1.1** for Class of loading.

Table 24 Recommended Dimensions of Goods Lifts with Machine Room Series B Vertical Sliding Doors (Entrance, Type 4 and Type 5)

(*Clause* 5.10.3.1)

All dimensions are in millimetres.

Series B Car with Vertical Sliding Door

Sl No.	**Rated Load**	**Rated Speed**	**Car Size**		**Door**	**Shaft Size**		**Car Height**	**Entrance Height**	**Overhead Height**	**Pit Depth**	**Machine Room Size**		**Machine Room Height**	**Min Floor to Floor Height**
	kg	m/s	Width	Depth	Width	Width	Depth	CH	EH	HR	PH	Width	Depth	MR	MM
			(b_1)	(d_1)	(b_2)	(b_3)	(d_2)	(h_4)	(h_3)	(h_1)	(d_3)	(b_5)	(d_5)	(h_2)	(h_5)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
i)	2 000	0.5 to 1.0	1 800	3 100	1 800	2 700	3 550	2 500	2 500	5 300	1 800	b_3 + 1 200	d_2 + 2 000	3 000	(h_3 + f)
ii)	2 500		2 100	3 300	2 100	3 000	3 850	2 500	2 500	5 300	1 800	b_3 + 1 200	d_2 + 2 000	3 000	
iii)	3 500	0.25 to 0.5	2 400	3 600	2 400	3 300	4 050	2 500	2 500	5 300	2 000	b_3 + 1 200	d_2 + 2 000	3 000	
iv)	5 000		3 000	3 600	3 000	4 000	4 050	2 500	2 500	5 300	2 000	b_3 + 1 200	d_2 + 2 000	3 000	

NOTES

1 For minimum floor to floor height requirement refer below:

Minimum floor to floor height (h_5) for vertical sliding door is (h_3 + f), where óh_3ô is clear entrance height and dimension ófô depends upon the type of door. Refer Table 20 for vertical sliding door types.

2 In case counterweight safety is applicable check for dimensions with lift manufacturer.

3 Recommended dimensions for pit depth, overhead and machine-room for different lift speeds are given in the table above. These dimensions may differ in practice as per individual manufacturerôs design depending upon load, speed and drive. However, the pit depth and overhead shall be such as to conform to the requirements of bottom clearance and top clearance in accordance with the accepted standards [D-5A(1)].

4 All dimensions given above for machine room lifts are recommended dimensions for architects and building planners. Any variations mutually agreed to between the manufacturer and the purchasers are permitted. However, the minimum rated load for the goods lift shall be based on Class of loading for the net inside car area. Refer 8.3.1.1 for Class of loading.

Table 25 Recommended Dimensions of Goods Lifts with Machine Room Series B Vertical Sliding Doors (Entrance, Type 6)

(*Clause* 5.10.3.1)

All dimensions are in millimetres.

Series B Car with Vertical Sliding Door

Sl No.	**Rated Load**	**Rated Speed**	**Car Size**		**Car Area**	**Loading**	**Door**	**Shaft Size**		**Car Height**	**Entrance Height**	**Overhead Height**	**Pit Depth**	**Machine Room Size**	**Machine Room Height**	**Min Floor to Floor height**	
	kg	m/s	Width	Depth	m^2	kN/m^2	Width	Width	Depth	CH	EH	HR	PH	Width	Depth	MR	MM
			(b_1)	(d_1)			(b_2)	(b_3)	(d_2)	(h_4)	(h_3)	(h_1)	(d_3)	(b_5)	(d_5)	(h_2)	(h_5)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
i)	2 000	0.5 to 1.0	1 800	3 100	5.580	3.515	1 800	2 750	3 550	2 500	2 500	5 300	1 800	b_3 + 1 200	d_2 + 2 000	3 000	(h_3 + f)
ii)	2 500		2 100	3 300	6.930	3.538	2 100	3 050	3 850	2 500	2 500	5 300	1 800	b_3 + 1 200	d_2 + 2 000	3 000	
iii)	3 500	0.25 to 0.5	2 400	3 600	8.640	3.973	2 400	3 350	4 050	2 500	2 500	5 300	2 000	b_3 + 1 200	d_2 + 2 000	3 000	
iv)	5 000		3 000	3 600	10.800	4.540	3 000	4 050	4 100	2 500	2 500	5 300	2 000	b_3 + 1 200	d_2 + 2 000	3 000	

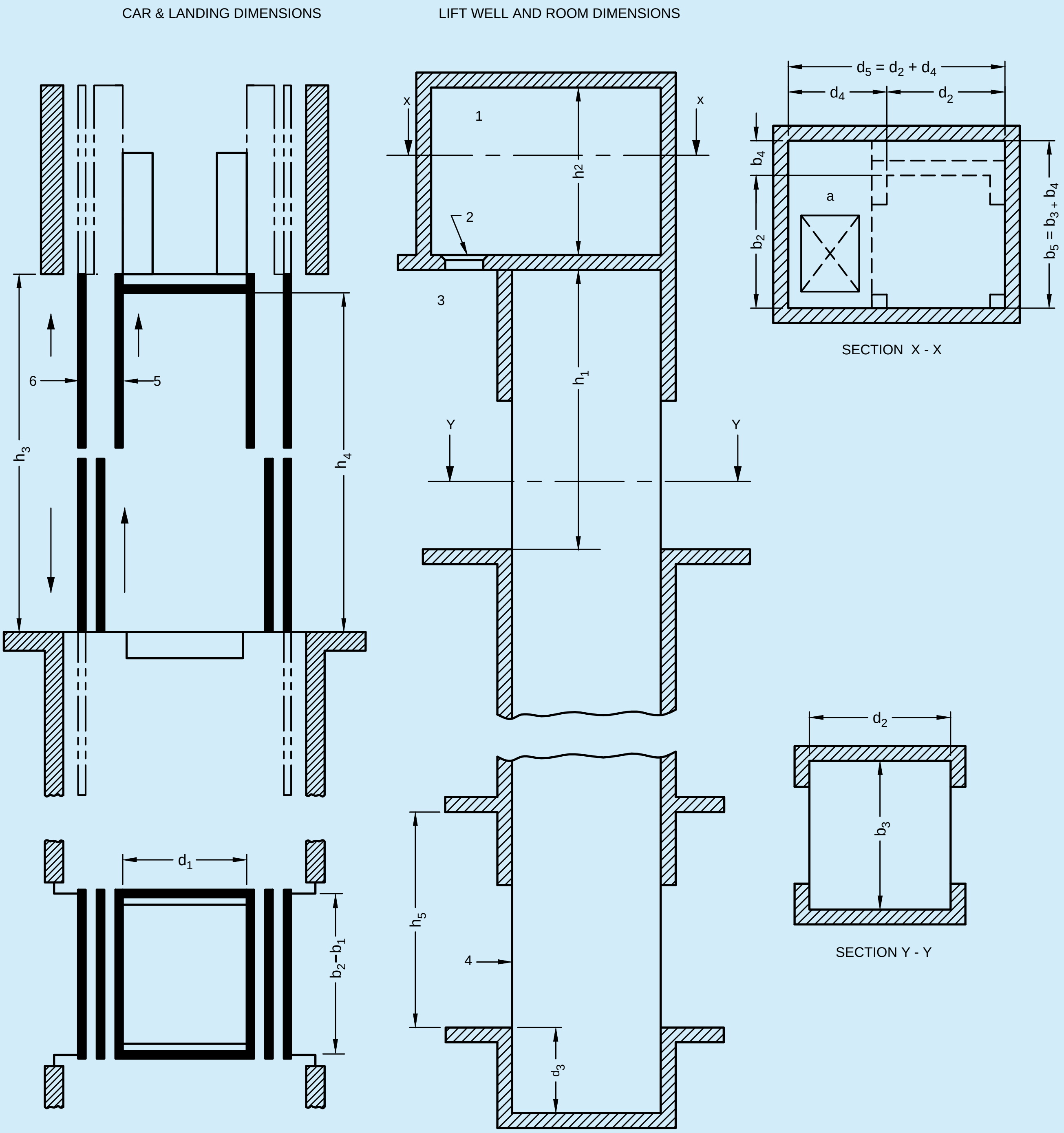
NOTES

1 Minimum floor to floor height (h_5) for vertical sliding door is (h_3 + f), where ó$h_3$ôis clear entrance height and for dimension óf’ depends upon the type of door. Refer Table 20 for vertical sliding door types.

2 In case counterweight safety is applicable check for dimensions with lift manufacturer.

3 Recommended dimensions for pit depth, overhead and machine-room for different lift speeds are given in the table above. These dimensions may differ in practice as per individual manufacturerôs design depending upon load, speed and drive. However, the pit depth and overhead shall be such as to conform to the requirements of bottom clearance and top clearance in accordance with the accepted standards [D-5A(1)].

4 All dimensions given above for machine room lifts are recommended dimensions for architects and building planners. Any variations mutually agreed to between the manufacturer and the purchasers are permitted. However, the minimum rated load for the goods lift shall be based on cass of loading for the net inside car area. Refer **8.3.1.1** for class of loading.


CAR & LANDING DIMENSIONS
LIFT WELL AND ROOM DIMENSIONS
x
x
1
2
3
h_2
h_1
Y
Y
6
5
h_3
h_4
d_1
b_2-b_1
h_5
4
d_3
$d_5 = d_2 + d_4$
d_4
d_2
b_4
b_2
a
$b_5 = b_3 + b_4$
SECTION X - X
d_2
b_3
SECTION Y - Y

KEY :

1 - MACHINE ROOM
2 - TRAP DOOR
3 - HIGHEST LEVEL SERVED
4 - LOWEST LEVEL SERVED
5 - TELESCOPIC UPWARDS
6 - BI-PARTING (CENTER OPENING)
b_1 - CAR WIDTH
b_2 - ENTRANCE WIDTH
b_3 - WELL WIDTH
b_4 - MACHINE ROOM EXTENSION WIDTH

b_5 - MACHINE ROOM WIDTH
d_1 - CAR DEPTH
d_2 - WELL DEPTH
d_3 - PIT DEPTH
d_4 - MACHINE ROOM EXTENSION DEPTH
d_5 - MACHINE ROOM DEPTH
h_1 - OVERHEAD HEIGHT
h_2 - MACHINE ROOM HEIGHT
h_3 - ENTRANCE HEIGHT
h_4 - CAR HEIGHT

IT IS NECESSARY TO HAVE AN ACCESS DOOR TO THE MACHINE ROOM ALTHOUGH THIS IS NOT INDICATED ON THE SKETCH

FIG. 12 (TABLE 26) AUTOMOBILE LIFTS WITH MACHINE ROOM -THROUGH TYPE CAR SERIES B VERTICAL SLIDING DOOR

Table 26 Recommended Dimensions of Automobile Lifts with Machine Room ð Through Type Car Series B Vertical Sliding Door (Entrance, Type 4)

(*Clause* 5.10.3.1)

All dimensions are in millimetres.

Sl No.	**Rated Load**	**Rated Speed**	**Car Size**		**Door Size**	**Shaft Size**		**Car Height**	**Entrance Height**	**Overhead Height**	**Pit Depth**	**Machine Room Size**		**Machine Room Height**	**Below Lintel Height**	**Min Floor to Floor Height**
	kg	m/s	Width (b_1)	Depth (d_1)	Width (b_2)	Width (b_3)	Depth (d_2)	CH (h_4)	EH (h_3)	HR (h_1)	PH (d_3)	Width (b_5)	Depth (d_5)	MR (h_2)		MM (h_5)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
i)	2 500	0.5 and 1.0	2 500	5 300	2 500	3 600	5 910	2200	2 000	5 000	1 600	(b_3 + 1 000)	(d_2 + 2 500)	2 500	2 075	(h_3 + f)
ii)	3 000	0.5	2 700	5 400	2 700	3 900	6 010	2200	2 000	5 000	1 800			3 000	2 075	
iii)	4 000		3 000	5 800	3 000	4 200	6 410	2200	2 000	5 000	1 800			3 000	2 075	
iv)	5 000		3 000	6 000	3 000	4 200	6 610	2200	2 000	5 000	1 800			3 000	2 075	

NOTE ð For width and depth of Machine size dimensions requirement refer below,

1 For width and depth of machine size dimensions requirement refer below:

a) Machine room Width is (b_3 +b_4), where b_3 is width of shaft size and b_4 as 1 000 mm to be considered;

b) Machine room Depth is (d_2 +d_4), where d_2 is depth of shaft size and d_4 as 2 500 mm to be considered; and

c) Minimum floor to floor height (h_5) for vertical sliding door is (h_3 + f), where ôh_3ô is clear entrance height and Dimension ôfô depends upon types of door. Refer Table 20 for vertical sliding door types.

2 Car height normal range is 2 200 mm to 2 700 mm.

3 Overhead height for all values of car height CH shown above.

4 In case counterweight safety is applicable check for dimensions with lift manufacturer.

5 All dimensions given above for machine room lifts used for auto mobiles are recommended dimensions for architects and building planners. Any variations mutually agreed to between the manufacturer and the purchasers are permitted. However, the minimum rated load for the automobile lift shall be based on a load of not less than 1.45 kN/m^2 of the net inside car area.

6 Dimensions of pit depth and overhead may differ in practice as per individual manufacturerôs design depending upon load, speed and drive. However, the pit depth and overhead shall be such as to conform to the requirements of bottom clearance and top clearance in accordance with the accepted standards [D-5A(1)].

7 The lift car width should be selected such that in case of emergency while the automobile is in the lift car the driver should be able to open the automobile door and come out of the automobile.

Table 27 Recommended Dimensions of Passenger Lifts MRL COPD

(*Clause* 5.10.3.1)

All dimensions in millimetres.

Sl No.	**No. of Passengers**	**Rated Load**	**Car Size**		**2 P COPD Door**	**1.0 m/s ÒRated Speed Ò 2.0 m/s**		**Rated Speed = 2.5 m/s**		**Rated Speed = 3.0 m/s**	
						Shaft Size		Shaft Size		Shaft Size	
		kg	Width	Depth	Width	Width	Depth	Width	Depth	Width	Depth
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
i)	4	272	800	950	700	1 600	1 300	ï	ï	ï	ï
ii)	6	408	1 000	1 100	800	2 000	1 550	ï	ï	ï	ï
iii)	8	544	1 300	1 100	800	2 150	1 550	ï	ï	ï	ï
iv)	10	680	1 300	1 350	800	2 250	1 800	2 300	2 150	ï	ï
v)	13	884	1 500	1 450	900	2 250	1 900	2 550	2 150	2 550	2 250
vi)	15	1 020	1 500	1 600	1 000	2 550	2 050	2 650	2 150	2 650	2 250
vii)	16	1 088	1 500	1 650	1 000	2 550	2 050	2 650	2 200	2 650	2 300
viii)	20	1 360	1 700	1 800	1 000	2 550	2 350	2 850	2 350	2 850	2 350
ix)	22	1 496	1 800	1 900	1 000	2 700	2 400	2 800	2 450	2 750	2 450
x)	24	1 632	1 500	2 400	1 000	2 500	2 900	2 750	2 850	2 750	2 850
xi)	26	1 768	1 900	2 000	1 000	2 850	2 700	2 850	2 700	2 850	2 700
xii)	29	1 972	1 900	2 200	1 200	2 900	2 750	3 100	2 200	ï	ï

NOTES

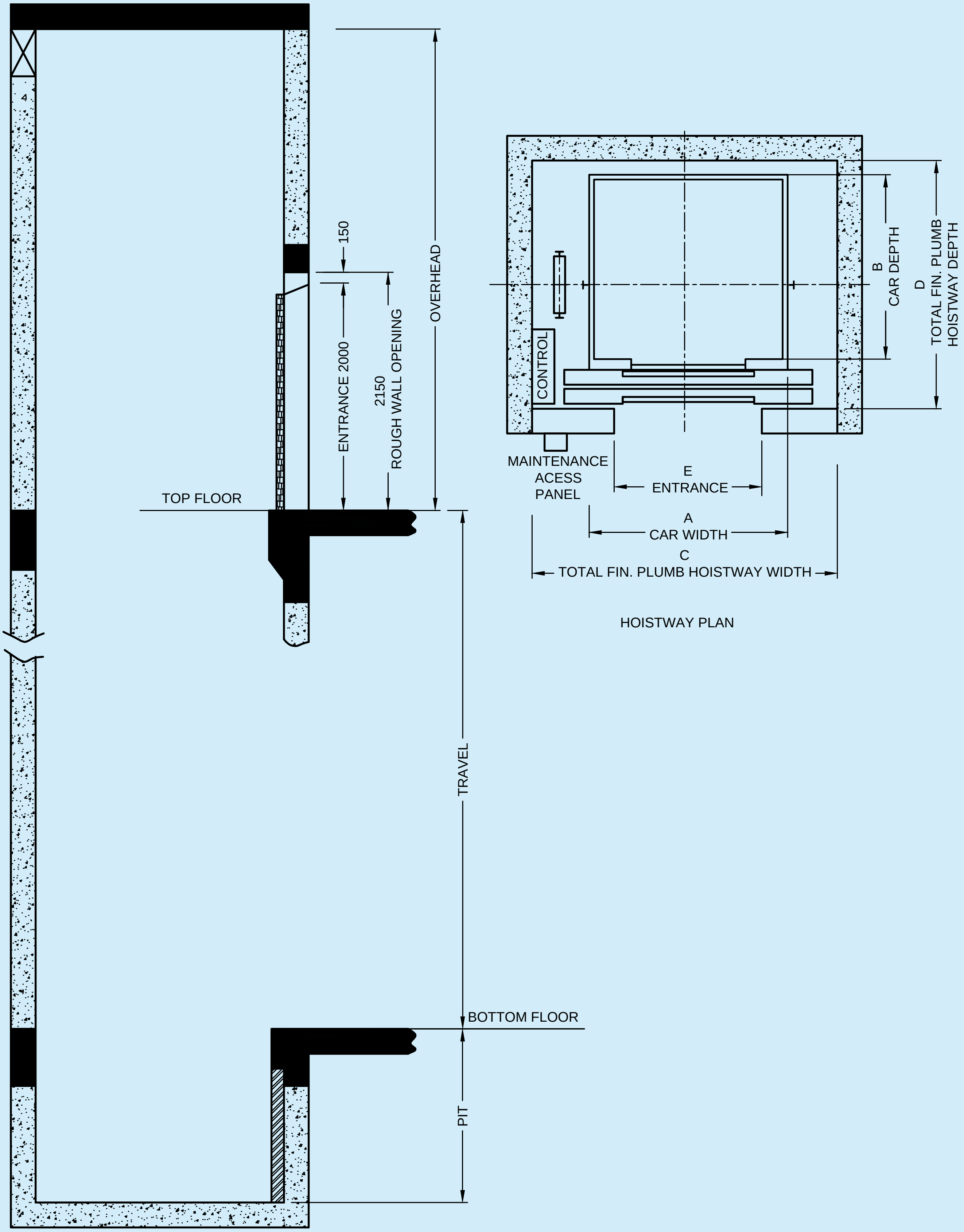
1 All dimensions given above for lifts having centre opening power operated doors (COPD) with counterweight at side, are recommended dimensions primarily for architects and building planners. Any variations mutually agreed to between the manufacturer and the purchaser are permitted. However, variation in:

a) car inside dimensions shall be within the maximum area limits specified in accordance with Table 37;

b) entrance width on higher side is permitted; and

c) entrance width on lower side is permitted up to 100 mm subject to minimum of 700 mm.

2 The minimum size of the lift car and all other requirements relating to accessibility, in all public buildings shall be in accordance with good practice [D-5A(3)] .


150
OVERHEAD
ENTRANCE 2000
2150
ROUGH WALL OPENING
TOP FLOOR
TRAVEL
BOTTOM FLOOR
PIT
CONTROL
B
CAR DEPTH
D
TOTAL FIN. PLUMB
HOISTWAY DEPTH
MAINTENANCE
ACESS
PANEL
E
ENTRANCE
A
CAR WIDTH
C
TOTAL FIN. PLUMB HOISTWAY WIDTH

HOISTWAY PLAN

ELEVATION

Fig. 13 (Table 27) for MRL Lifts COPD

Table 28 Recommended Dimensions of Stretcher/Hospital lifts MRL (2P Telescopic Door/4P COPD, Speed 1.0 m/s to 2.0 m/s)

(*Clause* 5.10.3.1)

All dimensions in millimetres.

Sl No.	**Rated Load**		**Car Size**		**Door Size**	**Shaft Size**	
	Persons	kg	Width	Depth		Width	Depth
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	15	1 020	1 000	2 400	1 000	2 150	2 900
ii)	20	1 360	1 300	2 400	1 000	2 350	2 950
iii)	24	1 632	1 500	2 400	1 000	2 400	2 950
iv)	26	1 768	1 600	2 400	1 000	2 550	3 000
v)	29	2 000	1 500	2 700	1 000	2 450	3 250

NOTES

1 All dimensions given above for lifts having 2 panel telescopic or 4 panel centre opening power operated doors (4P COPD) with counterweight at side, are recommended dimensions primarily for architects and building planners. Any variations mutually agreed to between the manufacturer and the purchaser are permitted. However, variation in:

a) car inside dimensions shall be within the maximum area limits specified in accordance with Table 37;

b) entrance width on higher side is permitted; and

c) entrance width on lower side is permitted up to 100 mm subject to minimum of 700 mm.

2 Car depth of 2 100 mm may be considered in residential/commercial buildings where use of only ambulance stretcher is envisaged. The hoist-way depth maybe reduced accordingly.

Table 29 Pit Depth for Passenger/Stretcher/Hospital Lifts MRL

(*Clause* 5.10.3.1)

All dimensions in millimetres.

Sl No.	**No. of Passengers**	**Pit Depth for Speed**					
		1 m/s	1.6 m/s	1.8 m/s	2 m/s	2.5 m/s	3 m/s
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	4	1 600	1 800	2 000	2 200	ï	ï
ii)	6	1 600	1 800	2 000	2 200	ï	ï
iii)	8	1 600	1 800	2 000	2 200	ï	ï
iv)	10	1 600	1 800	2 000	2 200	ï	ï
v)	13	1 700	1 800	2 000	2 200	2 500	3 100
vi)	15	1 700	1 800	2 000	2 200	2 500	3 100
vii)	16	1 700	1 800	2 000	2 200	2 500	3 100
viii)	20	1 800	1 800	2 000	2 200	2 500	3 100
ix)	22	1 800	1 800	2 000	2 200	2 500	3 100
x)	24	1 800	1 800	2 000	2 200	2 500	3 100
xi)	26	1 800	1 800	2 000	2 200	2 500	3 100
xii)	29	1 800	1 800	2 000	2 200	2 500	ï

NOTE ð Recommended dimensions for pit depth for different lift speeds are given in the table. These dimensions may differ in practice as per individual manufacturerôs design depending upon load, speed and drive. However, the pit depth shall be such as to conform to the requirements of bottom clearance and top clearance in accordance with the accepted standards [D-5A(6)].

Table 30 Overhead Height for Passenger and Stretcher/Hospital Lifts MRL

(*Clause* 5.10.3.1)

All dimensions in millimetres.

Sl No.	**No. of Passengers**	**Overhead Height for Speed**				
		1 m/s	1.5 m/s ÒRated Speed Ò1.75 m/s	2 m/s	2.5 m/s	3 m/s
(1)	(2)	(3)	(4)		(5)	(6)
i)	4	CH + 1 900	CH + 2 400	ï	ï	ï
ii)	6	CH + 1 900	CH + 2 400	ï	ï	ï
iii)	8	CH + 1 900	CH + 2 400	CH + 2 600	ï	ï
iv)	10	CH + 1 900	CH + 2 400	CH + 2 600	CH + 3 200	ï
v)	13	CH + 1 900	CH + 2 400	CH + 2 600	CH + 3 500	CH + 3 700
vi)	15	CH + 1 900	CH + 2 400	CH + 2 600	CH + 3 600	CH + 3 800
vii)	16	CH + 1 900	CH + 2 400	CH + 2 600	CH + 3 700	CH + 3 900
viii)	20	CH + 2 300	CH + 2 600	CH + 2 700	CH + 3 800	CH + 4 000
ix)	22	CH + 2 300	CH + 2 600	CH + 2 700	CH + 3 800	CH + 4 000
x)	24	CH + 2 500	CH + 2 600	CH + 3 200	CH + 4 100	CH + 4 300
xi)	26	CH + 2 600	CH + 2 600	CH + 3 250	CH + 4 250	CH + 4 450
xii)	29	CH + 2 600	CH + 2 600	ï	ï	ï

NOTE ð Recommended dimensions for overhead height for different lift speeds are given in the table, where CH is the clear car height from car finished floor to car roof. These dimensions may differ in practice as per individual manufacturerôs design depending upon load, speed and drive. However, the overhead shall be such as to conform to the requirements of bottom clearance and top clearance in accordance with the accepted standards [D-5A(6)].

Table 31 Recommended Dimensions of Goods Lifts MRL (Speed 1.0 m/s)

(*Clause* 5.10.3.1)

All dimensions in millimetres.

Sl No.	Rated Load	Car Size		Door Size	Telescopic Door		4P COPD		2P COPD		Overhead Height	Pit Depth
					Shaft Size		Shaft Size		Shaft Size			
	kg	Width	Depth	Width	Width	Depth	Width	Depth	Width	Depth	HR	PH
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
i)	500	1 100	1 200	900	ï	ï	ï	ï	2150	1650	CH + 1900	1 600
ii)	1 000	1 400	1 800	1 100	ï	ï	ï	ï	2 600	2 200	CH + 1900	1 600
iii)	1 500	1 700	2 000	1 500	ï	ï	2 650	2 550	ï	ï	CH + 2400	1 800
iv)	1 600	1 400	2 400	1 300	2 700	3 000	3 200	3 050	ï	ï	CH + 2700	1 800
v)	2 000	1 700	2 500	1 500	2 550	3 300	2 600	3 300	ï	ï	CH + 2700	1 800
vi)	2 500	2 000	2 500	1 800	3 150	3 050	3 200	3 050	ï	ï	CH + 2700	1 800
vii)	3 000	2 000	2 700	1 800	ï	ï	3 350	3 300	ï	ï	CH + 3000	1 800
viii)	4 000	2 100	3 400	1 800	ï	ï	3 400	4 000	ï	ï	CH + 3100	2 100
ix)	5 000	2 500	3 500	2 200	ï	ï	3 800	4 100	ï	ï	CH + 3200	2 200

NOTES

1 CH is the clear car height from car finished floor level to car roof (goods lifts will normally not have any false ceiling).

2 Normal range for CH is 2 100 mm to 2400 mm.

3 Door height is less than or equal to the car height CH.

4 In case counterweight safety is applicable check for dimensions with lift manufacturer.

5 All dimensions given above for lifts having telescopic or centre opening power operated doors (COPD) with counterweight at side, are recommended dimensions primarily for architects and building planners. Any variations mutually agreed to between the manufacturer and the purchaser are permitted. However, the minimum rated load for the goods lift shall be based on a load of not less than 3.45 kN/m^2 of the net inside car area.

6 Recommended dimensions for overhead height and pit depth for different lift speeds are given in the table. These dimensions may differ in practice as per individual manufacturerôs design depending upon load, speed and drive. However, the overhead height and pit depth shall be such as to conform to the requirements of bottom clearance and top clearance in accordance with the accepted standards [D-5A(1)].

7 Car inside dimension shall be with in maximum area limit specified in accordance with Table 38.

Table 32 Recommended Dimensions of Automobile Lifts MRL COPD (Speed 0.5 m/s to 1.0 m/s)

(*Clause* 5.10.3.1 *and* *Table* 16)

All dimensions in millimetres.

Sl No.	**Rated Load**	**Car Size**		**6P COPD Door Size: Opposite Entrances**	**Shaft Size**		**Overhead Height**	**Pit Depth**
	Kg	Width	Depth	Width	Width	Depth	HR	PH
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
i)	2 500	2 500	5 000	4P-2 500	3 800	5 480	5 000	2 500
ii)	3 000	2 500	5 500	2 200	3 800	6 450	5 000	2 500
iii)	4 000	3 000	6 000	2 700	4 300	6 950	5 000	2 500

NOTES

1 Car height normal range is 2 100 mm to 2700 mm.

2 Overhead height shown is required for all values of car height CH shown above.

3 In case counterweight safety is applicable check for dimensions with lift manufacturer.

4 All dimensions given above for machine room less lifts with 6 panel centre opening power doors (6P COPD) used for automobiles are recommended dimensions for architects and building planners. Any variations mutually agreed to between the manufacturer and the purchaser are permitted. However, the minimum rated load for the automobile lift shall be based on a load of not less than 1.45 kN/m^2 of the net inside car area.

5 Dimensions of pit depth and overhead height may differ in practice as per individual manufacturerôs design depending upon load, speed and drive. However, the pit depth and overhead height shall be such as to conform to the requirements of bottom clearance and top clearance in accordance with the accepted standards [D-5A(1)].

6 The lift car width should be selected such that, in case of emergency while the automobile is in the lift car the driver should be able to open the automobile door and come out of the automobile.

6 CIVIL AND ELECTRICAL REQUIREMENTS FOR LIFTS

6.1 Civil Requirements

Lift well enclosures, lift pits, machine rooms and machine supports besides conforming to the essential requirements given below should form part of the building construction and comply with the lift manufacturerôs drawings.

6.1.1 *Requirements of Lift Well Enclosure*

The requirements of lift well enclosures are as given hereunder:

a) *Totally enclosed well* ð Lift wells shall be totally enclosed by imperforate walls, floor and ceiling, constructed for protection against all weather and of dust free surface material or should be painted to minimize dust circulation on to moving apparatus and from being pumped by the car movement into machine room or on to landings and shall be rendered minimum 120 min fire-resistant.

   The lift well may have openings for landing doors, inspection and emergency doors, vent openings for escape of gases and smoke in case of fire, ventilation openings, openings in the machine room floor for connecting lift components such as ropes, cables, etc.

b) *Partially enclosed well* ð In case of partially enclosed lift wells used for applications, for example, observation lifts in connection with galleries or atriums, tower buildings, etc, the well does not need to be totally enclosed, provided the height of the enclosure at places normally accessible to persons is sufficient to prevent such persons:

   1) being endangered by moving parts of the lift; and
   2) interfering with the safe operation of the lift by reaching lift equipment within the well either directly or with handheld objects.

   The height of the enclosure shall be minimum 3.5 m at the landing door side. The height of enclosure at other sides shall be 2.5 m minimum when the horizontal distance between the moving parts of the lift and enclosure is 0.5 m minimum. The height of enclosure at other sides may be reduced to 1.1 m progressively if the horizontal distance between the moving parts of the lift and enclosure increases to 2 m. The enclosure shall be located within 150 mm of the edge of the floor. The enclosure shall be imperforate and made of non-combustible material.

c) *General requirements related to the lift well* ð The well shall be exclusively used for lifts. It shall not contain ducts, cables, or devices, etc, other than those for the lift. Permanently installed adequate lighting shall be provided comprising sufficient number of lamps fixed throughout the lift well such that the illumination level 1 m above the car roof within its vertical projection at any position of the car in the well and 1 m above pit floor everywhere shall be at least 50 lux and at least 20 lux at remaining locations, even when all the doors are closed (so that a person can stand, work and/or move between the working areas).

   NOTE ð Additional lamps may be fixed on the car top as a part of the well lighting system to achieve this.

   Well lighting switches (or equivalent) shall be located both in the pit and in machine room or in controller (in case of machine room less application) so that the complete well lighting can be operated from either location that is, it shall be an arrangement of 2-way switch in machine room/controller (in case of MRL) and pit for controlling well lighting. Well lighting switch shall be in the machine room close to the main switch and pit lighting switch in lift well close to and easily accessible from lowest landing door. Each point of well lighting shall consist of bulkhead with bulb, 3-pin socket and switches to control supply.

   Should a lift entrance open out into an area exposed to the weather, the entrance should be protected by a suitable canopy and the ground level sloped up to the lift entrance to prevent rain or drainage water entering the lift well through the clearances around the landing doors. Any push buttons exposed should be of weatherproof type.

   The natural or artificial lighting of the landings in the vicinity of landing doors shall be at least 50 lux at floor level, such that a user can see ahead when they are opening the landing door to enter the lift, even if the car light has failed. The approach of the landing door on each floor shall be kept lit during the whole time the lift is available for use at night, and during the day time, if so required, due to insufficient natural light.

When the distance between consecutive landing door sills exceeds 11 000 mm, intermediate emergency landing(s) with lift landing door(s) shall be provided such that the distance between any two consecutive landings is not more than 11 000 mm. Rescue to these landings is permissible in case of automatic rescue device operation.

No counterweight shall be allowed to travel in any lift well, or part of any lift well other than that to which it belongs.

In the case of a lift well which is common to more than one lift and where the lift car or the counterweight of one lift is working in juxtaposition to the lift car or counterweight of another lift, such lift cars or counterweights shall be guarded carefully and adequately in order to protect persons working in the lift well or on the lift cars from accidental contact with such cars or counterweights in any part of their travel.

d) *Construction of the lift well* ð The side walls of the lift well may be made of reinforced cement concrete at least 150 mm thick; or brick or similar fire resisting materials provided tie beams are made available for lift guide rail fixings at such heights as specified by the lift manufacturer, to provide satisfactory anchoring arrangement for fixing guide rails and other equipment to the lift well.

The inner surface of the lift well and its enclosure facing any lift-car entrance shall, so far as practicable, be kept smooth and flush devoid of projections or recesses. Where any projection or top of the recesses cannot be rendered flush, they shall be levelled on the underside to an angle not less than 60ę from the horizontal, by means of metal plates, cement rendering or other fire resisting material.

Where a lift car levelling device is operative with the lift car door open, such interior surfaces shall always form a smooth and flush surface below each landing level for a depth of at least the depth of the car-levelling zone plus the distance through which the lift car may travel of its own momentum when the power is cut-off.

The horizontal distance between the sill of the car and sill of the landing doors shall not exceed 35 mm. The distance between the lift well enclosure on the sides facing any lift-car entrance and the sill edge of the car shall not be more than 35 mm in the landing zone below the landing gate. If such distance is more than 35 mm in the lift well enclosure, the same shall be finished with suitable and smooth plaster work or fascia plates so as to make the surface thereof devoid of all projections and recesses. In case the enclosure wall on the sides facing the lift-car entrance is more than 130 mm from the sill edge of the lift-car platform, the lift-car door of such lift shall be provided with means to prevent it from being opened except when the lift-car is at the landing served by such car entrance.

Sufficient space shall be provided between the guides for the car and the side walls of the lift well enclosure to allow safe and easy access to the parts of the safety gears for their maintenance and repairs.

All landing openings shall be protected by gates or doors which shall extend to the full height and full width of the landing openings. These openings shall not be less than 2 000 mm in clear height and 700 mm clear in width (*see* **5.10.3.1**) when the gates or doors are fully opened. There shall not be any common wall between lift well and water tank.

e) *Strength of the walls of the well* ð The structure of the well shall be able to support at least the loads which may be applied by the machine, by the guide rails at the moment of safety gear operation, by eccentric load in the car, by the action of buffers, by the application of anti-rebound devices, by loading and unloading the car, etc.

The walls of the well shall withstand a force of 1 000 N, being evenly distributed over an area of 0.09 m^2 in round or square section and applied at right angles to the wall at any point on either face,

1) without permanent deformation greater than 1 mm; and
2) without elastic deformation greater than 15 mm.

Glass panels, plane or formed shall be made of laminated glass. Such panels and their fixings shall withstand horizontal static force of 1 000 N applied on an area of 0.09 m^2 at any point, from either side, without permanent deformation.

f) *Partition walls between lifts in a common lift well* ð In case of common lift well for multiple lifts, the partition wall(s) of the common lift well may be either be of RCC or brick or steel or glass which may be provided with openings for escape of air displaced due to movement of lift in the adjacent well. For high speed lifts the partition between the lifts maybe of suitable wire grill/expanded metal of following specifications:

   1) It shall be made of at least 2.2 mm thick steel wire or expanded metal;
   2) A ball of 25 mm diameter shall not pass through the wire grill; and
   3) It shall be so fixed as not to deflect more than 15 mm when subjected to a force of 450 N applied horizontally at any point from either side.

6.1.2 *Requirements of the Pit*

Pit shall be soundly constructed and maintained in a dry (waterproofed) and clean condition. Where necessary, provision shall be made for permanent drainage. The floor of the pit shall be able to support beneath each guide rail, force due to mass of guide rails plus the reaction due to safety gear operation. The floor of the pit shall be able to support beneath the car buffer supports, force in Newton, equal to 4 times the static load being imposed by the mass of fully loaded car:

$$4.\mathrm{g}\,(P + Q)$$

where

g = acceleration due to gravity;

P = mass of empty car and components supported by the car that is, part of travelling cable, compensating rope/chain, if any, etc, in kg; and

Q = rated load, in kg.

The floor of the pit shall be able to support beneath the counterweight buffer support, a force in Newton, equal to 4 times the static load being imposed by the mass of the counterweight:

$$4.\mathrm{g}\,(P + q.Q)$$

where

g = acceleration due to gravity;

P = mass of empty car and components supported by the car, that is, part of travelling cable, compensating rope/chain, if any, etc, in kg;

q = live load balancing factor (normally, $q = 0.5$); and

Q = rated load, in kg;

The floor of the pit shall be able to support upward thrust of the tied down rope compensation device, if provided. If accessible spaces do exist below the well, the base of the pit shall be designed for an imposed load of at least 5 000 N/m^2 and the counterweight shall be equipped with safety gear. In addition, it is recommended to provide double slab for the lift pit.

NOTES

1 Lift wells should preferably not be situated above a space accessible to persons.

2 Enclosing projected area of the lift well under the pit in accessible spaces will not nullify the above provisions.

There shall not be any common wall/slab between lift pit and any water reservoir.

The pit shall be accessible by an access door. A permanent ladder inside the well may be provided close to the last landing *in-lieu* of access door, if the pit depth does not exceed 2.5 m.

NOTE ð In case of structural limitations for providing pit access door at pit floor level, alternative arrangement to access pit may be provided which shall allow access to pit with complete safety.

A physical means of protection shall be provided to prevent accidental contact with the counterweight.

The pit shall be equipped with a stop switch which is easily accessible from the lowest landing and the pit floor. If more than one switch is required, they shall be wired in series.

6.1.3 *Requirements Associated with Machine Room and Pulley Room*

It must be noted that generally lifts have machine rooms immediately over the lift well and this should be arranged, whenever possible, without restricting the overhead distance required for normal safety precautions. In case where machine room provision on top is a limitation, either machine room less lift or basement drive or side drive lift can be considered. The spaces and tolerances shall be in accordance with the following:

a) *Requirements associated with machine room and pulley room* (*where lift machinery is placed in the machine room*)

   1) The lift machine, controller and all other apparatus and equipment of a lift installation, except such apparatus and equipment having functional location in the lift well or other positions, shall be placed in the machine room which shall be adequately lit and rendered fire-resistant and weather-proof.

      If parts of different lifts are present in one machine room and/or pulley room each lift shall be identified with a number, letter or colour consistently used for all parts (machine, controller, over speed governor, switches, etc). If the machine room contains several lifts, it is necessary to have one switch per car to control the supply to the circuit for lighting and socket outlets of the car. This switch shall be located close to the corresponding main power switch.

   2) Machine room should be considered as plant space, and conditions provided to permit reliable operation of electrical switchgear and rotating machinery and be conducive to good maintenance. The machine room shall be either air conditioned or adequately ventilated so as to maintain the ambient temperature therein between + 5 ÁC and + 40 ÁC. The machine room shall be such that the motors and equipment as well as electric cables, etc are protected as far as possible from dust and humidity. Machine room should also be protected from all weather and if ventilation louvers are provided, they should be designed and located to prevent entry of rainwater in the machine room. Preferably, metal or wooden louvers should be provided.

      The well, machinery spaces and pulley rooms shall not be used to provide ventilation of rooms other than those belonging to the lift.

   3) Rescue instructions with required tools and tackles, if any, shall be made available in the machine room.

   4) Machine room floor shall be provided with a trap door, if necessary. The size of the trap door shall be as per manufacturerôs recommendation. Since the purpose of the trap door is to lift or lower the machinery, controller, etc between machine room and the top landing, it may be necessary to provide trap door of same size in the terrace slab which coincides with trap door in machine room, depending on the design of the building.

      The trap door when closed shall be able to support 2 000 N on an area of 0.20 m Ĭ 0.20 m at any position. The trap door shall not open downwards. Hinges, if any, shall be of a type which cannot be unhooked. Trap doors shall be locked. When the trap door is in the open position, precautions shall be taken to prevent the fall of persons (for example, by a guardrail) and prevent the trapdoor from closing such as to cause a crushing hazard (for example, by counterbalance).

   5) Lighting shall be provided to give at least 200 lux around the controller and machine. At least one plug socket point with button shall be provided in the machine room for every lift. The switch for the machine room light shall be fixed near the entrance of the machine room. The machine room walls, ceiling and floor should be finished in dust-resisting materials, tiles, etc or painted as a

minimum to stop dust circulation, which otherwise could damage rotating machinery and cause failure of switchgear.

6) The machine room shall be so designed as to allow free and easy access to all parts of the equipment and the width of the clear space around the machine from any two sides shall in no case be less than 600 mm. Provision shall be made to allow the removal and replacement of various units. The entrance of the machine room shall be minimum 1 000 mm wide and 2 000 mm high to allow removal and replacement of machinery therein. The floor of the machine room shall be designed and constructed to carry safely at any point the heaviest part of the equipment and withstand the loads and forces to which they are intended to be subjected to. If the floor does not extend to the enclosing wall, the open sides shall be adequately guarded by suitable means for example, rails, guards, etc.

7) The height of the machine room shall be sufficient to allow any portion of the equipment to be accessible and removable for repairs and replacement. Distance between the machine lifting point and the machine room hook shall be at least 1 000 mm and there shall be a clear vertical distance of at least 300 mm above the rotating parts of the machine. Machine room height shall not be less than 2 100 mm clear from the floor of the access area and working area in any case. This clear height for movement is taken to the underside of the lowest striking point and measured from the floor of the access area.

8) The machine room shall be locked and shall be accessible to only those who are concerned with the operation and maintenance of the machinery or equipment. Machine room doors shall not open towards the inside of machine room. They shall be provided with a key-operated lock, capable of being reclosed and relocked without a key and be openable from inside the machine room without a key, even when locked. Approach way to machine room from top landing level shall be direct, easy and safe to walk by way of stairs. If stairs are not possible, sufficiently wide and deep permanent structural steps may be used. These structural steps shall be provided with adequate hand holds and shall not be too steep. Minimum width of the steps shall be 1 000 mm.

9) A danger notice board shall be displayed permanently on the outside of the machine room door, trap door and near the machinery. Refer 8.1(e) for the warning signs.

10) There shall not be any common wall/slab between machine room and any water reservoir.

11) The machine room shall not be used as a storeroom or for any purpose other than housing the machinery/components connected with the lift installation. The machine room shall not act as a passage to any other room or utility.

The lift well, machine and pulley rooms may, however contain:

i) Equipment for air conditioning or heating of these spaces, excluding steam heating and high-pressure water heating. However, any control and adjustment devices of the heating apparatus shall be located outside the lift well, machine room and pulley room; and

ii) Fire detectors and/or suppression system, with a high operating temperature (for example, above 80 ÁC), appropriate for the electrical equipment and suitably protected against accidental impact.

For requirements of sprinkler, when sprinkler systems are used, refer **9.24.4** of good practice [D-5A(7)].

NOTE ð Such smoke, fire detection and sprinkler systems are the responsibility of the building management.

12) Machine room floor shall be designed to carry an imposed (live) load of not less than 10 kN/m^2 over the whole area and any load which may be imposed thereon by the equipment used in the machine room or by any reaction from any such equipment both during periods of normal operation, maintenance and repair.

13) One or more beams or hooks with the indication of the safe working load, as appropriate, shall be provided in the machinery spaces. Position of the beams or hooks shall be according to the layout

provided by lift manufacturer. Hoisting beams or hooks shall be tested for safe working load (SWL) before indicating the lifting capacity on it.

14) The total load on overhead beams used for supporting machinery shall be assumed as equal to all equipment resting on the beams plus twice the maximum load suspended from the beams.

15) The factor of safety for all overhead beams and supports based on ultimate strength of the material and load in accordance with (14) shall not be less than the following:

    i) For steel : 5

    ii) For reinforced concrete : 7

    The deflection of the overhead beams under the maximum static load calculated in accordance with above shall not exceed 1/1 500 of the span.

16) The place in which the overhead pulleys, over speed governors and similar machinery are fixed shall be easily accessible for maintenance and repair purposes. It shall be lit adequately and safe working procedure shall be established for maintenance and repair works.

17) It is recommended that emergency exit is provided in case of large machine rooms having four or more lifts.

18) Where the machine room occupies a prominent position on roof of a building, provision should be made for lightning protection in accordance Part D ôBuilding Services, Section 2 Electrical and Allied Installationsô of this NBCS and applicable standards.

b) *Requirements associated with machine spaces* (*where machinery is placed in the well*)

1) Access to the interior of the machinery and pulley spaces shall be capable of being properly lit by a permanent electric light fixture(s) with intensity of at least 200 lux at floor level, easy to use, and completely safe in all circumstances without necessitating entry into private premises.

2) Machinery spaces inside the well shall be designed and constructed to withstand the loads and forces they are subjected to.

3) In the case of partially enclosed wells located at the exterior of the building, the machinery shall be suitably protected against environmental influences.

4) Provision should be given to access the machine for maintenance purpose either from car top or otherwise.

5) The clear height for movement shall not be less than 2 000 mm.

6) The machinery spaces shall be suitably ventilated. The electric equipment of the machinery shall be protected as far as it is reasonably practicable from dust, harmful fumes and humidity.

7) The working area and machinery spaces shall be provided with permanently installed electric lighting with at least 200 lux at floor level.

8) One or more beams or hooks with the indication of the safe working load, as appropriate, shall be provided in the machinery spaces. Position of the beams or hooks shall be according to the layout provided by lift manufacturer. Hoisting beams or hooks shall be tested for safe working load (SWL) before indicating the lifting capacity on it.

9) The total load on overhead beams used for supporting machinery shall be assumed as equal to all equipment resting on the beams plus twice the maximum load suspended from the beams.

10) The factor of safety for all overhead beams and supports based on ultimate strength of the material and load in accordance with (9) shall be not less than the following:

    i) For steel : 5

ii) For reinforced concrete : 7

The deflection of the overhead beams under the maximum static load calculated in accordance with above shall not exceed 1/1 500 of the span.

c) *Requirements associated with machine spaces* (*where machinery is placed outside of the well*)

1) Machinery spaces outside of the well shall be constructed to withstand the loads and forces to which they are subjected;

2) The total load on beams used for supporting machinery shall be assumed as equal to all equipment resting on the beams plus twice the maximum load suspended from the beams;

3) The factor of safety for all beams and supports based on ultimate strength of the material and load in accordance with (2) above shall be not less than the following:

   i) For steel : 5

   ii) For reinforced concrete : 7

   The deflection of the overhead beams under the maximum static load calculated in accordance with above shall not exceed 1/1 500 of the span.

4) Access to the interior of the machinery and pulley spaces shall be:

   i) capable of being properly lit by a permanent electric light fixture(s) with intensity of at least 200 lux at floor level; and

   ii) easy to use and completely safe in all circumstances without necessitating entry into private premises.

   The clear height for movement shall not be less than 2 000 mm.

5) The machinery shall be located inside a cabinet consisting of imperforate walls, floor, roof and lockable door(s).

6) The machinery cabinet shall be suitably ventilated. It shall be such that the machinery is protected as far as it is reasonably practicable from dust, harmful fumes and humidity.

7) The inside of the machinery cabinet shall be provided with permanently installed electric lighting with at least 200 lux at floor level. The switch placed inside shall be close to the door(s), at an appropriate height, to control lighting of the cabinet.

d) *Dimensional tolerances*

1) *Lift well dimensions* ð Plan dimensions of lift wells given by the lift manufacturer, represent the minimum clear plumb sizes. The purchaserôs representative, in conjunction with the builder, should ensure that adequate tolerances are included in the building design so that the specified minimum plumb dimensions are obtained in the finished work. Dimensions in excess of these minimum plumb dimensions for lift well and openings (but not less) can be accommodated by the lift manufacturer up to certain maximum values beyond which changes in design may be necessary involving additional expense or work by the builder. The purchaserôs representative should take these factors into account when specifying the lift well structural dimensions on the basis of the constructional tolerance appropriate to the building technique.

2) *Landing door openings* ð It is very important that finished landing openings should be accurate to design size and plumb one above the other for the full travel of the lift. In constructing the structural openings in concrete walls to lift wells it is not possible to achieve a degree of accuracy vertically which will allow doors and frames to be inserted in the opening without some form of masking or packing to overcome inaccuracies. Provisions should therefore be made in design by increasing the nominal height from design finished floor level and width of openings to each jamb and head. In addition, the alignment of the outer face of the front wall of the lift well is of importance when architrave of fixed dimensions are called for and in this case the alignment of the outer face from

floor to floor should not vary to a greater extent than can be accommodate by the subsequent front wall finish, the architrave being set accurately plumb.

3) *Structural limits for lift wells at any level* ð If the net plumb well (dimensions A and B in Fig. 14) and the nominal structural entrance openings (dimensions C and D in Fig. 14) are defined by plumb lines, the actual wall should not encroach on these dimensions.

Dimension K (inside face of wall of Fig. 14) should fall within the following limits:

i) For wells up to 30 m : 0 mm to 25 mm

ii) For wells up to 60 m : 0 mm to 35 mm

iii) For wells up to 100 m : 0 mm to 50 mm

iv) For wells taller than 100 m : 0 mm to 50 mm for any 100 m portion of the well.

When architraves are to be supplied by the lift manufacturer dimension L (side of structural opening of Fig. 14) should fall within the limits of 0 mm and 25 mm and dimension M (outer face of the front wall of Fig. 14) should not vary to a greater extent than can be accommodated by the subsequent front wall finish, the architrave being set accurately plumb. When the entrance linings are supplied by the builder, corresponding provision should be made for the finished openings to be accurately plumb one above the other for the full travel of the lift end to design size.

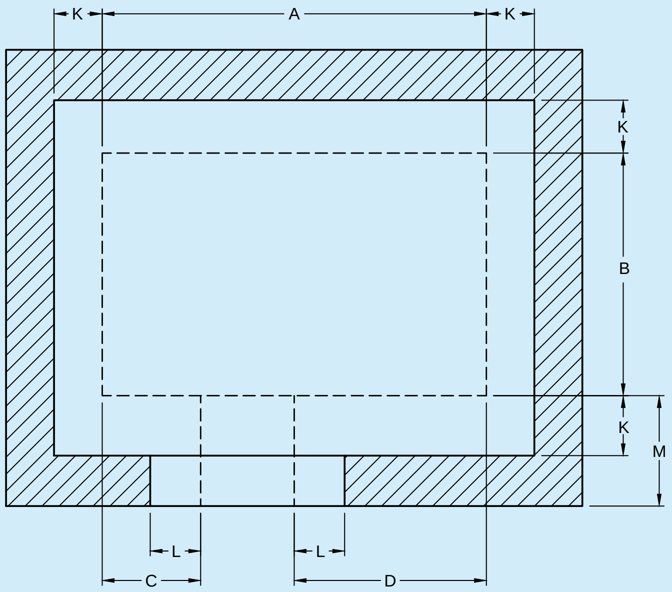


FIG. 14 LIFT WELL TOLERANCE

6.2 Electrical Installation Requirements

The lift manufacturer should specify, on a schedule, particulars of full load current, starting current, maximum permissible voltage drop, size of switches and other details to suit requirements. The main power cable and lighting cable shall be separate and routed through respective lift shaft for every lift. Every electric supply line other than the earthed or earthed neutral conductor of any system or the earthed external conductor of a concentric cable, shall be protected by a suitable switchgear by its owner. It is important that the switchgear at the intake and in the machine room which are provided by the electrical contractor of owner are of correct size. No form of ðNO VOLTô trip relay should be included anywhere in the power supply of the lift.

6.2.1 *Main Switchgear*

For each lift, a main switchgear capable of breaking the supply to the lift on all the live conductors shall be provided. This switchgear shall be capable of interrupting the highest current involved in normal conditions of use of the lift.

This switchgear shall not cut the circuits feeding the following:

a) Car lighting and ventilation;

b) Socket outlet on the car roof;

c) Lighting of machinery spaces;

d) Socket outlet in the machinery and pulley spaces and in the pit;

e) Lighting of the lift well including pit;

f) Alarm device; and

g) Automatic rescue device.

The switchgear shall be located:

1) in the machine room, where it exists;

2) where no machine room exists, in the distribution box (DB) on top floor near the controller or meter room; or

3) at the emergency and test panel, when control panel is mounted in the well.

The following points shall be taken into consideration while fixing location of distribution box:

i) It shall be installed in common areas where there is no hindrance to reaching and operating, especially during emergency conditions; and

ii) Suggested height above floor level shall be such that it is beyond the reach of children. But the replacement/reset of protective devices shall be in an accessible position without the aid of any tackle, for example, at an average height between 1.8 m and 2.1 m.

If the emergency panel is separate from test panel, the switchgear shall be at emergency panel. If the main switch is not easily accessible from the controller cabinet, then the cabinet shall be provided with an isolating switch.

The main switchgear shall have stable open and closed positions and shall be capable of being locked-off in the open position with the use of a padlock or equivalent, to ensure no inadvertent operation takes place.

For a single lift, this switchgear should be fixed adjacent to the machine room entrance in the machine room or in distribution box (DB) near controller (in case of MRL). In a machine room common to more than one lift, each main switch should be conveniently situated with respect to the lift it controls. Main switch for each lift shall be conspicuously marked.

The supply to the car light should be from a separate circuit and controlled by a switchgear in the machine room or in distribution box (DB) near controller (in case of MRL). For multiple lifts with a common machine room a separate supply and switch gear should be provided for each car. The car lighting and well lighting supply should be independent of the power supply mains. Switch gear for car light and well light of each lift shall be separate and conspicuously marked.

Any capacitors to correct the power factor shall be connected before the main switch of the power circuit.

6.2.2 *Supply Cables Wiring and Apparatus*

The main power supply cables providing the electricity supply to a lift installation shall be flame retardant, low smoke, low halogen with cross-linked polyethylene (FRLSH XLPE) insulated armoured cables. The cables shall be terminated in the main switchgear panels/distribution box using cable glands such that the armour of the cables is positively connected to the metal body of switchgear panels/distribution box. For each lift, one $415\ \text{V}\ ^{+6\ \text{percent}}_{-10\ \text{percent}}$, 3-phase, 4-wire, 50 Hz and one single phase $230\ \text{V}\ ^{+6\ \text{percent}}_{-10\ \text{percent}}$, 3-wire, 50 Hz supply shall be independently provided. Other than this, power circuit at $230\ \text{V}\ ^{+6\ \text{percent}}_{-10\ \text{percent}}$ for power and lighting sockets in the lift machine room and the lift shaft shall be provided. This is to facilitate maintenance and other related works with lighting and socket outlets while the lift is switched off.

The cables for lift shall be run in respective lift wells. Cables which are not part of lift installation shall not run in the lift well.

Fixed electrical wiring for circuit voltage up to 250 V located in lift wells shall be one of the following:

a) PVC wires encased in rigid conduit (or trunking) made either of metal or plastic;

b) PVC insulated PVC sheathed cables; and

c) PVC wires in flexible metallic or plastic conduits not exceeding 1 500 mm in length for limit switches, interlocks, push buttons and similar devices.

Control cables on lift cars shall run in rigid/flexible metallic/plastic conduit or trunking. Short runs of flexible conduits may be used, where they are securely fastened in place and not exposed to oil and grease. Short runs of flexible cord may be used as flexible connections between fixed wirings on the car and the switch on car door, provided that the chord is securely fastened in position and so located as not to be subjected to mechanical damage.

Wiring in machine room shall be run in rigid metallic trunking. The trunking in machine room floor shall be flush with the finished floor to avoid trip hazard. The following additional requirements may also be taken care of:

1) Dedicated power supply feeder shall be given for all lifts, which shall be separate from other building services. This feeder shall be distinctly identified and shall have controlled access such that it cannot be switched off by unauthorized person

2) The lift sub-circuit from the meter room should be separate from other building services. Each lift should be capable of being isolated from the mains supply. This means of isolation shall be with lock-out and tag-out facility. The electric supply cables shall run in a route safe from fire, subsequently within the respective lift shafts to the machine room.

3) For banks of interconnected lifts, a separate sub-circuit is required for the common supervisory system, in order that any car may be shut down without isolating the supervisory control of the remainder lifts.

4) When the alarm system is connected to a transformer or trickle charger, the supply should be taken from the machine room lighting.

5) All electrical supply lines and apparatus in connection with the lift installation shall be so constructed and shall be so installed, protected, worked and maintained that there may be no danger to persons therefrom.

6) All metal casings or metallic coverings containing or protecting any electric supply lines of apparatus shall be efficiently earthed.

7) No bare conductor shall be used in any lift car as it may cause danger to persons.

8) All cables and other wiring in connection with the lift installation shall be of suitable grade for the voltage at which these are intended to be worked and if metallic covering is used it shall be efficiently earthed.

9) Suitable caution notice shall be affixed near every equipment or apparatus in which voltage used exceeds 250 V.

10) A single trailing cable for lighting control and signal circuit shall be permitted, if all the conductors of this trailing cable are insulated for maximum voltage running through any one conductor of this cable.

11) *Emergency signal or intercom* ð The lift car shall be provided either with an emergency signal that is operative from the lift car and audible outside the lift well or with intercom.

12) When an alarm bell is to be provided, each car is fitted with an alarm push button which is wired to a terminal box in the lift well at the ground floor by the lift manufacturer. This alarm bell, to be supplied by the lift manufacturer (with indicator for more than one lift) should be fixed in an agreed position and wired to the lift well. The supply may be from a battery (or transformer) fixed in the machine room or, when available, from the building fire alarm supply.

13) An intercom system or similar device, powered by the emergency supply, shall be installed for communication between inside the car, someone outside the lift (security/reception/BMS room) and the place from which the emergency operation is carried out, if the lift travel exceeds 15 m or if direct acoustic communication in- between these locations is not possible. When an intercom is to be provided in the lift car the lift manufacturer should fit it in the car and provide wiring from the car to a terminal box adjacent to the lift well. Alternatively, a hands-free unit may be provided. The type of intercom should be stated in the enquiry.

6.2.3 *Earthing*

Earthing provides safety of human beings, livestock and apparatus against earth faults. Any system is characterized by the type of distribution system, which include types of systems of live conductors and types of system earthing.

The subject of earthing covers the problems associated with connection of exposed conductive part of installations to the main earthing terminal of that installation and to achieve automatic disconnection of supply before the fault voltage creates a shock hazard. The terms earth and earthing have been used interchangeably, to denote a low impedance return path of the fault current. The earth is mainly used for fixing the voltage of system neutrals and is not used as a part of return circuit.

6.2.3.1 *System earthing*

Earthing of system is designed, primarily, to preserve the security of the system by ensuring that the potential on each conductor is restricted to value consistent with the level of applied insulation. It is equally important that earthing should ensure efficient and fast operation of protective gears, in the case of earth faults. Commonly used system earthing are TN, TT and IT.

6.2.3.2 *TN system*

A system having one or more points of the source of energy directly earthed, the exposed conductive-parts (and extraneous conductive parts) of the installation are connected by means of protective conductors to the earthed point(s) of the source, that is, there is a metallic path for earth fault currents to flow from the installation to the earthed point(s) of the source. TN systems are further sub-divided into TN-S, TN-C-S and TN-C systems.

a) *TN-S system* ð A system with separate neutral and protective conductor throughout the system (*see* Fig. 15).

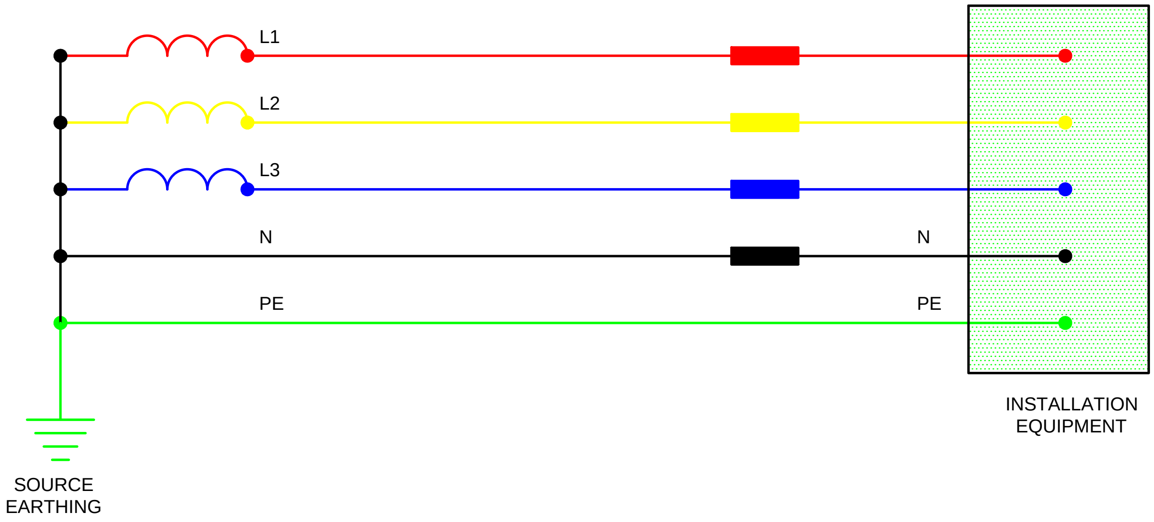


FIG. 15 TN-S SYSTEM WITH SEPARATE NEUTRAL AND EARTH CONDUCTOR FROM THE SOURCE

b) *TN-C-S system* ð A system in which neutral and protective conductors are combined in a single conductor in part of the system. The PEN conductor referred to as a combined neutral and earth (CNE or PEN) conductor, is earthed at the source and at multiple points. Multiple earthing of the PEN conductor ensures that if the conductor becomes open circuit due to any reason, exposed-conductor parts remain connected to earth. Under such conditions, the supply voltage between the installation line and neutral conductor is substantially reduced (*see* Fig. 16).

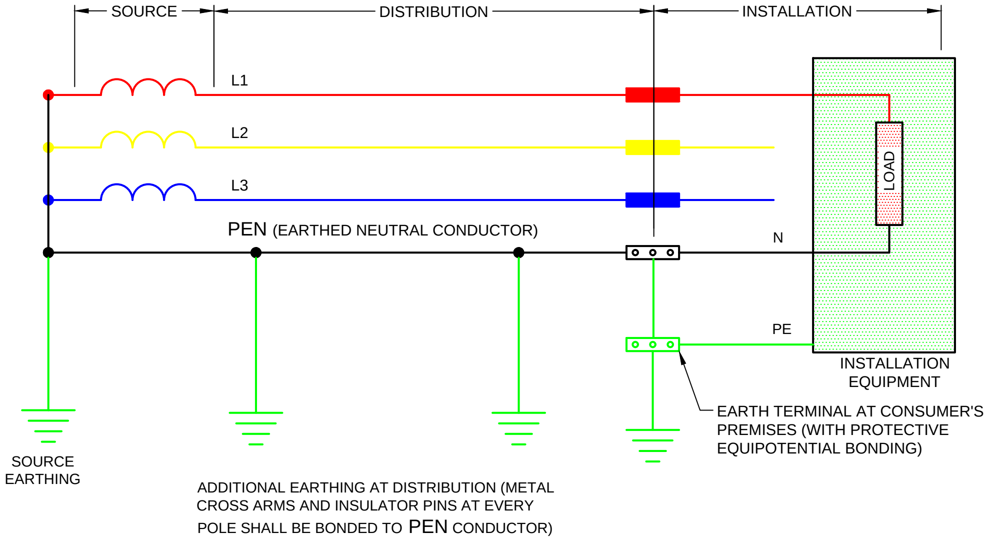

SOURCE
DISTRIBUTION
INSTALLATION
L1
L2
L3
LOAD
PEN (EARTHED NEUTRAL CONDUCTOR)
N
PE
INSTALLATION EQUIPMENT
EARTH TERMINAL AT CONSUMER'S PREMISES (WITH PROTECTIVE EQUIPOTENTIAL BONDING)
SOURCE EARTHING
ADDITIONAL EARTHING AT DISTRIBUTION (METAL CROSS ARMS AND INSULATOR PINS AT EVERY POLE SHALL BE BONDED TO PEN CONDUCTOR)

FIG. 16 TN-C-S SYSTEM WITH PROTECTIVE MULTIPLE EARTHING (PME) USED IN PUBLIC DISTRIBUTION

c) *TN-C system* ð A system in which neutral and protective conductors are combined in a single conductor throughout the system. TN-C is not permitted inside consumer premises (*see* Fig. 17).

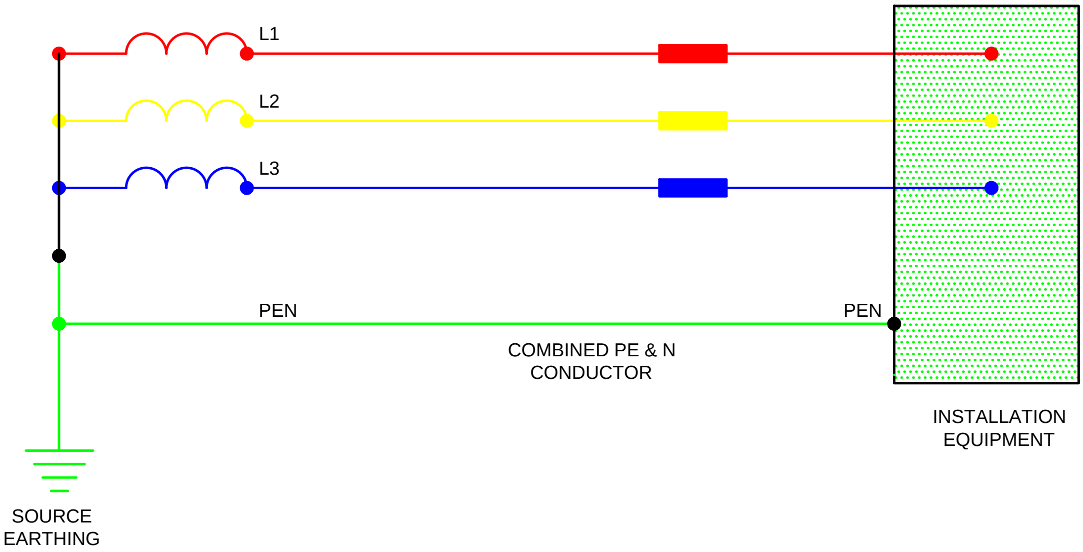

L1
L2
L3
PEN
PEN
COMBINED PE & N CONDUCTOR
INSTALLATION EQUIPMENT
SOURCE EARTHING

FIG. 17 TN-C SYSTEM (NEUTRAL AND PROTECTIVE FUNCTION COMBINED IN A SINGLE CONDUCTOR THROUGHOUT SYSTEM)

6.2.3.3 *TT system*

In this system one or more points of the source of energy are directly earthed and the exposed and extraneous conductive parts of the installation are connected to a local earth electrode, electrically independent of the source earth. Every consumer installation shall be protected with an RCD for earth fault protection at the origin of installation (*see* Fig. 18).

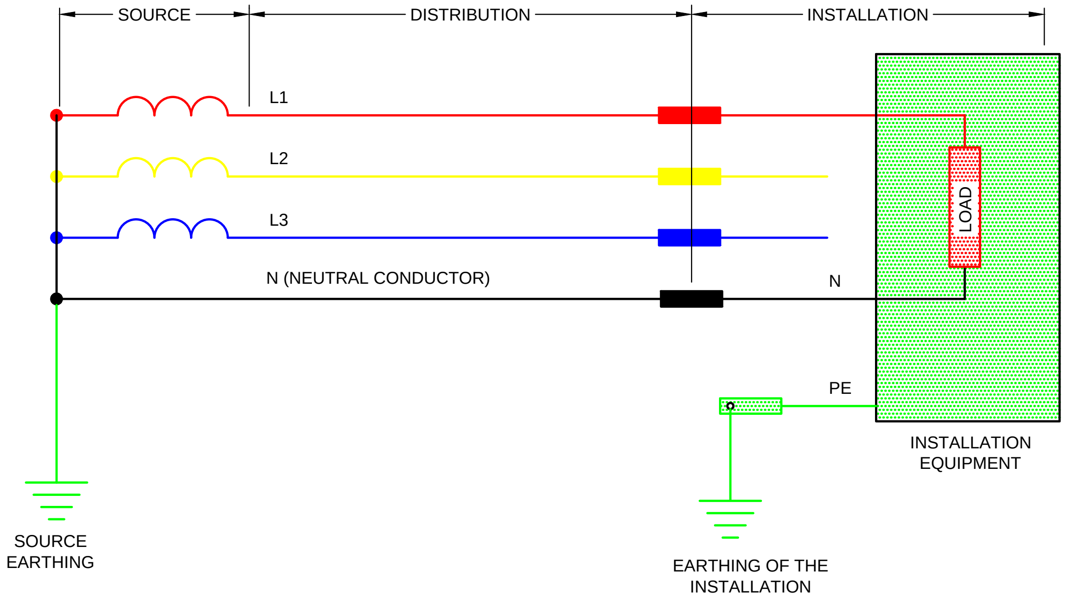

SOURCE
DISTRIBUTION
INSTALLATION
L1
L2
L3
N (NEUTRAL CONDUCTOR)
N
LOAD
PE
INSTALLATION EQUIPMENT
SOURCE EARTHING
EARTHING OF THE INSTALLATION

FIG. 18 TT SYSTEM

6.2.3.4 *IT system*

The live parts have no direct connection/isolated from earth or one point is connected to earth through an impedance. The exposed-conductive-parts of the electrical installation are earthed independently or collectively. The IT systems are generally used for special applications such as operation theatre in hospitals. It is not intended for use in lifts (*see* Fig. 19).

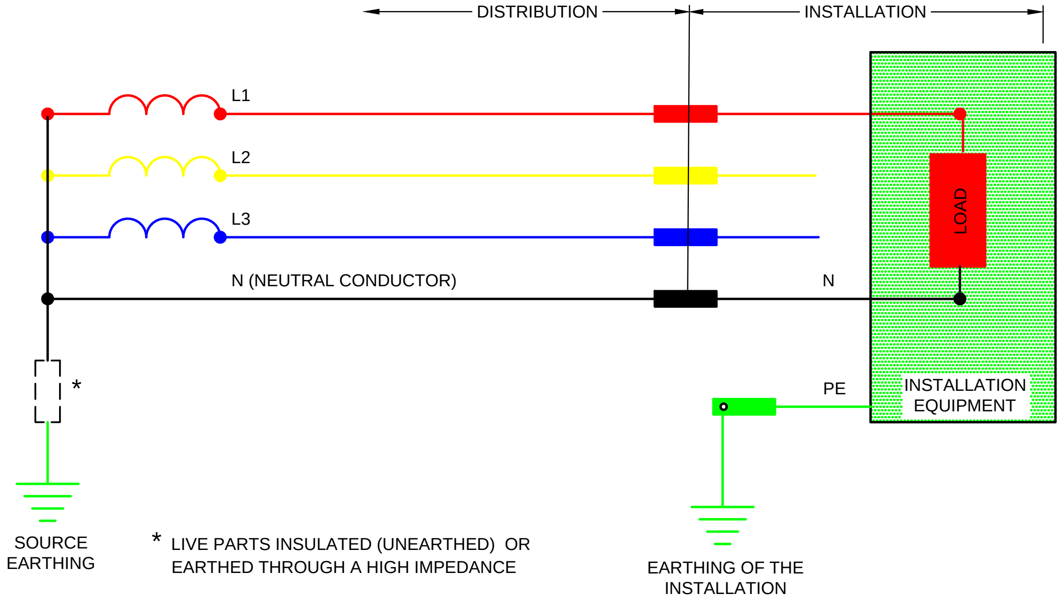

DISTRIBUTION
INSTALLATION
L1
L2
L3
N (NEUTRAL CONDUCTOR)
N
LOAD
PE
INSTALLATION EQUIPMENT
*
SOURCE EARTHING
* LIVE PARTS INSULATED (UNEARTHED) OR EARTHED THROUGH A HIGH IMPEDANCE
EARTHING OF THE INSTALLATION

FIG. 19 IT SYSTEM

6.2.3.5 *Basic purpose of earth fault protection*

The occurrence of an earth fault in an installation creates two possible hazards:

a) Voltages appear between exposed conductive parts and extraneous conductive parts and if these parts are simultaneously accessible, these voltages constitute a shock hazard. This condition is known as indirect contact.

b) The fault current that flows in the phase and protective conductors of the circuit feeding the faulty equipment may be of such a magnitude as to cause an excessive temperature rise in those conductors, thereby creating a fire hazard.

The protective measure known as protective equipotential bonding and automatic disconnection of the supply is intended to provide a high degree of protection against both hazards. The choice of protective device for disconnection is influenced by the type of system of which the installation is a part, because either:

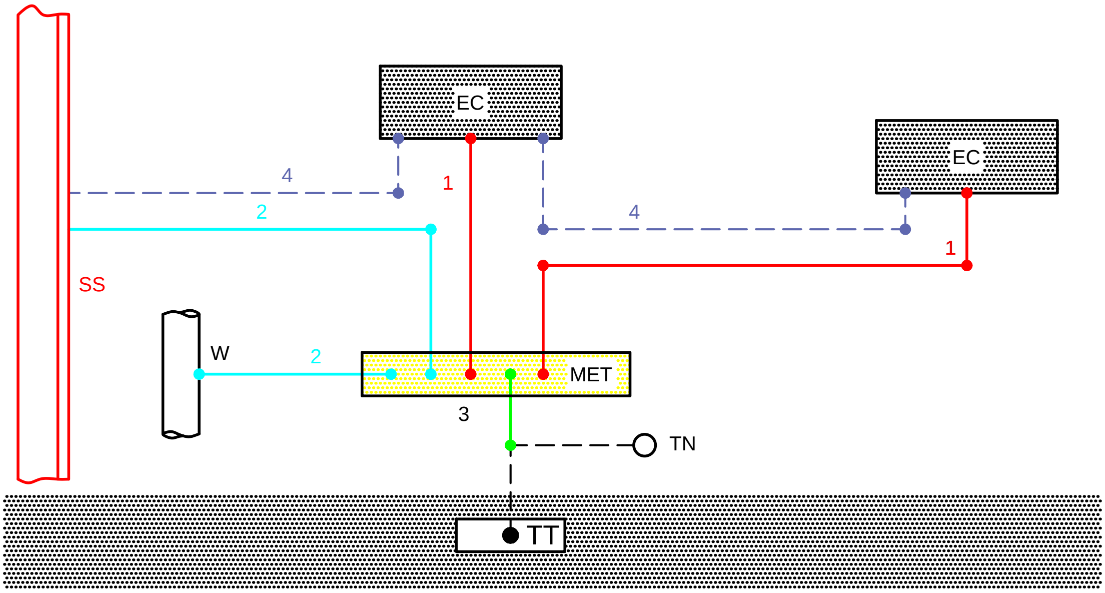
1) the earth fault loop impedance shall be low enough to allow adequate earth fault current flow to cause an overcurrent protective device (for example, a fuse or circuit breaker) in the faulty circuit to operate in a sufficiently short time; or

2) where it is not possible to achieve a low enough earth fault loop impedance, disconnection may be initiated by fitting a residual current device (RCD).

6.2.3.6 *Protective equipotential bonding*

Protective equipotential bonding is through connecting extraneous conductive parts in a building to the main earthing terminal of the installation by protective bonding conductors. Where such conductive parts originate outside the building, they shall be bonded near their entry point within the building.

Typical illustration of earthing and protective conductors is shown in Fig. 20.



Key

EC	Exposed conductive part (part board body)
MET	Main earthing terminal
SS	Structural steel (extraneous conductive part)
W	Metallic water pipe (extraneous conductive part)
TT	Earth electrode in a TT or IT system
TN	Other means of earthing in a TN system, for example, connection to earthed point of the point of the power system
1	Circuit protective conductor
2	Main protective bonding conductor
3	Earthing conductor
4	Supplementary protective bonding conductors (additional bonding, if required)
1,2,3,4	Protective conductors

FIG. 20 ILLUSTRATION OF EARTHING AND PROTECTIVE CONDUCTORS

In each building the earthing conductor, the main earthing terminal and the following conductive parts shall be connected to the protective equipotential bonding (*see* Fig. 21):

a) metallic pipes supplying services into the building, for example, gas, water;

b) structural extraneous conductive parts, if accessible in normal use, metallic central heating and air-conditioning systems; and

c) metallic reinforcements of constructional reinforced concrete, if reasonably practicable.

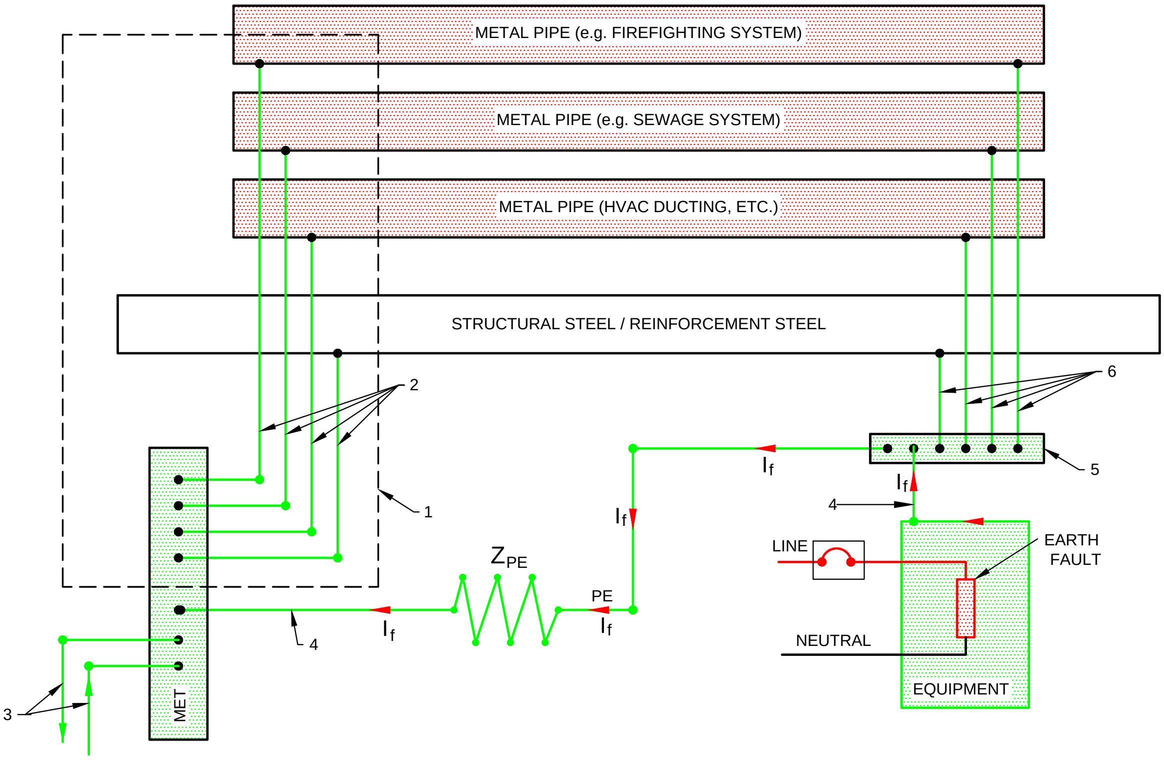

METAL PIPE (e.g. FIREFIGHTING SYSTEM)
METAL PIPE (e.g. SEWAGE SYSTEM)
METAL PIPE (HVAC DUCTING, ETC.)
STRUCTURAL STEEL / REINFORCEMENT STEEL
2
6
5
1
4
I_f
I_f
I_f
I_f
I_f
4
Z_{PE}
PE
LINE
EARTH
FAULT
NEUTRAL
EQUIPMENT
MET
3

FIG. 21 ILLUSTRATION OF MAIN AND ADDITIONAL PROTECTIVE EQUIPOTENTIAL BONDING

The connection of various conductors in an earthing arrangement shall be proper. The connection shall be by exothermic welding, pressure connectors, clamps or other suitable mechanical connectors. Mechanical connectors shall be installed in accordance with the manufacturerôs instructions. Where a clamp is used, it shall not damage the electrode or the earthing conductor.

Two separate copper protective earthing conductors shall be provided from main earthing terminal (MET) to lift controller. Refer to Table 33 for cross sectional area of protective conductor.

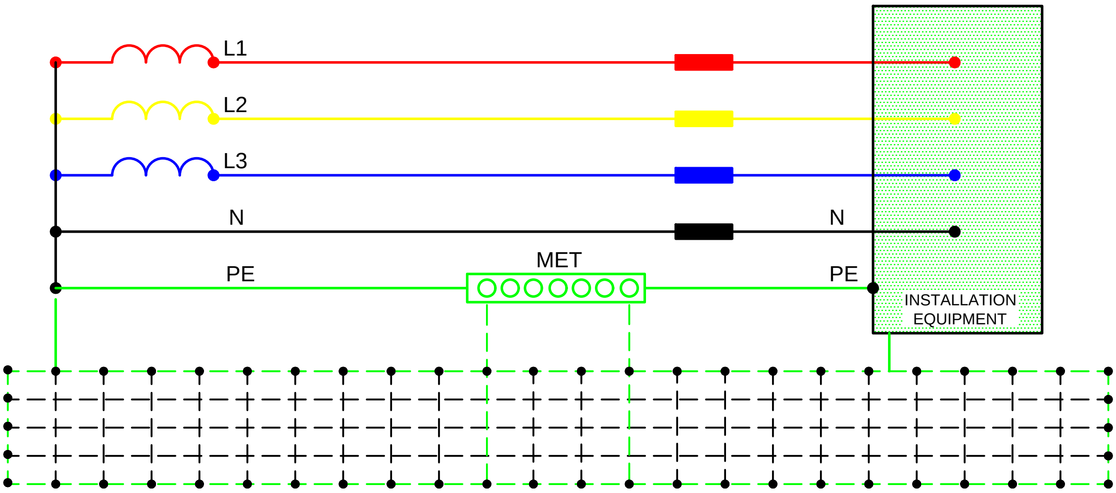
Table 33 Cross Sectional Area of Protective Conductor

(*Clause* 6.2.3.6)

Sl No.	**Cross-sectional Area of Line Conductor, S** mm^2 Cu	**Minimum Cross-Sectional Area of the Corresponding Protective Conductor** mm^2 Cu
(1)	(2)	(3)
i)	*S* Ò16	S
ii)	16 < *S* Ò35	16
iii)	*S* > 35	0.5 *S*

Earthing system above 230 V should be designed as a protective multiple earthing (PME) system with separate protective conductor (TN-S). Protective multiple earthing system shall be implemented to reduce the earth fault loop impedance and to ensure reliable disconnection of supply during an earth fault by the over current protective device (OCPD), for example MCB/MCCB. In PME system, neutral of the supply transformer and the non-current carrying metal parts in the system are interconnected by the common earth grid, in addition to the separate protective conductor.

Hence, it is recommended to have TN-S system with PME (as shown in Fig. 22), where the neutral of the source and exposed conductive parts in the installation are solidly connected to the MET and an earthing grid. In this interconnected system, earth fault current is returned to the neutral, through the interconnected system consisting of the PE conductor and earth grid. Protective earth (PE) conductor shall run in parallel and proximity to line conductors.



GRID INTERCONNECTING NEUTRAL OF THE SOURCE AND EXPOSED CONDUCTIVE PARTS IN THE INSTALLATION (GRID REDUCES THE EARTH FAULT LOOP IMPEDANCE

FIG. 22 SYSTEM WITH SEPARATE EARTH CONDUCTOR (TN-S) WITH PROTECTIVE MULTIPLE EARTHING (PME), RECOMMENDED FOR INDUSTRIAL AND COMMERCIAL USE

The continuity resistance of the earth return path through the earth grid shall be less than one ohm.

6.2.3.7 *Automatic disconnection of power supply in case of a fault*

Automatic disconnection of supply is a protective measure in which:

a) basic protection is provided by basic insulation of live parts or by barriers or enclosures; and

b) fault protection is provided by protective equipotential bonding and automatic disconnection in case of a fault in accordance with **4.2.11.3** to **4.2.11.6** of the good practice given in [D-5A(8)].

A protective device shall automatically interrupt the supply to the line conductor of a circuit or equipment in the event of a fault of negligible impedance between the line conductor and an exposed-conductive-part or a protective conductor in the circuit or equipment within the disconnection time specified in **4.3.11.2.2**, **4.3.11.2.3** and **4.3.11.2.4** of the good practice given in [D-5A(8)].

If automatic disconnection cannot be achieved in the time required, supplementary protective equipotential bonding shall be provided as specified in **4.2.15.2** of the good practice given in [D-5A(8)].

In general, every circuit is provided with a means of overcurrent protection. If the earth fault loop impedance is low enough to cause these devices to operate within the specified times (that is, sufficient current can flow to earth under fault conditions), such devices may be relied upon to give the requisite automatic disconnection of supply. If the earth fault loop impedance does not permit the overcurrent protective devices to give automatic disconnection of the supply under earth fault conditions, the first option is to reduce that impedance. It may be permissible for this to be achieved by the use of protective multiple earthing or by additional earth electrodes.

An alternate approach is to be adopted for the complete safety of the operating personnel and equipment from the hazards that may result from earth faults. This is to use residual current devices with appropriate settings to clear the faults within the permissible time, based on the probable contact potential. This method is equally applicable where earth loop impedances cannot be improved.

6.2.3.8 *Residual current device* (*RCD*)

RCD's can be used for fault protection and additional protection. RCD is used for automatic disconnection of supply during earth fault, in case of failure of this protection by OCPD/MCB. The good practice given in [D-5A(8)] recommends that in locations where fault protection is achieved by 500 mA RCD, earth fault loop impedance test is not required.

RCD of I_{qn} Ò30 mA shall be used as an additional protection against electric shock in locations where the chance of shock is high.

In addition to giving protection against earth fault or shock protection, RCDôs may also give fire risk protection, the degree of protection being related to the sensitivity of the device and magnitude of leakage current. The good practice given in [D-5A(8)] recommends use of 300 mA RCD for protection against fire in building due to leakage current.

Residual current device (RCD), when provided, right type and sensitivity shall be selected.

The RCD shall,

a) have maximum rating of I_{qn} 500 mA as tripping current suitable for frequency converters with a 3-phase supply against earth faults; and

b) be sensitive for sinusoidal currents up to 1 000 Hz, and insensitive for currents more than 1 000 Hz.

NOTE ð National Electrical Code of India 2023 recommends Type B RCD for applications which may create smooth DC residual current, for example, three-phase variable frequency drive.

6.2.3.9 *Reinforced protective earthing conductors for currents exceeding 10 mA in the protective earthing conductor*

For lifts with ACVF of higher KVA ratings if the current in the protective earthing conductor exceeds 10 mA the following applies:

a) where the ACVF has only one protective earthing terminal, the protective earthing conductor shall have a cross-sectional area of at least 10 mm^2 Cu or 16 mm^2 Al, through its total run; or

NOTE ð Refer **5.4.3.4** of the good practice given in [D-5A(8)].

b) where the ACVF has a separate terminal for a second protective earthing conductor, a second protective earthing conductor of at least the same cross-sectional area as required for fault protection shall be run from a point where the protective earthing conductor has a cross-sectional area not less than 10 mm^2 Cu or 16 mm^2 Al.

6.2.3.10 *Additional protection*

Additional protection by means of a residual current device (RCD) with a rated residual operating current not exceeding 30 mA shall be provided for:

a) socket outlets;

b) control circuits for landing controls and indicators and the safety chain with voltage higher than 50 V AC; and

c) circuits on the lift car with voltage higher than 50 V AC.

This requirement is to protect persons from direct shock risk. It is different to automatic disconnection of supply offered by residual current device (RCD) > 30 mA as they are intended to protect persons from indirect shock risk to persons in contact with earthed part. Due to the inherent leakages from electronic devices such as power supplies and VFD's, an RCD of 30 mA as a fault protective measure could create unwanted tripping due to excessive PE conductor current. Refer **5.3.2.2.1.3** of the good practice given in [D-5A(8)]. Therefore, 3-phase power supply for the lift should never be protected with a 30 mA residual current device (RCD). The 30 mA RCD trips easily when the lift starts to drive and prevents the lift to run. If the construction-time power supply is for some reason protected with a 30 mA residual current device (RCD), suitably sized isolation transformer needs to be provided by the electrical contractor.

6.2.3.11 *Earth fault loop impedance*

The impedance of the earth fault current loop (phase to earth loop) starts and ends at the point of earth fault. Table 34 gives the recommended values. The earth fault loop comprises the following, starting at the point of fault:

a) the circuit protective conductor;

b) the consumer's earthing terminal and earthing conductor, and for terre-neutre (TN) systems, the metallic return path;

c) for terra-terra (TT) and isolated-terra (IT) systems, the earth return path;

d) the path through the earth neutral point of the transformer;

e) the transformer winding; and

f) the line conductor from the transformer to the point of fault.

Table 34 Recommended Maximum Earth Fault Loop Impedance Values (Zs) for MCBs

(*Clause* 6.2.3.11)

Sl No.	MCB Rating	Zs Ω		
	Amp	Type B MCB	Type C MCB	Type D MCB
(1)	(2)	(3)	(4)	(5)
i)	6	5.11	2.56	1.28
ii)	10	3.07	1.53	0.77
iii)	16	1.92	0.96	0.48
iv)	20	1.53	0.77	0.38
v)	25	1.23	0.61	0.31
vi)	32	0.96	0.48	0.24
vii)	40	0.77	0.38	0.19
viii)	50	0.61	0.31	0.15
ix)	63	0.49	0.24	0.12
x)	80	0.38	0.19	0.10
xi)	100	0.31	0.15	0.08
xii)	125	0.25	0.12	0.06

6.2.3.12 *Verification of effectiveness of automatic disconnection*

The effectiveness of the measures for protection against indirect contact by automatic disconnection of supply shall be verified according to **6.2.3.6** and **6.2.3.7** of the good practice given in [D-5A(8)].

Ensuring effectiveness of automatic disconnection of earth fault is essential in every lift. For this, earth fault loop impedance must be measured and compared with the characteristics of OCPD/MCB or test the disconnection time of RCD which is installed as an earth fault protective measure. This test shall be carried out before the lift is released for public usage.

NOTES

1 In TN systems, fault protection (protection against indirect contact) shall be offered by:

  a) Overcurrent protective device (MCB/MCCB); and

  b) Residual current protective devices (RCDs).

2 In TT systems, RCDs shall be used for fault protection.

3 Where an RCD is used for fault protection:

  a) The circuit shall also be protected by an overcurrent protective device that is, standalone RCD shall not be used;

  b) The disconnection time shall be according to Table 35; and

  c) Fault protection is provided in this case also if the fault impedance is not negligible.

Table 35 Minimum Disconnection Time

(*Clause* 6.2.3.12)

Sl No.	**Voltage** V	**Disconnection Time** s			
		TN System		TT System	
		a.c.	d.c.	a.c.	d.c.
(1)	(2)	(3)	(4)	(5)	(6)
i)	50 $<U_0$ Ò120	0.8	*See* Note	0.3	*See* Note
ii)	120 $<U_0$ Ò230	0.4	5	0.2	0.4
iii)	230 $<U_0$ Ò400	0.2	0.4	0.07	0.2
iv)	$U_0 > 400$	0.1	0.1	0.04	0.1

NOTE ð Disconnection may be required for reasons other than protection against electric shock.

The terminal for the earthing of the frame of the motor, the winding machine, the frame of the control panel and similar electric appliances which normally carry the main current shall be at least equivalent to a 10 mm diameter bolt, stud or screw.

The terminal for the earthing of the metallic cases and covers of door interlocks, door contacts, call and control buttons, stop buttons, car switches, limit switches, junction boxes and similar electrical fittings which normally carry only the control current shall be at least equivalent to 5 mm brass screw (such terminal being one specially provided for this purpose) and the earth conductor size shall be at least equivalent to 0.5 mm^2 copper.

The earth conductor shall be secured to earthing terminal in accordance with the recommendations made in good practice [D-5A(9)] and also in conformity with the latest provisions of *Electricity Act*, 2003 and the CEA Regulations framed thereunder from time to time.

The exposed metal parts of electrical apparatus installed on a lift car shall be sufficiently bonded and earthed.

Where screwed conduit screws into electric fittings carrying control current making the case and cover electrically continuous with the conduit, the earthing of the conduit may be considered to earth the fitting. Where flexible conduit is used for leading into a fitting, the fitting and such length of flexible conduit shall be effectively earthed.

7 FIRE PROTECTION REQUIREMENTS FOR LIFTS AND EVACUATION LIFTS

7.1 Fire Protection Requirements of Lifts in High Rise Buildings

7.1.1 *Buildings of Height* 15 m *and Above*

Following requirements over and above those specified in **6** and **8** are applicable to all lifts provided in buildings having height more than 15 m:

a) All materials of construction in load bearing elements, stairways and corridors and facades shall be non-combustible.

b) The interior finishing materials shall be of very low flame spread.

c) Walls of the lift well enclosure for a lift or group of lifts shall have a fire rating of 2 h. The lift well shall have a vent at the top, of area not less than 0.2 m^2 per lift.

d) *Landing doors* ð Lift landing doors shall be imperforate. Collapsible doors shall not be permitted. Lift landing doors shall have a minimum fire resistance rating of 1 h for integrity in accordance with accepted standard [D-5A(10)].

e) *Lift car door* ð Lift car doors shall be imperforate. Collapsible car doors shall not be permitted.

f) Telephone or other communication facilities shall be provided in the lift car and the lift main lobby. Communication system for lifts shall also be connected to the fire control room of the building, if provided. For lifts used by persons with disabilities, the facilities shall be provided in accordance with good practice [D-5A(3)].

g) Photo luminescent safety signs shall be posted and maintained on every floor at or near the lift indicating that in case of fire, occupants shall use the stairs unless instructed otherwise. The sign shall have the plan of the respective floor showing location of the stairways. The plan shall indicate the direction to and the level of refuge floors. All signs posted and maintained on every floor of buildings open to and used by the public shall comply with the requirements of accessible signage given in good practice [D- 5A(3)].

h) All lifts (firemanôs lifts/non firemanôs lifts) shall be provided with Phase I operation as per **7.1.1(j)** (grounding operation).

j) The grounding operation may be initiated by individual switches for lifts or a common switch for a group of lifts or by a signal from smoke detector/fire alarm system/BMS room of the building where available.

k) *Firemanôs lift* ï The firemanôs lift is provided in a building for the purpose of aiding firemen in evacuating trapped persons in the building and to take the equipment for fighting fire to upper levels with minimum delay. Some lifts out of all the lifts shall be identified as firemanôs lifts.

The number of required firemanôs lifts and their locations in a building will vary depending on the size, design, complexity of the building. Some considerations are as follows:

1) There shall be at least one firemanôs lift per building;

2) If there are multiple wings in the building, there shall be at least one firemanôs lift per wing;

3) If there are multiple banks of lifts in the building, there shall be at least one firemanôs lift per bank of lifts;

4) If the building height is up to 600 m and it is zoned height-wise and it does not have firemanôs lift serving every floor of the building, then there shall be at least one firemanôs lift per zone which shall serve the main level/fire access level and shall serve all the landings in the respective zones; and

5) If the building height is more than 600 m and it does not have any single lift serving all the floors, that is, it has all lifts serving only respective zones, the firemanôs lift shall be provided in each zone separately, serving all landings in respective zones, with a transfer landing for transferring from one zone to another.

Considering all above the firemanôs lift(s) shall be identified on the building plan by the concerned firefighting authority. This shall be respected.

To be effective in firemen operation the firemanôs lift(s) shall be identified on the building plan and duly displayed in fire command centre. The firemanôs lift shall fulfil the following requirements:

i) The firemanôs lift may be used by the occupants in normal times;

ii) The firemanôs lift shall be provided with a firemanôs switch. The switch shall be a two position (ON/OFF) switch fixed at the evacuation floor (normally main entrance floor) to activate firemanôs mode. The switch shall be housed in a box with glass cover along with suitable label and fixed adjacent to the lift at the entrance level. When the switch is turned on, all landing operating panels shall become inoperative, and the lift shall operate only from car operating panel or priority control device. When the switch is off, the lift will return to normal working;

iii) The firemanôs lift shall be provided with an audio and visual signal in the car;

iv) The firemanôs lift shall have a floor area of minimum 1.43 m^2. It shall have load capacity of not less than 544 kg (8 persons lift);

v) The firemanôs lift shall be provided with power operated (automatic) doors of minimum 0.8 m width;

vi) The speed of the firemanôs lift shall be 1.0 m/s or more such that it can reach the top floor from main floor/fireman access level within 1 min. In case the building is zoned, the firemanôs lift shall operate from the lowest served landing to the topmost served landing in 1 min;

vii) Reliable back up source of power supply shall be provided for all firemanôs lifts through automatically operated change-over switch. In case of failure of normal electric supply, it shall automatically changeover over to alternate supply. The route of wiring shall be safe from fire;

viii) The normal power feeders and backup power feeders shall be provided with 2 h fire resistance rated enclosures until they reach the machine room/controller;

ix) Suitable arrangements such as providing slope in the floor of lift lobby shall be made at all the landings to prevent water used during firefighting from entering the lift shafts;

x) For requirements of sprinkler refer **9.24.4** of accepted standard [D-5A(7)];

xi) The words óFIREMAN LIFTô shall be conspicuously displayed in fluorescent paint/colour on the lift landings at each floor level;

xii) *Operational requirements of firemanôs lift* ð The lift shall be provided with the following operational controls, Phase I and Phase II:

A) *Phase* I: *Return to evacuation floor* ð Shall start when the firemanôs switch at the evacuation floor is turned to the óONô position or the signal from smoke detector/fire alarm system (if provided by the building management system) is on. All lifts controlled by this switch/signal shall cancel all existing car calls and separate from landing calls and no landing or car calls shall be registered. The audio and visual signal shall be turned on. All heat and smoke-sensitive door reopening devices shall be rendered inoperative.

If the lift is travelling towards the evacuation floor, it shall continue driving to that floor.

If the lift is travelling away from the evacuation floor, it shall reverse its direction at the nearest possible floor without opening its doors and return non-stop to the evacuation floor.

If the lift is standing at a floor other than the evacuation floor, it shall close the doors and start travelling non-stop to the evacuation floor.

When at the evacuation floor the lift shall park with doors open.

The continuous audio signal is turned off after this return drive. The visual signal shall remain activated until the lift is restored to normal operation.

NOTE ð If the building is designed for alternative evacuation floor, in case of fire at main floor the lifts shall park at the alternative evacuation floor with doors open.

B) *Phase* II*: Operation of the lift* ð The Phase II is started after Phase I, if the firemanôs switch is óONô.

If the lifts are grounded by the signal from smoke detector/fire alarm system, for Phase II to begin it shall be necessary to turn the firemanôs switch óONô.

The lift does not respond to landing calls but registers car calls. All heat and smoke sensitive door reopening devices are rendered inoperative.

When the car call button is pressed the doors start closing. If the button is released before the doors are fully closed, they re-open. The car call is registered only when the doors are fully closed.

After registering a car call the lift starts driving to the call. If more than one car call is registered, only the nearest call is answered, and the remaining calls will be cancelled at the first stop.

At the floor the doors are opened by pushing the door open button. If the button is released before the doors are fully open, they re-close.

The lift returns to normal service when it stands at the evacuation floor with doors open and the switch is turned óOFFô thereafter.

The operation of firemanôs lift shall be by means of a full set of push buttons in the car. Other operating systems shall be rendered inoperative.

7.1.2 *Buildings of Height* 60 *m and Above*

The following requirements over and above those specified in **7.1.1** are applicable to the lifts and lift enclosures provided in buildings having height more than 60 m:

a) *Firemanôs lifts* — Following additional requirements apply to all firemanôs lifts in the building:

   1) The firemanôs lift shall have loading capacity of not less than 1 000 kg and floor area not less than 2.35 m^2;

   2) Electrical equipment within the firemanôs lift well and on the car, located within 1.0 m of any wall containing a landing door, shall be protected from dripping and splashing water or provided with enclosures classified to at least IPX3 according to good practice [D-5A(11)];

   3) The electrical switchgear placed less than 1 m above lift pit floor shall be protected to IP67 according to good practice [D-5A(11)]. The socket outlet and lowest lamp shall also be located at least 0.5 m above the highest permissible water level in the pit;

   4) Suitable means shall be provided in the lift pit to ensure that water will not rise above the level of the fully compressed car buffer;

   5) Means shall be provided to prevent the water level in the pit from reaching equipment which could create a malfunction of the firemanôs lift; and

   6) Alternative source of power supply shall be provided for all firemanôs lifts through automatically operated changeover switch. In case of failure of normal electric supply, it shall automatically change over to alternative supply. The route of wiring shall be safe from fire.

b) There shall be fire command centre (FCC) and/or building management system (BMS) room in the building. CCTV cameras shall be fixed in the lift lobbies and the display screen(s) shall be placed in the FCC or BMS room.

7.2 Evacuation Lifts

Buildings, particularly super high rise (height more than 200 m) buildings, may be designed for a systematic evacuation of persons in case of emergencies that are relevant to a specific building. There are many reasons why a building may need to be evacuated, for example, a fire, explosion, chemical or biological attack, flooding, storm damage, earthquake, etc. Not all of these are relevant to every building hence those which are not relevant can be disregarded. Designers of buildings shall determine if a particular hazard is sufficiently great as to require addressing. This clause deals primarily with fire situation although similar logic can be used in case of other situations as well.

It defines intended use of the lift(s) by persons in order to assist the evacuation, either partial or complete, of a building in case of a fire emergency in the ógolden periodô that is, after detection of the fire and before arrival of the fire brigade at the affected building; so long as use of the lift(s) is safe, thereby preventing possible human casualties, especially in case of complex high-rise buildings.

The lifts may be planned only supplementary to, not as a replacement of, exits. In fact, using lifts instead of stairs may well increase evacuation times in many building designs, especially low and medium rise buildings. However, lifts may be allowed to play a positive role in assisting and improving efficiency of the building evacuation strategy especially for persons with disabilities. The building designers should decide, if they want to use lifts for evacuation purpose. The evacuation lift may be used by the occupants in normal times. It may be noted that in general a firemanôs lift may be suitable as an evacuation lift. Three evacuation operation methods are possible for lifts to be used for evacuation of persons. One or a combination thereof may be selected based on the building type and fire evacuation strategy planned for that building. These are:

a) Automatic evacuation operation;

b) Remote assisted evacuation operation; and

c) Manually assisted evacuation operation.

To ensure that the lift(s) is available in the event of an evacuation, following principles shall be considered:

1) The evacuation strategy and process has been defined consistent with the operation of the evacuation lift(s) as described here;

2) Building requirements mentioned in this document are followed; and

3) Until the evacuation of persons is complete, the evacuation strategy and process ensure that the evacuation lift(s) is dedicated to their evacuation.

The number and size of lifts required, or the size of door opening shall be determined on a case-by-case basis by the building designer for calculating the number of lifts required, and the fire evacuation plan for the building, in collaboration with lift specialists and fire officials.

In case of an emergency, the usual way for the occupants of a building to escape to an exit floor by taking to the building stairs shall continue to be available.

7.2.1 *Pre-requisites to Using Lifts for Evacuation in Case of Fire*

7.2.1.1 *Building interface and requirements for implementing an evacuation*

Evacuation operation is designed with the assumption that the following building provisions are in place:

a) The building shall be constructed and shall not sustained structural damage, for example, from fire, explosion, flood, lightning strike, earthquake, storm, etc;

b) The automatic sprinkler system required is installed except that sprinklers in lift machine rooms and in hoist ways are prohibited;

c) The building shall be provided with a means to protect the lift(s) from the effects of fire and smoke at every landing, a safe area directly outside the lift door, and a fire-resistant structure;

d) The lift lobby at each floor shall be enclosed and separated from the remainder of the floor by a smoke barrier. The lift lobby door shall be 2 h fire rated and shall close automatically upon initiation of building fire alarm. The lift lobby shall be large enough to accommodate at least 25 percent of the floor population at 0.28 m^2 per person;

e) The lift lobbies and staircase shall be pressurized, if required;

f) The lift lobbies shall be provided with CCTV cameras with the monitor located in FCC/BMS room;

g) Fire/smoke/temperature detectors shall be provided in the building in a thoughtful manner in all areas of the building including lift shaft, machine room, lift lobbies, etc;

h) Activation of any of those detectors which signifies unsafe operating environment for the evacuation lift(s) shall initiate Phase I operation of the firemanôs/non firemanôs lift; and suspend the evacuation operation;

j) The fire alarm system may have a provision to automatically send public announcement messages to the residents of the floor with active alarm and to the residents of two upper and two lower contiguous floors;

k) Power supplies shall be secure and reliable; the provision of a secondary supply is essential. The cable providing power to the lift(s) shall be fire protected to the same fire protection level as given to the lift well structure;

m) The secondary power supply shall be sufficient to run the evacuation lift at the rated load and rated speed for a minimum period equal to the planned evacuation time consistent with the evacuation strategy;

n) The car lighting shall be also supplied by secondary power supply;

p) The normal power feeders and backup power feeders shall be provided with 2 h fire resistance rated enclosures until they reach the machine room/controller;

q) The source of the secondary supply, the level of independence between the primary and secondary supplies;

r) The source of the secondary power supply and automatic switch gear shall be located in a fire protected area;

s) The building shall be designed to minimize the risk of flooding into the lift or lift well. To this end sprinkler discharge, burst pipes, fire hose, etc should not be located to discharge towards the lift and any water close to the lift should be directed away from it by sloping floors, etc;

t) Water sensor shall be provided in the pit to shut down the lift in case the operation becomes unsafe due to accumulation of water in the pit;

u) Interior exit stairwell doors if locked, shall automatically unlock permitting exit and re-entry upon setting of alarm;

v) The lift shall be maintained, and the evacuation operation shall be tested at suitable regular intervals;

w) The building shall have a fire safety and evacuation plan including procedures for evacuation using stairs and lifts, the role of wardens, a routine training and drills for occupants;

y) Training shall include the message that lifts shall not be used for evacuation in buildings not having lifts provided with special occupant evacuation operation;

z) The machine room and lift lobbies shall be maintained with minimal fire load;

aa) Responsibility for safe evacuation shall rest with and shall be in the control of a trained person(s) located at the building premises; and

bb) Those with a disability shall be evacuated with the help of specially trained persons or with their personal assistant.

7.2.1.2 *Detecting fire, smoke and temperature*

Methods of fire detection are well established. If the lifts are to operate a safe evacuation service, good monitoring of the fire in relation to lift equipment is essential.

To ensure the safety of users and lift equipment; the lift machine room, lift well (including lift pit and overhead areas) and landing areas shall be provided with means to detect and monitor for the presence of smoke and heat. Temperature in any safe area provided for persons to wait (lobby, refuge, etc) and the lift well, machine room, etc, should be continuously monitored to determine if it is safe and remains safe for persons and equipment. When an unsafe temperature or presence of smoke is detected, the information should be sent to the BMS or FCC. The BMS or FCC should determine what is to be done next and send appropriate signals to the lift, for example remove lift from service at the respective floor *x* with doors parked open or closed as required. The equipment used for this sensing and monitoring of heat and smoke should be specified by those responsible for the design of the building fire and smoke detection system and not the lift manufacturer.

7.2.1.3 *Location of an event in relation to lifts*

In detecting an event like fire it will be important to know its location in relation to any lift intended for evacuation use. Experts in fire detection systems and lift experts should be consulted to determine the best solution for the design in question. The more the level of sophistication of detection system employed, the more precise will be the level of information available to make decisions and more meaningful these decisions will be. The building designer shall determine the degree of sophistication required taking into account the importance of the building, type of occupancy, etc.

7.2.1.4 *Emergency power provisions*

Secondary (emergency) power shall be provided that has sufficient capacity to run all the evacuation lifts at full speed for the required evacuation time. The route of the wiring shall be safe from fire.

7.2.2 *Operational Decisions for Evacuation*

7.2.2.1 *Types of evacuation*

The evacuation strategy developed should lead to an obvious evacuation type. Lifts will not be able to evacuate all floors at once, so to some degree a systematic evacuation will be governed by the capacity of lifts and the number of persons to be evacuated. Lift engineers can calculate the number of persons that can be moved for a given set of circumstances but the first thing to determine is the number of persons to be evacuated within the required evacuation time. Fire engineers and other experts shall determine these figures. It shall also be determined what proportion of wheel chair and others with impaired mobility may be there and if there is likely to be a floor or building area with a particular concentration of them.

In many instances some sort of phased evacuation will be desirable while at other times a full evacuation may be essential. Phased evacuation involves the evacuation of certain areas first, usually those floors areas at greatest risk followed by other key areas. Also, there could be horizontal evacuation, partly or fully, for example, in case of hospitals.

7.2.2.2 *Evacuation process*

There are 3 types of lift operation methods to hasten the building evacuation process.

a) *Automatic evacuation operation* ð The evacuation operation is completely automatic;

b) *Remote assisted evacuation operation* ð The evacuation operation is controlled remotely by the óremote evacuation assistantô; and

c) *Manually assisted evacuation operation* ð The evacuation operation is controlled by an assistant in the car ómanual evacuation assistantô.

The type of evacuation operation(s) to be deployed in a building shall depend on the specific building fire evacuation strategy. The evacuation service shall be operational between the floors as decided by the building designer. The logic of operation shall be mutually agreed between the building designer, the lift designer and the fire expert.

7.2.2.2.1 *Evacuation service* (*Phase* 1)

7.2.2.2.1.1 *Initiation of evacuation service*

Evacuation service shall be initiated by a two-position switch having START-STOP functions provided at the emergency exit lobby (EEL) for the manually assisted evacuation operation and/or a switch at the remote-control panel located in FCC/BMS room for the remote assisted evacuation and/or another switch at the remote-control panel for the automatic evacuation operation**.**

This switch shall enable either starting (START) or stopping (STOP) the evacuation process. When this switch is turned to START position, the lift system shall be ready to evacuate all floors served by that group of lifts.

7.2.2.2.1.2 On activation of the evacuation service, the lift shall behave as described below:

a) All registered car and landing calls shall be cancelled and no new calls shall be registered;

b) In the car the door re-open button, the door close button, and the door protective device shall remain operative; and

c) The lift, occupied or unoccupied, shall proceed to the EEL as follows; except in case of automatic evacuation operation wherein the lift if unoccupied, shall proceed to the affected floor directly as per the pre-determined priority logic for serving the affected floors; and park there with doors closed till a landing call from the affected floor is initiated:

    1) A car stationary at a landing in no call condition, shall close the doors if open and travel nonstop to the active EEL;

    2) Visual indication in car operating panel shall display óEvacuation Serviceô;

    3) A car travelling away from the active EEL shall make a normal stop at the nearest landing without opening the doors, make an audible message such as óEvacuation Serviceô and return to the active EEL;

    4) A car travelling towards the active EEL shall continue its travel nonstop to EEL;

    5) If the lift has already started stopping at a level, it shall continue to make a normal stop and without opening the doors, with message displayed óevacuation serviceô, proceed to the active EEL;

    6) On reaching at the active EEL, the evacuation lift car shall open its door and shall provide an audio-visual indication óExit Liftô. The audible signal shall have a sound level of between 35 dBA and 55 dBA adjustable to suit the site conditions with a typical recommended level of 50 dBA;

    7) If the door is not closed at the active EEL after 20 s, the protective device shall be made inactive, the doors shall attempt to close, and an audible signal shall sound in the car until the doors are closed;

    8) To start the Evacuation Service:

        i) in case of automatic evacuation operation, any landing call at the affected floor(s) shall initiate the travel of the lift to that floor as per priority logic decided;

        ii) in case of remote assisted evacuation operation, the person-in-charge at the remote-control panel shall initiate the travel of the lift to the affected floor; and

iii) in case of manually-assisted evacuation operation, pressing the car call button at car operating panel (COP) shall initiate the travel of the lift to the affected floor.

7.2.2.2.2 *Evacuation service* (*Phase* 2)

After the evacuation service (Phase 1) is completed and any type of evacuation operation signal is active, the lift shall operate in Phase 2 as follows:

7.2.2.2.2.1 *Automatic evacuation operation*

In automatic evacuation operation the lift shall operate as per the detail below:

a) When automatic evacuation signal is active and when no higher priority signal is active, the lift shall operate in automatic evacuation operation and shall serve registered landing calls;

b) The priority of answering the landing calls shall be based on the distance from the active EEL, with the furthest landing call getting highest priority;

c) On arrival at a landing other than the active EEL, the car shall open the doors and give a voice announcement as óEvacuation Service. Enter the Carô.

d) Once the doors are closed, the car shall proceed towards the active EEL. If the car is empty, it may respond the next landing call without visiting the active EEL.

e) The car if not full, may serve other landing calls on the way to the active EEL. If the car makes stops on the way to the active EEL, it shall provide audio-visual indication óDo Not Exitô. The audible signal shall have a sound level of between 35 dBA and 55 dBA adjustable to suit the site conditions with a typical recommended level of 50 dBA.

f) Actuation of the landing call booking device shall not prevent a loaded car from closing its doors and leaving the floor.

g) On arriving at the active EEL, the evacuation lift car shall open its door and shall provide an audio-visual indication óExit Liftô. The audible signal shall have a sound level of between 35 dBA and 55 dBA adjustable to suit the site conditions with a typical recommended level of 50 dBA.

7.2.2.2.2.1.1 *Deactivation of automatic evacuation operation:*

Automatic evacuation operation shall cease when:

a) the automatic evacuation signal is deactivated; or
b) the remote assisted evacuation signal is activated; or
c) the manually assisted evacuation signal is activated; or
d) the suspend service signal is activated; or
e) The lift receives Phase 1 signal of the fireman's control.

In these cases, the car shall return to the active EEL.

7.2.2.2.2.2 *Remote assisted evacuation service:*

Remote assisted evacuation is the evacuation under the control of an authorized person óremote evacuation assistantô, who controls the lift from remote evacuation control panel located in BMS/FCC room in the same building.

NOTE ð Remote assisted evacuation operation shall be subjected to cybersecurity. Cybersecurity of industrial control systems are specified in the IEC 62443 series of standards and in the accepted standard [D-5A(12)].

In the remote assisted evacuation operation, control from outside the lift car that is, from a remote location, is permitted provided there are communication means between the remote-control location and the lift car. The use of remote assisted evacuation and the communication means shall be selected based on building evacuation strategy.

Activation of the remote assisted evacuation operation shall override the automatic evacuation signal, if any.

7.2.2.2.2.2.1 *Remote assisted evacuation operation*

After the completion of Phase 1 of evacuation service, if the remote assisted evacuation signal is active and no higher priority signal is active, the lift shall operate as per details below:

a) Information sharing between the lift and the remote evacuation control panel shall be opened by the lift control;

b) After communication sync is established, the remote evacuation control panel is activated to operate in remote control mode;

c) The alarm button and door open button in the car operating panel shall remain operative; and other controls of the lift shall be operable solely from the remote evacuation control panel;

d) The remote evacuation control panel shall have displays indicating the registered landing calls, car position and direction of travel, and car door status;

e) A call registered through remote evacuation control panel shall cause the lift doors to close and the car to travel to the required landing;

f) If the door closing is prevented by a door protective device, a separate door close command from remote evacuation control panel shall bypass the protective device and the doors shall attempt to close;

g) At any time, it shall be possible to register a new call from the remote evacuation control panel. The previous call shall be cancelled. The car shall travel in the shortest time to the newly registered landing;

h) On arrival at a landing, the lift shall open the doors and shall provide an audio-visual indication “Evacuation Service. Enter the Car”. The audible signal shall have a sound level of between 35 dBA and 55 dBA adjustable to suit the site conditions with a typical recommended level of 50 dBA; and

j) On arriving at the active EEL, the evacuation lift car shall open its door and shall provide an audio-visual indication “Exit Lift”. The audible signal shall have a sound level of between 35 dBA and 55 dBA adjustable to suit the site conditions with a typical recommended level of 50 dBA.

7.2.2.2.2.2.2 *Deactivation of remote assisted evacuation*

Remote assisted evacuation operation shall cease when:

a) The remote assisted evacuation signal is deactivated; or

b) The remote evacuation control panel becomes inactive; or

c) The connection between the remote evacuation control panel and the lift is interrupted for more than 30 s; or

d) The audible or video communication system is interrupted for more than 30 s; or

e) The manually assisted evacuation signal is activated; or

f) The suspend service signal is activated; or

g) The lift receives Phase 1 signal of the fireman's control.

In these cases, the car shall return to the active EEL.

7.2.2.2.2.3 *Manually assisted evacuation operation*

Manually assisted evacuation operation shall override the automatic evacuation operation or remote assisted evacuation operation.

Manually assisted evacuation is the evacuation under the control of an authorized trained person(s), who controls the lift from car operating panel and assists occupants to evacuate the building.

After the completion of Phase 1 of evacuation service, if the manually assisted evacuation operation signal is active, the lift shall operate as per details below:

a) Registered landing calls shall be indicated in the car operating panel by blinking car call acceptance light of the given landings;

b) Where multiple lifts in a group are in evacuation operation, all registered landing calls shall be indicated in each lift. If one of the lifts serves the landing call, the landing call shall be cancelled from the other lift(s) as well;

c) The active EEL location shall be indicated in the car;

d) All heat and smoke sensitive door protection devices shall be made inactive;

e) Constant pressure on any car call button or on the door close button shall cause the car door to close. Closing shall start only after 1 s to 2 s delay. If the button is released before the car door is fully closed, the doors shall automatically reopen;

f) Car call shall be registered when the car door is fully closed, and the car shall start to travel to the destination landing;

g) If car doors are closed by the door-close button and car call is not registered within 15 s, the car shall travel to the active EEL and open its doors;

h) At any time, it shall be possible to register a new call from within the car. The previous car call shall be cancelled, and the car shall travel to the newly registered landing; and

j) On arrival at any destination, the car shall automatically open its selected door and remain at the landing until the car door is closed by the attendant and a new car call is registered or until timeout expires.

7.2.2.2.2.3.1 *Deactivation of manually assisted evacuation operation*

Manually assisted evacuation operation shall stop when the car is at the EEL; and when the manually assisted evacuation operation signal is no longer active or when the suspend service signal is active or when the lift receives Phase 1 signal of the fireman's control.

7.2.2.3 The following decision for evacuation may be taken based on below:

a) *If evacuation is required* (*building management*)

This is a decision to be made by other experts and those responsible for building management. In large buildings evacuation may take some time and it shall not be assumed that continued use of a particular lift or lifts is guaranteed. Serious thought shall be given to how information will be displayed to those managing the building especially where the BMS system is capable of providing a large amount of information. It should be possible to see at a glance if lifts are operating correctly and what services they are running. There shall always be provision made to allow the building management or authorities to override any automatic evacuation signal that is generated by a smart BMS. Irrespective of the systems employed the evacuation decision cannot be made by a lift system and therefore other experts in this field shall determine what risks will constitute the need for evacuation and the type of evacuation (partial or full).

b) *If lifts are to be used for the evacuation*

If for some reason a significant number of lifts are not available for use then it may be prudent to remove all lifts from automatic evacuation service rather than have too few. If too few lifts are in service, delays will result that could be dangerous or cause panic. In such circumstances it is probably desirable to run a limited service for the evacuation of those who have difficulty negotiating stairs. Any such service needs to be managed by lift attendants who will drive the lift, manage possible crowding and assist those who need it. The decision to operate some form of service when not all lifts are available shall be taken by those managing the building evacuation.

7.2.2.5 *Building evacuation information*

When evacuation is required, updated information shall be provided through the building systems informing persons concerned including those in waiting areas which lifts to use during the particular emergency. This information shall be in both audible and visual format. Any safe areas/waiting areas should also have an emergency communication system.

7.2.3 *Specifications of Automatic Evacuation Lift*

7.2.3.1 *Determining the number and size of lifts*

To calculate the number and size of lifts required for an adequate evacuation service, the handling capacity of a given lift or group of lifts shall be determined considering possibility that a lift or lifts may not be available for some reason such as planned maintenance, repairs, etc. This analysis can be done by the lift designer. Also, due consideration shall be given to the requirement of accommodating a wheel chair in the lift car.

7.2.3.2 *Protection of lift equipment*

Lift shafts and machine rooms or machinery spaces located outside the shaft should be fully enclosed. The temperature in the enclosures should be monitored and maintained to acceptable levels for the equipment, as determined by the lift supplier in consultation with the building management. Protection from water may be considered, if required as per overall evacuation strategy.

7.2.3.3 *Removal or suspension of lifts from evacuation service*

Where a lift receives a command from a BMS or manual signal to stop or suspend service to a floor or area of the building, any stop shall be a controlled stop at a safe area. A controlled stop means allowing the lift to slow down and stop at a floor in the normal manner. Where a lift or lifts are instructed to suspend service the lift(s) shall inform the FCC and any BMS once it is no longer available for service.

7.2.3.4 *Remote lift car surveillance*

At times of emergency, it is vital to be able to see that lifts do not contain trapped passengers who may be incapacitated. A means to display the entire floor area of the car shall be provided with information to the occupants that the lift car is under surveillance. At least one viewing terminal shall be located in the FCC and clearly marked "Lift Car Surveillance" with the lift designation identified.

7.2.3.5 *Communication system requirements*

As a minimum a 3-way communication system shall be available for passenger use to permit direct communication between the lift car and safe area and FCC. Operation of the communication device in the lift car shall be simply by means of a single button, operation of which shall connect the system to the FCC. Further operation of the device in the lift car shall be hands free.

7.2.3.6 *Initiation of evacuation service*

Evacuation service can be initiated by a device such as a button or lever, key, etc located near the lift shaft at the evacuation landing, or from a signal sent by a BMS or hazard detection system. Where a button or other manual activated device is used it shall be protected against unauthorized use. Its purpose shall be clearly marked with a symbol and/or the words "LIFT EVACUATION SERVICE".

The evacuation service shall be operational between the floors as decided by the building designer. The logic of operation shall be mutually agreed to between the building designer and the lift designer. However, any lift will be automatically removed or suspended from evacuation service if, where provided, it is turned to firemen operation.

7.2.3.7 *Cancellation of evacuation service*

On cancellation of a signal from the device that initiated the service and receipt of a signal from an evacuation service cancellation switch, all lifts which are not at the main landing shall complete any allocated task and return to the main landing.

On arrival at the main landing the doors shall open and then the lift evacuation for that particular lift shall be cancelled. Any lift already at the main landing shall on opening its doors cancel its evacuation service.

7.2.4 *Information to be Provided to the Building Owner/Operator*

Detailed instructions shall be provided to the building owner/operator by the building designer in the form of a manual. The manual shall explain the evacuation strategies to be used, how any detection system operates, how they shall be maintained and how the lift will operate on evacuation service. It should also provide advice on periodic checks the owner/operator can make to ensure the system is working correctly and explain the importance of a suitable testing and maintenance system being in place. Training being very important aspect of this new concept, the manual shall include such details of training as who should be covered by training, how the training should be carried out, what should be the frequency, etc.

8 MINIMUM TECHNICAL AND SAFETY REQUIREMENTS

8.1 General Requirements

The following general requirements shall be adhered to:

a) Passenger and goods lifts shall comply with the safety requirements and/or protective measures as given below. In addition the passenger and goods lifts shall be designed according to good practices [D-5A(2)];

b) All labels, notices, markings and operating instructions shall be permanently affixed, indelible, legible and readily understandable (if necessary aided by signs or symbols). *See also* good practice [D-5A(3)]. They shall be of durable material, placed in a visible position, and written in the accepted language(s);

c) The minimum factor of safety for any part of the lift shall not be less than five. Higher factor of safety for various parts shall be applicable in accordance with good practice [D-5A(13)];

d) All passenger, goods, stretcher, automobile, dumbwaiter lifts shall have conformity with *Lifts Acts and Rules* in force, *The Electricity Act*, 2003, CEA Regulations and all relevant and applicable Indian Standards, applicable fire regulations, fire prevention act and rules in force;

e) *Notices* — The following notices shall be placed at respective places:

    1) A notice (*see* Fig. 23) bearing the following (typical) minimum inscription shall be fixed to the outside of doors or trap-doors (excluding landing doors and doors of emergency and test panels) giving access to machine and pulley rooms. Use of notice boards as per relevant standards is recommended, that is danger board shall be as per accepted standard [D-5A(14)]. Use of non-standard notice boards should be avoided; and

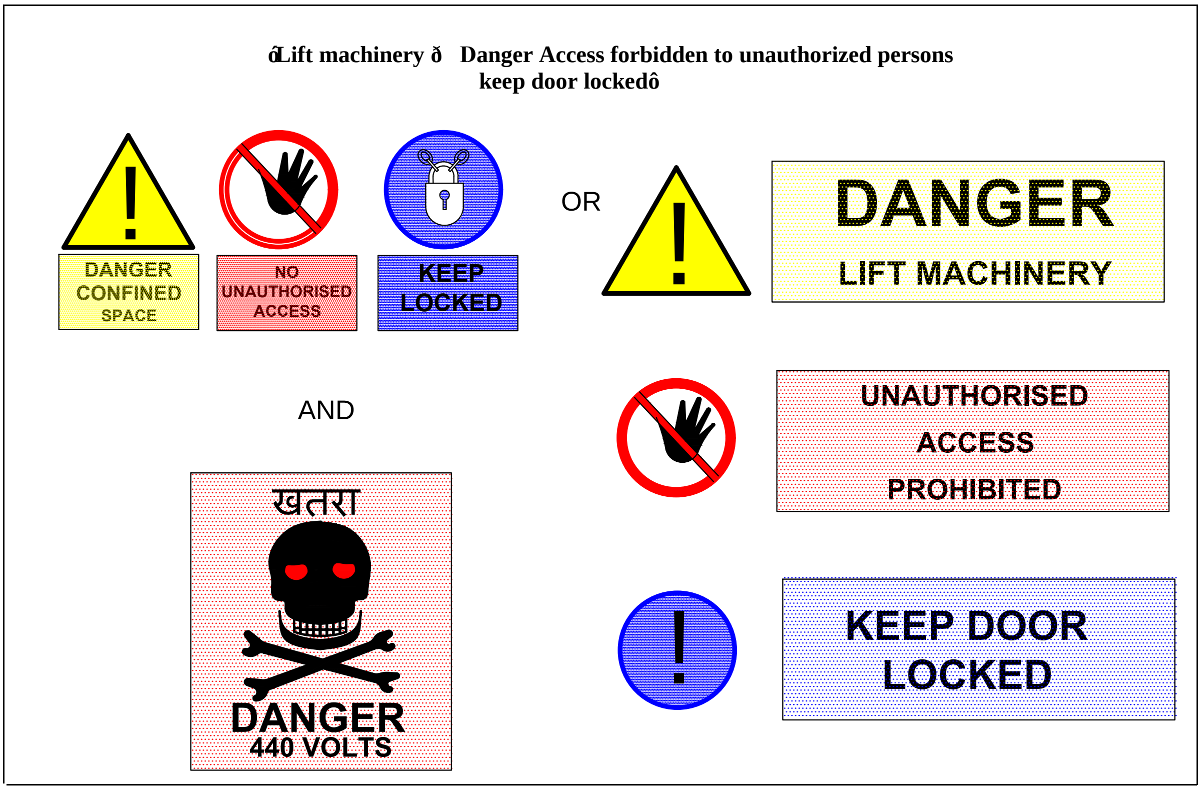

ðLift machinery ð Danger Access forbidden to unauthorized persons
keep door lockedô
DANGER CONFINED SPACE
NO UNAUTHORISED ACCESS
KEEP LOCKED
OR
DANGER
LIFT MACHINERY
AND
UNAUTHORISED ACCESS PROHIBITED
खतरा
DANGER
440 VOLTS
KEEP DOOR LOCKED

FIG. 23 TYPICAL INSCRIPTIONS ON DOORS

2) In the case of trap-doors, a permanently visible notice (*see* Fig. 24) shall indicate necessary warning to those using the trap-door.

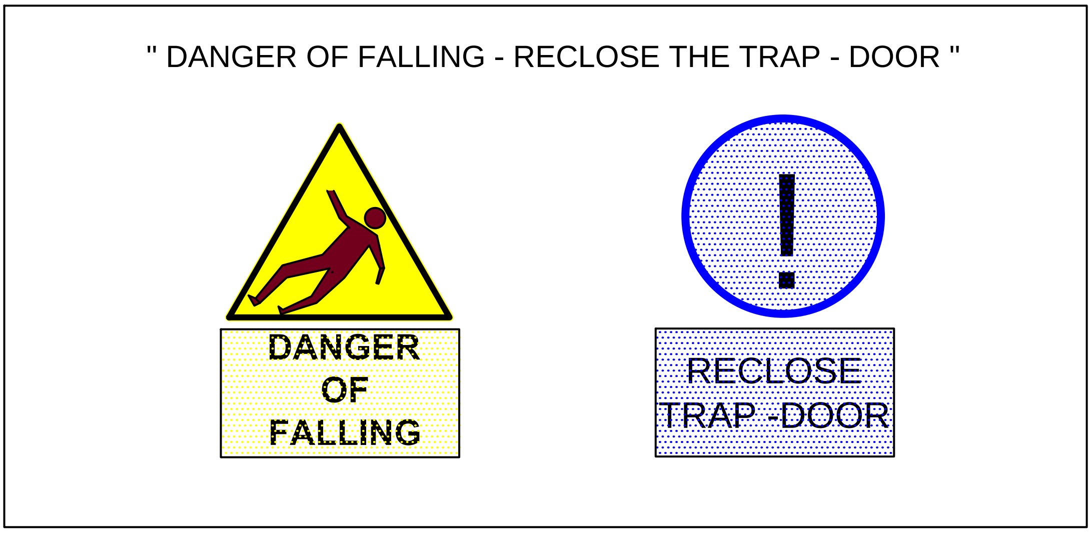

" DANGER OF FALLING - RECLOSE THE TRAP - DOOR "
DANGER OF FALLING
RECLOSE TRAP -DOOR

FIG. 24 TYPICAL NOTICE ON TRAP DOORS

3) Outside of the well, near the access doors and emergency doors, if any, there shall be a notice as shown in Fig. 25.

ΨΩ[LC¢ ² 9[[ς 5!bD9w
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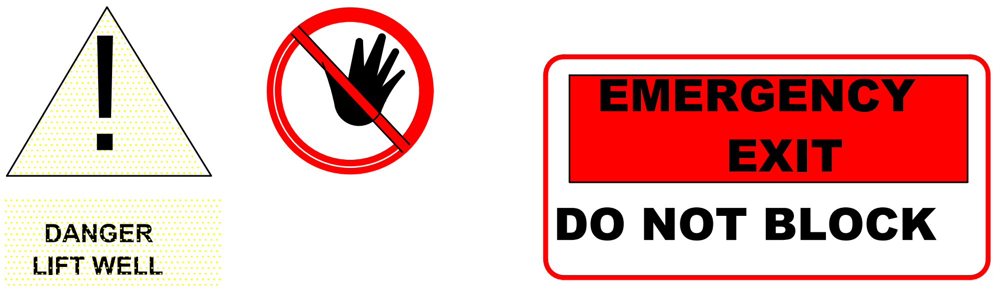


FIG. 25 TYPICAL NOTICE ON ACCESS DOORS AND EMERGENCY DOORS

4) A notice board with following instructions as applicable, and/or other applicable instructions shall be placed in conspicuous position in the lift car:

   i) Maximum capacity of lift ________ kg/_______ persons;

   ii) Close the car and landing door/gate properly, on entering, or while leaving the lift car;

   iii) Do not open the lift-car gate when the lift-car is moving. The gate should only be opened after the lift-car has stopped opposite a landing gate;

   iv) In case of danger, press the alarm button, but do not try to open the car door. Wait inside, until the lift car is brought opposite a landing, and do not attempt to leave the lift car until the landing door is opened fully; and

   v) Children under 12 years of age shall not use the lift, unless accompanied by an adult.

5) The Table 36 is a typical list of Doôs and Donôts that should be displayed in the lift car, and in case of lifts open to public use, in an accessible format complying requirements of accessible information board/signage, given in good practice [D-5A(3)]:

Table 36 List of Doôs and Donôts

[*Clause* 8.1(e)(5)]

Doôs	**Donôts**
a) Press call button lightly	a) Do not overload the lift beyond maximum capacity of the lift
b) Know your destination. Push lift call for direction you want to go	b) Do not press call button again and again
c) Stand aside for exiting passenger	c) Do not force-open the doors, it is dangerous
d) Pay attention to floor indicator	d) Do not stand in between the doors
e) Push and hold the door open button, if door needs to be held open	e) Do not fiddle with the equipment
f) Wait for the next car, if the lift is full	f) Do not step in until lift has stopped at landing and doors are fully open
g) Take the stairs, if there is a fire	g) Do not crowd in the middle of car
h) In case of emergency call customer service cell for rescue operation	h) Do not lean against car panels
j) Children of 12 years or below and pets shall always be accompanied by an adult inside the lift	j) Do not panic in case of power failure
	k) Do not attempt to jump out, if the lift has stopped out of floor level
	m) Do not try force open the doors when the lift is in motion

NOTE ð No other notices should be fixed in the lift car.

8.2 Power and Control Systems

8.2.1 *Features Associated with Power Systems*

The features associated with power systems are listed below.

8.2.1.1 *Industrial switchgear*

Switchgear for controlling lift power systems is characterized by its high duty cycle and its high rupturing capacity. Switchgear shall be robust enough and shall be so designed as to withstand the high duty cycle and high rupturing capacity introduced during the operation of the lifts.

8.2.1.2 *Levelling accuracy*

The levelling tolerances in accordance with good practice [D-5A(6)] are those which can be reasonably expected between no load and full load in either direction. With the VVVF drives good levelling accuracy can be expected.

8.2.1.3 *Corrective levelling*

This should only be used, when it is impossible otherwise to achieve the required levelling tolerances or on long travel lifts to maintain the required levelling tolerances during loading and unloading.

8.2.1.4 *Levelling with variable voltage*

A variable voltage system is one using continuous regulation which minimizes speed differences due to load variation. Therefore, the actual levelling speed is of less importance than the general refinement of its regulation control. In fact, no levelling speed as such may be identifiable.

8.2.1.5 *Overload tests*

A lift is designed to operate and transport the contract load, at the required duty cycle, and should not by intention or habitually be used to carry overloads. During test as a safeguard to cover variable supply and temperature conditions, a lift is checked for the car to complete one round trip with contract load plus 10 percent at nominal supply voltage and nominal ambient temperature. There is also a static test with contract load plus 25 percent to check that the brake will sustain the car. It is unnecessary to specify an additional overload test or capacity and in fact it is detrimental to the normal running efficiency and safety of the lift to do so.

8.2.1.6 *Occasional extra load*

It is not good practice to request that a lift should be designed to carry an occasional extra load. It is tantamount to specifying an excessive overload test which is detrimental to the normal running efficiency and safety of the lift.

8.2.2 *Description of Operation Systems*

The following description relates to the associated operating systems.

8.2.2.1 *Methods of control systems*

The methods of control systems are as follows [*see* 8.2.2.2(a)]:

a) Attendant and dual control; and

b) Automatic push button operation.

8.2.2.2 *Types of control systems*

The features of control systems shall be as described below:

a) *Automatic push button operation* — Automatic control is a method of operation by which a momentary pressure on a push button sets the car in motion and causes it to stop automatically at any required lift landing. This is the simplest control system and it is sometimes referred to as push button control. A car answers a landing or car call, whichever is actuated first by momentary pressure provided the lift is not in use. Momentary pressure of a car push button will send the car to the designated floor. The car always responds to a car push button in preference to a landing push button. With this type of control, a red landing signal light or direction arrow indicates that the car is in use that is the lift is travelling. This type of control is recommended for single passenger lifts serving up to 4 floors and goods lifts.

For special purposes, the following two systems may be considered:

1) Dispatch from landings as an additional feature for a goods lift with manually operated doors. The call is registered by pressing the car push button and when the doors are closed the car will travel to the designated floor.

2) Automatic with attendant control as an additional feature on goods lifts with a key operated switch in the car to transfer the control from normal automatic to attendant operation. There is also a visual call indicator with buzzer in the car to indicate to the attendant the landing floors at which push buttons have been pressed when the car is under attendant control.

b) *Collective control* — Collective control is a generic term for those methods of automatic operation by which calls made by pressing push buttons in the car and at lift landings are registered and answered by the car stopping in floor sequence at each lift landing for which calls have been registered irrespective of the order in which the calls have been made, and until all calls have had attention. Collective control of any form is usually not suitable for goods lifts except where loading is not expected to fill the car and additional loads can be taken at other stops.

c) *Single push button collective control* — Single push button collective control has a single push button at each landing. It is not recommended, as the direction in which it is desired to travel cannot be registered by the intending passenger.

d) *Down collective control* — Down collective is a control system where landing calls are registered from a single push button, irrespective of the car being in motion or the landing door being open and calls are stored until answered. Any number of car calls can be registered and the car will stop in sequence in the down direction at each of the designated floors. The car will travel in the up direction to the highest call registered stopping only in response to car calls. It will then travel downwards answering calls in floor sequence. If only one call has been registered the car travels to the floor of call.

This system is suitable where there is traffic between the ground and upper floors only and no inter floor traffic. Two or three car banks have interconnected control. With this type of control the following signals are included:

1) A landing signal light indicates that the call has been registered and will be answered.

2) Illuminated car position indicator above car entrance.

e) *Directional collective control for one car* — Directional collective control for one car is a control system having óUPô and óDOWNô push buttons at intermediate landings whereby the call is registered for the intended direction of travel. Calls from the car or landing push buttons are registered and stored until answered. The car will answer calls in floor sequence in one direction of travel. Calls for the opposite direction of travel are answered when the direction of travel is reversed.

This system is suitable for single lifts serving four or more floors with inter floor traffic, such as small office blocks, hotels and blocks of flats. With this type of control the following signals are included:

1) A landing signal light for each landing push button indicates that the call has been registered and will be answered.

2) Illuminated car position indicator above the entrance in the car.

3) Arrow shaped signal lights in the back of the car or on the landing to indicate to the entering person in which direction the car is going to depart.

f) *Directional collective control for two or three cars* — Directional collective control for two or three cars is a system covering a control in which the two or three cars in a bank are interconnected. One push button unit with óUPô and óDOWNô push buttons or floor buttons (in case of car control from floor) are required at each landing and the call system is common to all lifts. If for architectural balance, in the case of a three car bank, extra push button units are required, these should be specified. Each landing call is automatically allocated to the best placed car. The control is designed so that cars are effectively spaced and thus give even service. When a car reaches the highest floor to which there is a call its direction of travel is automatically reversed when it next starts. One or more cars will return to the parking floor. Automatically bypassing of landing calls when a car is fully loaded is an essential feature for three-car banks. It is also necessary for two-car banks in offices. Other cars will continue to provide service to all floors. When three-car banks serve 7 or 8 floors and over, some form of automatic supervisory control [*see* 8.2.2.2(g)] is generally necessary in the interest of efficiency. With this type of control the following signals are included:

1) A landing signal light for each landing push button to indicate that the call has been registered and will be answered.
2) Illuminated car position indicator above the entrance in the car.
3) Arrow shaped signal lights in conjunction with an audible single stroke gong or an indication on the landing call push button station above each landing entrance to indicate to the waiting person(s) which car is going to stop and in which direction it will continue its course.

g) *Group supervisory control* — A bank or group of intensive traffic passenger lifts requires a supervisory system to coordinate the operation of individual lifts which are all on collective control and are interconnected. The very nature of intensive service calls for a sophisticated automatic supervisory control system so as to match the speed capacity of these lifts. The supervisory system regulates the dispatching of individual cars and provides service to all floors as different traffic conditions arise minimizing such unproductive factors as idle cars, uneven service and excessive waiting time. The system will respond automatically to traffic conditions such as óUPô and óDOWNô peaks, balanced or light traffic and provides for other specialized features. If desired, a master station can be provided in the lift lobby which gives by indicators, visual information regarding the pattern under which the system is operating. Where the system is based on a definite programme, control means are provided for altering the type of traffic programme. There are other facilities, such as the removal of any lift from service.

h) *Destination control system* — In case of a bank of lifts having more than 6 lifts or as decided by user, destination control system (DCS) may be provided. The passengers enter their destination floors on the destination operating panels (DOPs) provided on the lift landings. The lift controller allocates a lift to every call registered which is displayed on the DOP. The passenger is expected to board the assigned lift and travel to his destination floor. He need not register his destination floor in the lift car operating panel (COP) again. In fact, COP in the lift car may not be provided with floor buttons in case of DCS control system. The principle behind the DCS is to group passenger with same destinations together thus reducing the number of stops of the lift reducing round trip time and boosting traffic.

j) *Number of DCS terminals* — Number of terminals at every floor shall be established based on the 5 min peak traffic, however it shall not be less than 2 on every floor.

It is recommended that the DCS input terminals barring one for people having special needs is not located in the position of the conventional hall buttons. It is recommended that the DCS input terminals are positioned outside the lift lobby or at the entrance to the lift lobby or integrated with the turnstiles.

The advantages of DCS system over conventional collective control are:

1) enhanced passenger handling capacity;
2) less transit time, few intermediate stops; and
3) passengers do not have to struggle through crowd to book the calls.

In addition to the DOPs the lift landings shall be provided with lift identifier. Indicators shall be provided on the car jambs indicating the car stops.

Hybrid destination control (HDCS) combines features of the DCS and conventional control system. The main floor is provided with DOPs, lift identifiers and the lift car is provided with the conventional COP as well. Thus, while availing benefit of traffic boosting HDCS provides convenience of call booking from inside the lift car as well.

8.2.2.3 *Features of operation systems*

The features associated with the operating systems are as follows:

a) *Car preference* ð Sometimes it is necessary to give a special personal service or a house service. When this service is required and for whatever purpose, it should be specified as ócar preferenceô; is activated by a key operated switch in the car. The operation is then from the car only and the doors remain open until a car call is registered for a floor destination. All landing calls are bypassed and car position indicators on the landing for this lift are not illuminated. The removal of the key when the special operation is completed, restores the control to normal service.

b) *Landing call automatic bypass* ð For collective operation, automatic bypassing of landing calls can be provided. This device will bypass landing calls when a car is fully loaded but the calls are not cancelled.

c) *Basement service* ð For lifts with collective control when service is required below the main parking floor, which is usually the ground floor, to a basement and/or a sub-basement, the lift manufacturer should be informed of the type of service required, as special technical considerations are then usually necessary.

d) *Hospital service* ð Lifts for carrying beds and stretchers require a car preference switch so that an attendant can have complete control of the car when required. This requirement should be specified as ócar preferenceô and it will function as described in 8.2.2.1. Otherwise such lifts can have the same control systems as for normal passenger lifts, the choice depending on the number of floors served, the service required and the number of lifts.

e) *Manually operated doors* (*without closers*) ð A ódoor openô alarm should be provided to draw attention to a car or landing door which has been left open.

f) *Automatically power closed doors* ð For passenger operation when the car arrives at a landing the doors will automatically open and then close after lapse of a time interval. This time interval can be overruled by the pressure of a push button in the car to give instant door closing. An óopen doorô push button is provided in the car to reverse closing motion of the doors or hold them open.

g) *Controlled power closed doors* ð When there are conditions that particularly affect the safety of passengers or damage to vehicles or trucks, the closing of the doors should only be made by the continuous pressure of push buttons in the car or on landings. A ódoor openô alarm should be provided to draw attention to a car or landing door which has been left open. This means of operation is required for some forms of goods lifts.

h) *Safe operation of doors* ð The safety of passengers passing through lift entrances is fully covered by the provision of good practice [D-5A(13)]. No modification of these provisions should be specified.

j) *Directorial service* ð There are many forms of giving special service for individuals, but they should always be avoided. They range from key operated switches at preferred landings to the complete segregation of one out of a bank of lifts. It is obvious that any preferential treatment of this nature can seriously jeopardize the efficiency of the service as a whole. When a bank of say three lifts is installed to meet the anticipated traffic requirements and then, when the building is occupied, one lift is detached permanently for directorsô service, the traffic handling can be reduced by a half rather than a third. When preferential service is imperative, then the car preference feature should be available [*see* 8.2.2.3(a)].

k) *Indication of car arrival* ð All lift cars are illuminated when available (in service). It is recommended that this illumination be used to signal the arrival of a car at a landing in preference to special signals such as óLIFT HEREô signs since signal lamps can fail when the lift is still operating satisfactorily.

   The following is the practice adopted for vision panels in doors:

   1) For lifts with manually operated car and landing doors, vision panels are provided in all doors.

   2) For lifts with power operated car doors and manually operated landing doors, vision panels are provided in the landing doors only.

m) *Service switches* ð When switches are provided to take cars out of service, that is because the remaining cars in the group can cater for the required passenger traffic, it is essential that such switches should not stop the firemanôs control from being operative in the event of the lift being designated as a firemanôs lift. Service switches should not be confused with maintenance switches which are only used when it is dangerous to attempt to operate the lift because maintenance work is actually in progress. A control station fitted on top of the car is regarded as a maintenance switch.

n) *Fire switch* — When required by the fire authority a fire switch has to be provided, the function of which is to enable the fire authority to take over the complete control of one or more lifts in an installation.

p) *Push buttons and signals* ð It is most important that the purpose of every push button and signal should be clearly understood by all passengers.

q) In public places where visually impaired are expected to use the lifts it is recommended to provide Braille/tactile buttons.

8.3 Capacity and Loading

The minimum rated load of a passenger lift car corresponding to the net inside car area shall bear the relationship given in Fig. 26; the net inside car area being evaluated as shown in Fig. 27. The net inside car areas for various passenger capacities with corresponding minimum rated loads have been given in Table 37 and for goods lifts in Table 38.

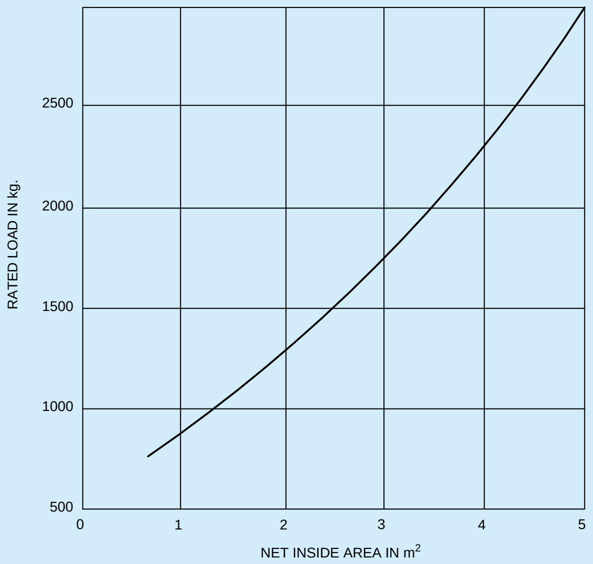
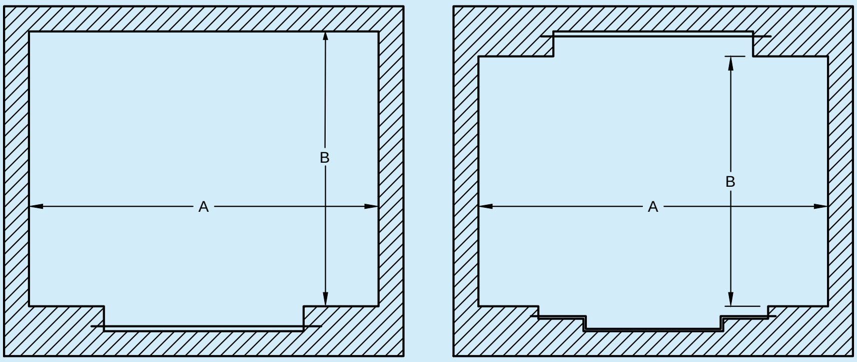


FIG. 26 MINIMUM RATED LOADS FOR PASSENGER LIFT CAR



NET INSIDE CAR AREA = A x B

NET INSIDE CAR AREA = A x B

FIG. 27 NET INSIDE CAR AREA FOR PASSENGER LIFTS

NOTES

1 The graph shown in Fig. 26 is based on the following formula:

$$W = 35.05\,A^2 + 325.66\,A$$

where

W = rated load, in kg; and

A = net inside areas, in m^2.

2 For rated loads exceeding those covered by the graph, value may be evaluated from the formula given above.

3 To avoid the possibility of serious overloading of bed lifts, they shall be treated as passenger lifts.

4 The minimum rated load for goods lifts shall be based on a load of not less than 3.45 kN/m^2 of the net inside car area.

5 The minimum rated load for automobile lifts shall be based on a load of not less than 1.45 kN/m^2 of the net inside car area.

6 When the load in a goods lift consists of pallets or similar single piece loads loaded by means of a power truck, it is necessary during loading and unloading to take into account the total load on the car platform the capacity of the brake and the resistance to slipping of the ropes on the sheave of a traction machine. Similarly, guide rails, guide fixing, car frame and platform shall be designed to withstand the horizontal thrust imposed by power trucks, motor vehicles and the like.

7 For motor vehicle and other special purpose lifts for transportation of light weight and heavy volume loads, the lift car inside dimensions mutually agreed to between the manufacturer and the purchaser will be permitted with the provision of a device to prevent the lift from starting from a landing in case of overloading.

8 A load plate giving the rated load of the lift shall be filled in each lift car in a conspicuous position. For passenger lifts, the rated load shall be given in number of person and kg. For goods lifts, the rated load shall be given in kg or other convenient units and in persons. For the purpose of this clause, a person shall be regarded as weighing 68 kg.

Table 37 Minimum and Maximum Net Car Areas for Various Rated Loads ð Passenger Lifts

(*Table 14*, *Table 15*, *Table 27*, *Table 28* *and Clause* 8.3)

Sl No.	**No. of Passengers**	**Rated Load W**	**Minimum Available Net Inside Area**	**Maximum Available Net Inside Area A**
		kg	m^2	m^2
(1)	(2)	(3)	(4)	(5)
i)	4	272	0.68	0.77
ii)	5	340	0.85	0.95
iii)	6	408	1.00	1.12
iv)	7	476	1.16	1.28
v)	8	544	1.31 (1)	1.45
vi)	9	612	1.46	1.60
vii)	10	680	1.61	1.76
viii)	11	748	1.77	1.91
ix)	12	816	1.92	2.05
x)	13	884	2.06	2.20
xi)	14	952	2.23	2.34
xii)	15	1 020	2.35	2.47
xiii)	16	1 088	2.48	2.61
xiv)	17	1 156	2.62	2.74
xv)	18	1 224	2.75	2.87
xvi)	19	1 292	2.88	3.00

Table 37 (*Concluded*)

Sl No. (1)	No. of Passengers (2)	Rated Load W kg (3)	Minimum Available Net Inside Area m^2 (4)	Maximum Available Net Inside Area A m^2 (5)
xvii)	20	1 360	3.01	3.13
xviii)	21	1 428	3.14	3.25
xix)	22	1 496	3.26	3.37
xx)	23	1 564	3.38	3.49
xxi)	24	1 632	3.50	3.61
xxii)	25	1 700	3.62	3.73
xxiii)	26	1 768	3.74	3.84
xxiv)	27	1 836	3.85	3.95
xxv)	28	1 904	3.96	4.07
xxvi)	29	1 972	4.08	4.18
xxvii)	30	2 040	4.17	4.29
xxviii)	31	2 108	4.25	4.39
xxix)	32	2 176	4.34	4.50
xxx)	33	2 244	4.44	4.61
xxxi)	34	2 312	4.53	4.71
xxxii)	35	2 380	4.62	4.81
xxxiii)	36	2 448	4.72	4.92

NOTES

1 The maximum available car area is calculated as per formula:

$W = 35.05A2 + 325.66A$,

where

W = the rated load, in kg; and

A = the maximum area, in m^2.

2 Beyond 36 passengers add 0.109 m^2 in maximum available area for each extra passenger.

3 Beyond 36 passengers add 0.104 m^2 in minimum available area for each extra passenger.

4 Hospital lifts shall be treated as passenger lifts and shall be designed according to above table.

5 Minimum net car inside area for fireman lift shall be 1.43 m^2.

For planning the quantity of lifts (passenger/service/hospital bed/ stretcher lifts) and deciding their main specification in any project, reference shall be made to 4. For ćenhanced personal spaceô in the lift car without impacting the rated load and the car area as specified; while planning for the lifts, passenger occupancy may be considered less than the 80 percent specified in 4, thereby providing larger area per person in the lift car. The suggested number of passengers may be displayed in the lobby and in the car alongside the statutory rating plate required as per **5.4.2.3.2** of good practice [D-5A(1)], by the user.

Table 38 Maximum Net Car Areas for Various Rated Loads — Goods Lifts

(*Table* 31, *Clauses* 8.3 *and* 8.3.1)

Sl No.	Rated Load kg	Maximum Available Net Inside Area A m^2
(1)	(2)	(3)
i)	250	0.71
ii)	500	1.34
iii)	750	1.91
iv)	1 000	2.43
v)	1 250	2.92
vi)	1 500	3.38
vii)	1 750	3.81
viii)	2 000	4.22
ix)	2 250	4.62
x)	2 500	5.00

NOTES

1 The maximum available area in above table is calculated as per formula:

$$W = 35.05A2 + 325.66A$$

where

W = the rated load, in kg

A = the maximum available area, in m^2.

2 Beyond 2 500 kg, add 0.16 m^2 for each extra 100 kg.

3 Refer to Notes under Fig. 27.

8.3.1 For goods lifts, the available area of the car may be greater than the value determined from Table 38, but shall not exceed the value in m^2 determined by dividing the rated load in kg by (3.45 kN).

For motor vehicle lifts, the available area of the car may be greater than the value determined from Table 38, but shall not exceed the value in m^2 determined by dividing the rated load in kg by (1.45 kN).

8.3.1.1 *Class of loading*

a) *General loading*

This applies where the load is distributed, the weight of any single piece of freight or of any single loaded hand truck is not more than 25 percent of the rated load of the lift, and the load is handled on and off the car platform manually or by means of hand trucks.

For this class of loading, the rated load of the lift shall be not less than the load (including any truck) to be carried, and shall in no case shall be based on less than 3.45 kN/m^2 of inside net platform area.

b) *Motor vehicle loading*

This applies where the lift is used solely to carry passenger automobiles up to the rated capacity of the lift.

For this class of loading, the rated load of the lift shall be not less than the load to be carried, and in no case shall be based on less than 1.45 kN/m^2 of inside net platform area.

c) *Concentrated load with/without powered/manual industrial truck*

This applies where the weight of the concentrated load including a powered industrial or hand truck if used, is more than 25 percent of the rated load; during loading and unloading the maximum weight on the car platform may exceed the rated load up to a maximum of 150 percent of rated load; and where the load to be carried does not exceed the rated load.

For this class of loading, the car platform and car frame shall be designed for 150 percent of rated load. The driving-machine motor, safety gear, brake and traction relation shall be designed to sustain and level the full 150 percent of rated load. The guide rails, guide fixings, car frame and platform shall be designed to withstand the horizontal thrust imposed by power trucks, motor vehicles and the like.

The rated load of the lift shall be not less than the load (including any truck) to be carried and shall in no case be based on less than 3.45 kN/m^2 of inside net platform area.

d) *Other loading with heavy concentrations*

This applies where the weight of the concentrated load including a powered industrial or hand truck, if used, is more than 25 percent of the rated load; where the static load during loading and unloading does not exceed the rated load; and where the load to be carried does not exceed the rated load.

For this class of loading; the guide rails, guide fixings, car frame and platform shall be designed suitable for the forces due to the heavy concentrated load and its location in the car. The rated load of the lift shall be not less than the load (including any truck) to be carried, and shall in no case be based on less than 3.45 kN/m^2 of inside net platform area.

8.4 Other Technical and Safety Requirements

8.4.1 All lifts shall be provided with one or more car door(s) and landing doors, passenger lifts shall be provided with power operated doors which are imperforate.

8.4.2 Power operated car doors on automatically operated lifts shall be so designed that their closing and opening is not likely to injure a person. The power operated car door shall be provided with a sensitive device which shall automatically initiate reopening of the door in the event of a passenger being struck or is about to be struck by the door, while crossing the entrance during closing movement. The effect of the device may be neutralized:

a) During the last 58 mm of travel of door panel in case of side opening doors;

b) When panels are within 58 mm of each other in case of centre opening doors; and

c) During emergency fire operation.

The force needed to prevent the door from closing shall not exceed 150 N and this measurement shall not be made in the first third of the travel of the door. In order to achieve this, it is desirable that all power operated doors have a full length (covering at least 1 600 mm of car door height from bottom) infrared or equivalent light curtain safety to retract the door in the event of coming across any obstacle during closing of the door.

8.4.3 Single speed and two speed drives which are poor in levelling accuracy and energy consumption shall not be used for new lifts in view of availability of latest technology energy efficient variable voltage variable frequency (VVVF) drive systems with improved levelling accuracy.

When a lift moves up or down in negative load conditions, that is empty car/less than 50 percent load in UP direction or more than 50 percent load/full load in DOWN direction and during lift system deceleration, the lift motor generates energy which is lost in the form of heat in set of resistors in traditional non-generative drives. The additional heating could also result in additional cooling costs to the building owner depending on the size, duty and number of lifts in a building.

The regenerative drive converts the energy generated by the motor and feeds it back to the building internal electrical grid thereby eliminating the need of using braking resistors. This energy can be utilized to feed other loads or users connected to the same network. The amount of energy savings due to regeneration depends on various system parameters and configurations such as car load, speed, length of run, traffic pattern and system efficiency. The efficiency of the regenerative drive in both motoring and generating modes should not be less than 0.8. Regenerative drives lower overall building operating costs, delivering significant annual savings to building owners and tenants year-after-year during the life of the lift. These drives help to reduce peak power demand and energy consumption. As a result, both the fixed costs based on peak power demand (kVA) and variable costs based on energy consumption (kWh) decrease. Depending on different parameters (traffic, load, speed, etc) energy saving can be up to 40 percent. It reduces the cost of the air conditioning system and eliminates excess heat in the building that would have been otherwise wasted.

If a stand-alone generator or uninterrupted power supply (UPS) is used to feed power supply to the lift system, the energy fed back to the stand-alone generator or UPS during negative load conditions or deceleration cannot be consumed. It is therefore imperative to connect sufficient load to the generator (other than lift load), which can consume the regenerated energy. If UPS is used, it shall be capable of handling the recuperated energy. If such measures are not implemented, it will lead to frequent breakdowns of the lift or failure of regenerative drive. Building owners should consult lift manufacturers to understand the amount of regenerated energy and implement suitable measures.

8.4.4 For passenger lifts with car call button control in car, an additional car operating panel with call buttons shall be provided for ease of access to call buttons when the car is wider than 1 600 mm and/or the rated capacity of the lift is 16 passengers and more. This additional car operating panel shall be suitably located in the lift car. The faceplate of an operating panel is recommended to be in contrast to its surrounding background.

8.4.5 Battery operated automatic rescue device (ARD) shall be provided on all lifts in accordance with [D-5A(1)] to take lifts to the nearest possible landing in case of power failure, which includes power failure of one or more phases. In case of lifts equipped with backup generator with automatic mains failure (AMF) panel, the provision of ARD is optional. For all lifts with ARD, an audio and visual indicator shall be provided inside the lift car to alert the persons trapped inside that they are being rescued. Capacity of batteries shall be such that minimum three rescue operations can be performed with full charged battery, without recharging. Emergency light and at least one fan inside the lift car shall be operational till the end of rescue operation. Levelling accuracy of ± 40 mm or better shall be achieved in the ARD Operation. The ARD should operate only when all safety circuits are operational. The safety circuits shall be checked and verified continuously during the rescue operation.

8.4.6 Minimum one stretcher lift shall be provided in each building having height more than 24 m so as to take care of medical as well as other emergencies. This lift shall have minimum car entrance width of 800 mm and car depth of 2 100 mm.

8.4.7 Every passenger lift shall be provided with an overload device in accordance with [D-5A(1)].

8.5 Painting at Works and on Site

Lift equipment will normally receive a protective coat of paint at works before dispatch to site. Further painting of lift equipment may be necessary and is normally in the form of a finishing coat and can take place on site. Alternatively, the further painting of the equipment may be carried out at works as a finishing coat with normal touching up after site erection as may be necessary. Any additional painting, due to site conditions during erection and/or final operating conditions in the premises, is subject to negotiation between the lift manufacturer and the purchaser. Decorative finishes are a subject for separate negotiation.

8.6 Emergency Manual Rescue

The emergency manual rescue operation with brake release should only be carried out in an emergency and by authorized persons who have received necessary instructions, because it is dangerous for any other persons to attempt to do so.

Before attempting to move the car, it is imperative that any person in the car be warned of the intention to move the car and that they shall not attempt to leave the car until they are advised that it is safe to do so. Any failure to carry out this precaution may render the person concerned guilty of negligence should an accident occur.

Before attempting to hand wind the lift machine, it is vital that the supply is switched off at the main switch. It is usually necessary to have two persons in the machine room: one to operate the brake release and the other to carry out the hand winding. The exceptions are small lift machines where the hand winding can be easily controlled by one man and larger machines which need two men to operate the hand winding alone with an additional man to control the brake release. In case of gearless machines especially, the brake shall be released and applied at very short intervals (of the order of 0.5 s to 1 s) so as to avoid the lift car attaining dangerously high speed due to the lift car and create unbalance in the absence of the gear box with large reduction ratio.

If the car is stuck in the lift well and cannot be moved when an attempt is made to move it in a downward direction, then no attempt at hand winding should be made because the car safety gear may have set. Any further procedure should be carried out under the instruction of a qualified lift mechanic. Provided the car is free to be moved in the downward direction, then it should be hand wound to the nearest floor. There is a preference to move the car in down direction. However, this may not always be practical owing to the distance involved and the time taken to complete the movement. In addition, the amount of out of balance load on the counterweight side, due to the size of car and the small number of persons inside it, may make it necessary to wind the car upwards.

In the case of high speed lifts the direction of hand winding will usually be governed by the effort required to move the car because of the absence of a large gear reduction ratio. It is essential that all detail operations be carried out according to the manufacturer's instructions for the lift concerned and these should be clearly stated and permanently displayed in the form of a notice in the machine room.

8.7 Flood Sensors

Water flood sensors shall be installed in the lift pit to monitor ingress of water levels. A warning hooter/alarm shall be provided to alert of any potential ingress of water in lift pit area. Two water level sensors to be installed in the pit to provide two input signals to the control system; one input is for warning and the other input is for shutdown of lift. When the first switch is activated, an alarm/hooter is to be generated, so that maintenance personnel can understand the situation of water ingress in the pit and eliminate the danger in advance by removing the water safely. In case action is not taken with first switch alarm and when the second switch is activated due to the rise in water level position which is going to affect the operation of the lift (for example, the potential submerged tension device switch), the lift shall stop at the nearest landing level and an alarm needs to be triggered again (*see* Fig. 28).

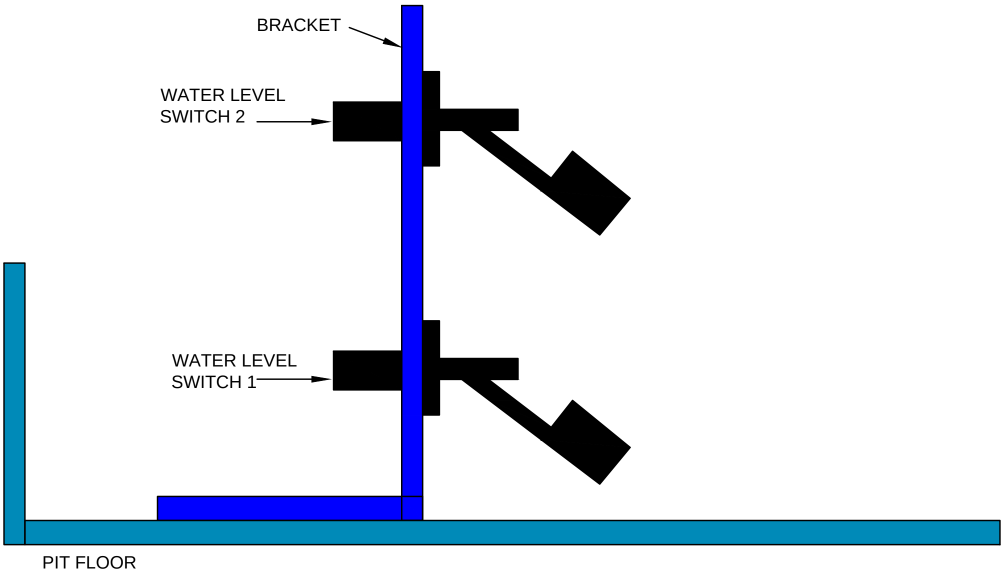


Fig. 28 Flood Sensors (Typical Representation of Arrangement)

The water level Switch 1 is recommended to be installed 50 mm to 100 mm above the pit floor to detect the low-level water accumulation. The water level Switch 2 is recommended to be installed at 200 mm to 300 mm above the pit so as to ensure that the water level detection switch lies below the lift's any electrical switch such as buffer and safety switches which monitor the safe operation of the lift.

The pit water ingress signal from water level detection switch may be used to connect to a water pump to remove water from pit.

9 SPECIAL TECHNICAL REQUIREMENTS

The objective of this clause is to define some special type of lifts that are used currently in buildings such as lifts without conventional machine rooms (MRL lifts), lifts used in private apartments (home lifts), hydraulic type of lifts and lifts required for differently abled persons, etc.

Additional requirement for lifts to be installed in hazardous (as classified) locations shall be considered. The electrical equipment or systems shall comply to Part D óBuilding Services, Section 2 Electrical and Allied Installationsô. Also, equipment shall need valid statutory approvals as applicable.

9.1 Lifts without Conventional Machine Rooms (MRL Lifts)

9.1.1 MRL lifts are a special type of lifts where hoisting machine is placed inside the lift shaft and control system may be inside and/or adjacent or at close proximity to top landing door, eliminating the need for conventional machine room.

9.1.2 The MRL lifts shall be in conformance with good practice [D-5A(15)] apart from other relevant provisions of this Section.

9.1.3 MRL lifts may be provided with emergency door on the top portion of the hoist-way which is equipped with electromechanical lock wired in series with lift safety chain and of size 700 mm Ĭ 700 mm minimum, so as to access the machinery space in case of emergency or safety device being activated on or above the top landing.

9.2 Lifts Used in Private Apartments/Houses/Villas (Home Lifts)

9.2.1 The home lift is designed especially for private home having up to 5 stops (maximum rise 12 m), where the usage of the lift is restricted primarily to the residents of the private home. Unlike conventional lifts which allow virtually unlimited access to members of the general public, in case of home lifts non-residents shall have limited access.

9.2.2 The rated capacity of the home lift shall be minimum 208 kg (3 persons) and maximum 272 kg (4 persons) and lift car speed shall not exceed 0.2 m/s.

9.2.3 The home lifts shall conform to good practice [D-5A(1)] and [D-5A(16)] apart from other relevant provisions of this Section.

9.2.4 Electric MRL type home lifts, shall in addition conform to the technical requirements specified in good practice [D-5A(1)].

9.2.5 Hydraulic type home lifts shall in addition conform to the technical requirements specified in good practice [D-5A(1)].

9.3 Hydraulic Lifts

9.3.1 The hydraulic lift is a special type of lift where the lift car is directly or indirectly driven by action of one or more hydraulic jacks.

9.3.2 The hydraulic lifts shall conform to good practice [D-5A(1)] apart from other relevant provisions of this Section.

9.3.3 These lifts should preferably be hole-less type of lifts.

9.4 Lifts Accessible for Persons with Disabilities

9.4.1 All lifts open to public shall adhere to the accessibility provisions in terms of size of the car, door width, control panel, flooring, finishes, handrails, communication systems and information, given in good practice [D- 5A(3)].

9.4.2 Lifts for differently abled persons shall conform to good practice [D-5A(17)] apart from other provisions of this Section.

9.5 Seismic Resistance in Lifts

When seismic protection of the passengers and equipment is a consideration, the safety requirements and protective measures given in good practice [D-5A(18)] may be adopted, the specified requirements being applicable when the units are subject to seismic conditions where the specified design acceleration (a_{d}) $\geq$1 m/s^2.

NOTE ð The design acceleration is a function of ground acceleration, soil behaviour, importance factor, etc. Thus, the value of (a_{d}) applicable to the building and to be considered for lift design/installation shall be provided by the building architect or structural designer to the lift manufacturer.

9.6 Automobile Lifts

Where required, lifts suitable for moving passenger vehicles such as light motor vehicles (LMV), small utility vehicles (SUV), etc, may be provided. The minimum requirements to be considered while providing such lifts are as given in **9.6.1** to **9.6.8**.

9.6.1 The minimum and maximum car area requirements for passenger lifts as defined in **6.1** of good practice [D-5A(1)] may not be applicable for automobile lifts. For this class of loading, the rated load shall be based on not less than 1.45 kN/m^2 of inside net platform area.

9.6.2 Strengthening stiffeners may be added to car panels to have sufficient strength to avoid permanent or temporary deflection of car panels beyond limits in case the vehicle touches the lift car panels while moving in or out. Under no circumstance, it should result into unsafe condition.

9.6.3 The hall button for calling the lift may be provided in the approach way at such a location that the button is accessible to the vehicle driver in the driving position without having to get off the vehicle. Optional light ray detection system or card reader system may be provided for automatic detection of vehicles and calling the lift to the floor.

9.6.4 Minimum entrance width of such lifts may be 2 400 mm and entrance height of 2 300 mm. The minimum car inside dimensions may be 2 500 mm wide and 5 300 mm deep and typically with entrance doors on both sides of the lift. This will enable the car to be driven inside and can be taken out in the same direction, without any need to reverse the same. Minimum load carrying capacity shall not be less than 2 500 kg.

9.6.5 Barricades may be provided outside the lift entrance door(s), so as to limit the size of the vehicle and preventing oversized vehicles from entering the lifts and possibly damaging the equipment.

9.6.6 There shall be sufficient place on both sides of the vehicle, once the vehicle is inside the lift. The lift car width should be selected such that in case of emergency while the automobile is in the lift car the driver should be able to open the automobile door and come out of the automobile.

9.6.7 The car operating panel, where the car call can be given, may be provided at such a location that is accessible by the vehicle driver in the driving position without having to get off the vehicle. The time duration for which the door remains open upon arrival at landing floor or upon stopping at landing floor shall be sufficient enough so as to enable smooth movement of the vehicles in and out of the lift car. Lift car entrance door(s), shall be equipped with light curtain device in accordance with **19.1.4** of good practice [D-5A(6)].

9.6.8 Overload warning device shall be installed in accordance with **6.2** of good practice [D-5A(1)].

9.7 Air Conditioning System for Lift Cabin (Car)

Where the lift car is equipped with air conditioning system, following additional requirements are recommended:

a) The whole equipment, its container, condenser, etc, should be typically made of corrosion resistant material, with average designed life span of 10 years.

b) The air conditioning system should work on single phase electric power supply of maximum 230 V a.c. and should be well within the current carrying capacity of trailing cable cores provided for the air conditioning system. The power supply for the air conditioning system shall be provided from RCCB of suitable rating. This RCCB shall be located in the lift machine room with proper identification and lock out tag out facility.

c) The air conditioning system should be provided with suitable air filters which should ensure clean air inside lift car. The filters should be easily accessible and serviceable from top of the lift car in a safe and easy manner.

d) The lift air conditioning should typically include functions such as:

   1) Cooling, with adjustable temperature setting provided on the unit itself or through remote control unit, which may be maintained in the lift car.

   2) Heating, with adjustable temperature setting provided on the unit itself or through remote control unit, which may be maintained in the lift car.

   3) Ventilation, with adjustable air flow having less than 52 dBA noise level in the car.

   4) De-humidification, with effective condensation water management system.

e) The lift air conditioning should be equipped with effective condensation monitoring and condensed water recycling system so as to avoid water spillover or leakage on top of the lift car and other lift components, as detailed below:

   1) Condensation water monitoring and dealing with it is a very important feature any lift air conditioner shall have. Condensation water leakage or spillover on the lift car top may cause damage to the lift and may lead to electrocution or even fire.

   2) When the condensation water level in the reservoir reaches high level and remains at that or above that level for three minutes, the compressor should stop working and the air conditioner should go into ventilation mode. In the ventilation mode the air conditioner fan still works, water pump still runs, the water is pumped to the condenser for condensation water to be vaporized. When the water goes below 80 percent, the compressor may restart and the air conditioner may go into cooling mode.

   3) When the condensation water level reaches 100 percent, and remains at that level for 1 min, to avoid the water spill over and damage to lift components, the air conditioner should power off by itself. All components of air conditioner should stop working. This air conditioning unit shut down should not be automatically resettable and should require manual intervention. Also, it should be possible for this condensation water to be drained out by opening the drain plug provided. This facility of draining off excess condensation water shall be safely accessible either from lift car or lift pit.

f) It shall be possible to manually switch óONô and óOFFô the lift air conditioning unit either by key switch provided in the lift car or by remote control.

9.8 Lift Interface with Building Management System (BMS)

Where required, a means to interface, monitor and control be provided by lift manufacturer, which should become the part of building management system. The following information and controls, but not limited to those, may be provided either through potential free contacts or building automation (BA) interface device suitable for providing necessary lift information over other accepted communication protocols. With potential free contacts only lift monitoring is possible. It shall not be possible to control the lift.

a) *Monitoring signals*:

   1) Floor position of the lift for each lif.

   2) Direction of travel for each lift.

   3) Load condition of each lift specially indicating overload status.

   4) Lift door status of each lift, whether open or closed.

   5) Lift modes such as attendant, automatic, independent operation, emergency fire service, seismic mode, emergency medical service and inspection mode for each lift.

b) *Control signals*:

    1) Bring the lift down to lobby floor in case of emergency or VIP movement.

    2) Park and shutdown lifts based on building and traffic requirements, so as to save power.

    3) Force the lift into emergency fire service, seismic mode or emergency medical service, etc through command from BA system based on respective sensorôs such as smoke detectors, seismic sensor, etc input to BMS.

c) *Reports* — Software tools may be developed to report out performance of each lift such as average response time, number starts per hour, average lift uptime, round trip time, etc with the flexibility to provide additional reports based on building requirements.

The above-mentioned requirement for potential free contacts, other standard protocols, etc, may be optional, if the full-fledged lift management system software is provided by lift manufacturer for monitoring and control of lifts in the building. This software may be custom built providing above mentioned requirements. The wiring between lift machine room to building management systems shall be planned and carried out by the builder along with other wiring in the building.

9.9 Closed Circuit Camera Inside Lifts for Monitoring (CCTV)

Where required, closed circuit camera is provided either by lift manufacturer or by third party supplier, inside the lift car for security purposes. Suitable warning mentioning óyou are under CCTV surveillanceô shall be posted inside the lift car. These cameras may be located at ceiling level and at any location which cannot be easily accessed, noticed or tampered with.

The cable used for connecting in car camera to monitoring system, provided by supplier, shall be of trailing grade. Ordinary co-axial or twisted pair wires shall not be lashed or tied along with trailing cables. Trailing cables are specialized cables used in lift applications. Wireless CCTV may also be considered alternatively.

If the camera signal is disconnected, either because of fault or intentionally, the lift monitoring system should get an alert indicating the same. Responsibility of monitoring, recording, organizing and maintaining CCTV shall be duly decided in advance.

9.10 Emergency Medical Service (EMS) for Hospitals

Optional emergency medical car operation may be provided especially for hospitals and operation theatre lifts and the lift behaviour in this mode is as described below. Activation of the emergency medical hall switch activates the in-car buzzer and illuminates a lamp in the car and hall. This forces the car to cancel car calls, reassigns hall calls, and return non-stop to the defined medical landing. Upon arrival, the door opens and the buzzer is deactivated.

The door remains open until the switch is turned off or the doors have been open for at least 60 s. If the medical switch is toggled, this operation remains in effect for additional 60 s. The second phase of EMS operation can only be activated when the doors are open at the medical landing. Once the car is on emergency medical operation fire service operation cannot be initiated, even though the fire service lamp and buzzer are activated.

If the car is performing fire service operations, emergency medical operations cannot be initiated, even though the medical lamp and buzzer are activated. The car automatically enters the emergency medical car operation after the doors are open at the medical return landing. If the emergency medical car switch is not activated within 60 s, the medical operation is cancelled.

To move the car, the emergency medical car switch needs to be activated. Prior to activation, the door cannot be closed and car calls cannot be registered. An active car switch allows car calls to be registered, which automatically closes the door and moves the car to the target landing. At the target landing the door opens and remains open until another car call is registered. The door close button has no effect on this operation.

If the car medical switch is deactivated away from the medical return landing with the doors open, the car remains at the landing not allowing car calls to be registered or the door to be closed. The car shall be returned to the medical landing and the emergency medical car switch deactivated to remove the car from emergency medical car operation.

9.11 Destination Control System (DCS)

The destination control system (DCS) uses passenger destination information to improve traffic flow and travel time in busy mid- and high-rise buildings. Instead of using standard hall call buttons, passenger enters specific floor number he wants to travel to, before entering the lift. The system groups passengers traveling to nearby floors to the same car.

9.11.1 Conventional destination control system requires keypads or touch screens at all floors to book the calls. This conventional DCS may be additionally provided the car operating panel (COP) in the lift car to improve passenger comfort. Alternatively, the COP in the lift car may be hidden. Traditional hall lanterns are no longer needed.

9.11.2 Hybrid destination control system requires keypads or touch screens only at the main floor allowing up-peak boosting of traffic. Traditional hall button stations and hall lanterns need to be provided at all other floors. A full COP is required in the lift. With both conventional and hybrid DCS provided with touch screens and/or keypads, hot button(s) may be provided to facilitate call booking to common floors as fast as possible.

9.11.3 *Identification of Lifts*

To avoid confusion between identification of lifts and floor nomenclature, particularly when braille is considered, it is recommended that the lift identification should be alphabetic and floor nomenclature to be numeric.

9.11.4 *DCS Car Loading for Simulation*

While 80 percent is considered as the average loading for traffic analysis with conventional controls, the car loading for simulation with DCS shall not exceed 80 percent

9.11.5 It is advisable that DCS input keypads at main floor to be placed at the entrance of lift lobby and not at conventional location (between two lifts) to avoid multiple calls by same person. When DCS keypads are integrated with turnstiles, additional DCS keypad to be provided in the lobby to re-register the call in case a person fails to enter lift.

9.11.6 Conventional control system allows maximum of 8 lifts in group operation, having not more than 4 lifts in row, however DCS provides an advantage of increasing number of lifts in group operation, which can be extended to 10 lifts in a group to 16 lifts in a group. The designer should note that arrangement for lifts shall be limited to 5 lifts in row.

9.12 Special Environments

Standard equipment is suitable for use inside normal residential, commercial and industrial buildings but when unusual environments are likely to be encountered, the advice of the lift manufacturer should be sought at the earliest possible stage to enable the most economic satisfactory solution to be found. Special mechanical protection and or electrical enclosures may be necessary as well as compliance with statutory or other regulations and with the purchaserôs particular requirements, which should be fully considered at the time of enquiry.

Examples of situations which necessitate special consideration are:

a) Exposure to weather, for example, car parks;

b) Low temperatures, for example, cold stores;

c) High temperatures, for example, boiler plant;

d) Hosing-down, for example, for hygiene or decontamination;

e) Corrosive atmosphere, for example, chemical works;

f) Dusty atmospheres, for example, gas plants;

g) Explosive and inflammable atmosphere, for example, gas plants, and petroleum and polyester industries; and

h) Nuclear/heavy water plants.

10 PERFORMANCE REQUIREMENTS FOR LIFTS AND EVACUATION LIFTS

10.1 It is necessary to have uniformity in the definition, measurement, processing and expression of vibration and noise signals that comprise lift ride quality. The aim of such uniformity is to benefit users by reducing variability in the results of lift ride quality measurements caused by differences in the methods of acquiring and quantifying the signals. Experience indicates that evaluation of vibration in terms of peak-to-peak levels is of particular relevance to passenger comfort. It is considered necessary to provide a dual form of expression, quantifying both the maximum peak-to-peak and A95 peak-to-peak vibration levels.

10.2 Measurement of Lift Ride Quality

Ride quality of all lifts shall be measured in accordance with accepted standard [D-5A(19)]. The selection and calibration of measuring and test equipment shall also be in accordance with this standard.

Measurements shall be made during normal building conditions, after the lift has been running under normal daily operation for at least one hour. Vibration measurements shall be made at the geometric centre of the car.

11 SPECIAL TECHNICAL REQUIREMENTS FOR SUPER TALL BUILDINGS

The provisions given hereunder describes the different physical phenomena that occur in super high-rise buildings (> 200 m high) and influence vertical transportation solutions.

Although there are no major differences regarding suspension and guidance systems between high-rise and low-rise lifts, there are other aspects to be considered such as system technology and passenger comfort levels. Control system artificial intelligence levels, safety requirements, load-bearing component ratings, rope weight, energy consumption, and thus cost increase exponentially with the height of the building.

11.1 Air Pressure Effect

In high rise buildings, air pressure is different on ground level and on top of the building. Practically, pressure change on the ear becomes uncomfortable for some persons when lift is landing faster than 10 m/s. The thresholds are lower for small children, elderly persons and passengers having flu. Therefore, practically, as a standard solution lifts are offered up to 10 m/s maximum speed.

11.2 Piston Effect

If high speed lifts, especially those having rated speed ≥ 4 m/s, are housed in single shaft, the displaced air due to movement of the lift car tries to escape through the gaps between the lift car walls and the shaft walls in turbulent flow. This phenomenon known as piston effect causes the ride quality in the lift to deteriorate. Noise level in the lift car may increase along with vibrations which will be felt by the passengers. The air being displaced past the car generates whining and whistling noises inside the car. Buffeting when passing doors may be audible and passenger may feel uncomfortable. Both lift car doors and landing doors may whistle at high speeds.

Therefore, high speed lifts should be preferably housed in common shaft with ventilation holes in the common wall(s), if any. These holes allow the air displaced due to the movement of the lift car to escape in the adjoining hoist-way. Thus, the velocity of the escaping air, which depends on the ratio of the lift car area to lift shaft area, reduces to mitigate the piston effect ensuring good ride comfort for the passengers. The size of the vent and the pitch at which the vents need to be provided depend on lift car size in relation to lift shaft size, as well as the speed of the lift and the ride comfort expected.

It is recommended to eliminate common wall between the shafts for lifts with speed ≥ 4 m/s. Shaft should be provided with divider beams at every bracket level for the support of the guide rails. Metallic wire mesh shall be provided for separation of shafts.

If a lift with speed ≥ 4 m/s is housed in an enclosed shaft which is standalone, it is recommended to increase the shaft size by 25 percent to 30 percent.

NOTE — The percentage increase in shaft is given as a range to have flexibility for builders and lift manufacturers to accommodate the lift and reduce the piston effect.

In addition, high speed lifts especially those having rated speed more than 6 m/s may have cars with aerodynamically designed exteriors. This special construction of the car however increases the requirements of the overhead and pit for which lift manufacturer should be consulted. To reduce hammering sounds caused by the passage of the lift past the landing doors, shaft in front of the lift car door may be clad with facia plates equal to full shaft width between the landing door sill of the upper floor and door header of the lower floor door to create an even, flush surface. Lift cars also need to be specially constructed to absorb noise and thus reduce transmission of noise in the car.

11.3 Stack Effect

Stack effect is defined as the vertical, natural air movement throughout a high-rise building caused by the difference in temperatures between the inside air and the outside air. Positive stack effect is characterized by a strong draft from the ground floor to the roof. Positive stack effect is more significant in cold climates because of the greater difference in temperature between the inside and the outside of the building. The colder the weather and the taller the building, the greater will be the stack effect. Negative stack effect can also occur in the reverse direction in hot climates but is not as significant because the difference in temperature is not as great.

The magnitude of stack effect is a function of:

a) building height;

b) air tightness of exterior walls;

c) air leakage between floors; and

d) difference in temperature between inside air and outside air.

The stack effect has following effects:

1) *Differential pressure on the lift landing doors* — The stack effect generates differential pressure on the landing doors. In case of buildings with airtight separation of each storey the differential pressure on a particular landing door from inside and outside of the lift shaft is small, however, the pressure on the door of the first landing and that on the last landing may vary a lot.

   In case of buildings with no air partitions the converse is true. The differential pressure on a particular landing is significant and is the maximum at the topmost and bottom most landings which are farthest from the neutral pressure level. At the neutral pressure level, which occurs somewhere in the mid section of the building height, the differential pressure on the landing door from inside and outside of the lift shaft is nil. The differential pressure on the landing door may cause difficulty in the operation of the door; and

2) *Smoke movement* — The stack effect influences the smoke movement. In case of positive stack effect, the air moves out from core of the building towards the exterior of the building above the neutral pressure level and it moves in from the exterior of the building to the core of the building below the neutral pressure level. In case of negative stack effect, reverse phenomenon occurs. This air movement naturally affects the smoke movement in case of fire and must be considered.

   Since stairwells, lift shafts and lifts tend to contribute to the stack effect it is essential that all lift lobbies are well sealed, and lifts parked with door closed to minimize stack effect. Especially in case of fire the stack effect needs to be controlled to prevent the spread of smoke in the building. On the other hand, the stack effect may be beneficially used to quickly drive smoke out of the building in case of fire.

11.4 Building Sway

The wind induced sway of the building may cause the lift suspension means and/or compensation ropes and lift car travelling cables to sway. Buildings have natural frequencies of oscillations. Similarly, lift ropes also have natural frequencies of oscillations which depend on the position of the car in the hoist-way amongst other parameters. When natural frequencies of the ropes and the building match, a large amount of energy is transferred to the ropes, and they start swaying violently. This results into reduced ride comfort for the passengers in the lift and increases possibility of ropes getting stuck to snag points in the shaft and damaging shaft equipment. In general, the rope and travelling cable resonance phenomenon should be considered in the lift design for over 200 m tall buildings and slender buildings over 150 m tall, for example, TV towers. It is a fact that the resonance cannot be completely avoided in high rise buildings, hence the need for the solutions to cope with the phenomenon. If resonance is not considered in the lift design, it could increase the lift down (out-of-service) time and decrease lift ride comfort.

The main purpose of the sway management is to improve lift safety and service time by reducing rope sway by optimizing tension of compensation ropes, providing shaft protection equipment to prevent ropes from entangling and damaging the lift equipment. A sway detector may be used to control the lift operations. The output signals from the sway detector are used to reduce the speed of the lifts or park them at a safe floor.

In order that the sway analysis is done, the building designer should be in touch with the lift designer since early design stage of the building and share information on the building natural frequencies, maximum amplitude of building displacement with probability of occurrence, etc. The lift designer would then be able to calculate the rope/cable sway and decide on the preventive measures to be taken in the lift design.

11.5 Ride Comfort

A robust car guide system with meticulously aligned guide rails is essential for reducing vibrations to an acceptable comfort level. Guide rails shall be rated for heavy-duty usage. Irregularity in the guidance system causes an unpleasant and uncomfortable transverse vibration within the car at high speeds. High-quality roller guide system is required for smooth ride. In addition, the lift guide system shall be able to withstand the effects of the building settling and the response of the buildingǿs structure to thermal and climatic changes.

11.6 Jump Lifts

In super high-rise buildings, there may be a need to start lift erection before the machine room is finished to compress total time required to complete the building. The self-climbing lift technique may be used to build the lift as the building construction progresses. Jump lift uses a temporary machine room that is moved upward as construction progresses. Typically, when the building construction reaches the seventh floor, the jump lift may start operating and start serving lower floors. Exterior hoists can be removed sooner, enabling the facade to be enclosed. This means that lower floors are ready for finishing much earlier and the entire building can be completed sooner. Since all transportation takes place in a dry, windproof shaft, construction can continue safely and unhindered, even in bad weather. The change-over to final lift is very quickly done.

11.7 How to Handle High-Density Population in Buildings

Due to continued exponential growth in urbanization, thickly populated buildings are becoming common in all metro and Tier-I cities. It has become quite essential to improve the efficiency of vertical transportation systems within the available shafts in the buildings, significantly beyond the conventional single deck system (*see* Fig. 29).

The following two different types of systems are possible solutions:

a) 2 cabins running independently in one single shaft; or

b) 2 cabins mounted one above the other.

These systems are compliant with the latest good practices as per [D-5A(1)] and [D-5A(20)].

11.7.1 The benefits of these systems are as follows:

a) optimal use of shaft with 2 lift cabins arranged one above the other;

b) connection of two main landing levels with the highest efficiency;

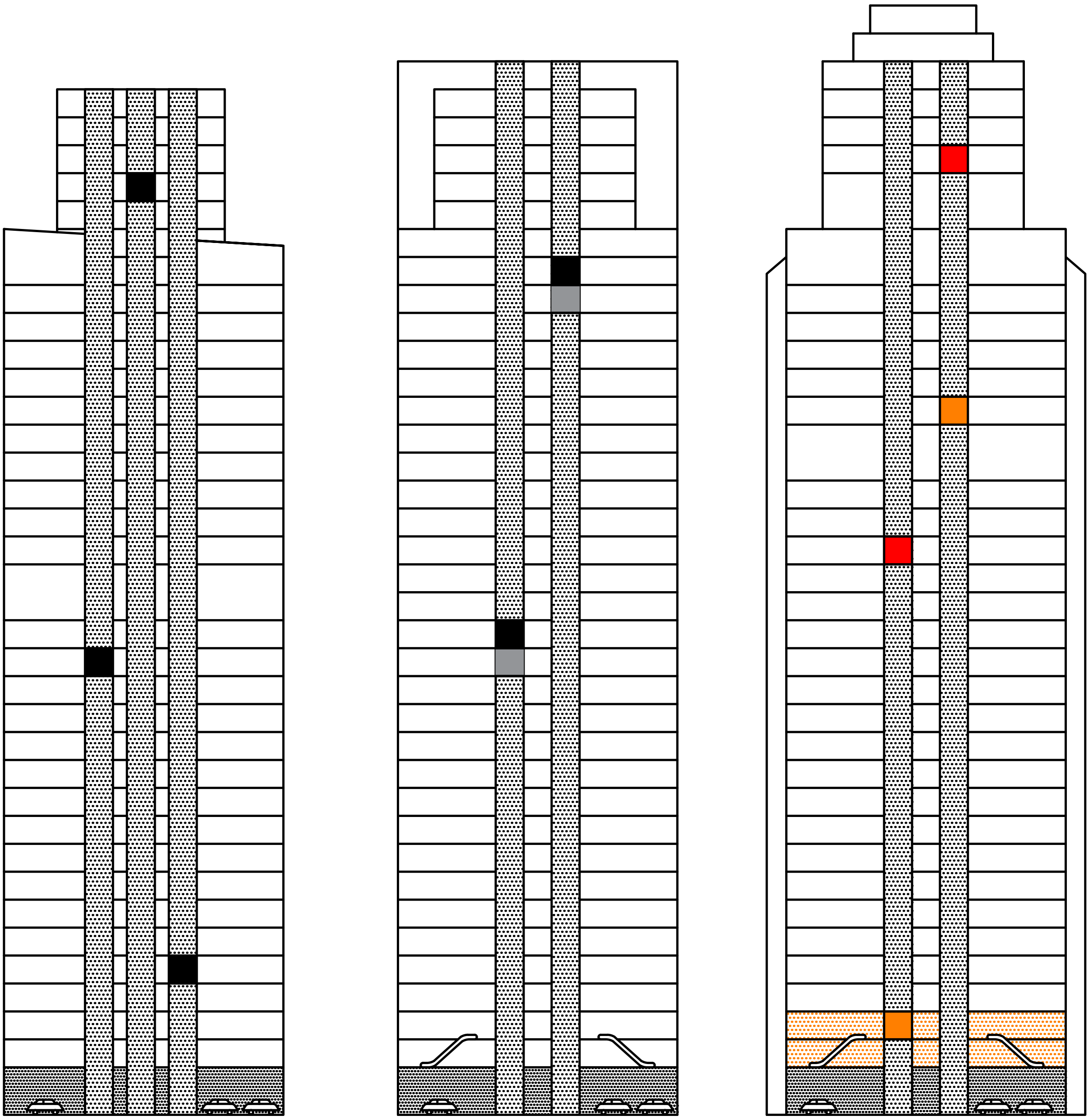
c) handling of high traffic volume and short travel times between two main landing levels; and

d) simultaneous filling of both lift cars.

In combination with other lift systems, double deck is generally used as a shuttle lift. It is particularly suitable for passenger transport from main entrance levels to defined terminal landings, for example outdoor viewing platforms or transfer landings, so-called sky lobbies.

Two independent cars in a single shaft solution, is used where both up-peak and inter-floor traffic is heavy.

The advantages come into their own when each of the landings in the access area or terminal landings are interconnected via escalators to split up the flows of passengers. In this case, both lift cars can be loaded and unloaded simultaneously.



29A CONVENTIONAL

29B TWO CABINS MOUNTED ONE ABOVE OTHER IN SINGLE SHAFT

29C TWO SEPARATE CABINS RUNNING INDEPENDENTLY IN SINGLE SHAFT

FIG. 29 DIFFERENT TYPES OF VERTICAL TRANSPORTATION SYSTEMS

11.7.1.1 The benefits for new installation projects include:

a) significantly more handling capacity with fewer lift shafts compared to conventional lifts;

b) 2 independent cars and 2 cars one above the other in one shaft reduce the building core by approximately 50 percent;

c) reduction in construction cost in both labour and material for the developer and contractor; and

d) increase in the rentable floor space and the rental income for the owner.

11.7.1.2 The benefits for modernization projects include:

a) increased handling capacity with two lift cabins in one shaft;

b) reduction in waiting time by around 30 percent to 40 percent over the conventional single deck system; and

c) replace single-deck lifts that can no longer handle the building capacity and passenger comfort demands.

Whether used in new buildings or as part of a modernization project, these 2 car systems in one shaft can transport up to 40 percent to 50 percent more passengers.

11.7.2 An overview of the system with 2 separate cabins moving independently inside the shaft is given below:

a) The lift group must be planned as a multiple car system. The cars must operate independently and use the same shaft. The lift cars are arranged one above the other and run independently;

b) Both cars use the same guide rails. The cars can move towards each other and are also able to move away from each other;

c) Each of the 2 lifts has its own drive system and counterweight. Each counterweight runs on its own guide rails. Both lifts have their own safety equipment where required. Both cars use the same landing doors;

d) The suspension of the cars is dependent on the lift speed and travel height. It can be 1 : 1 or 2 : 1;

e) Measures for rope compensation can be designed with compensation chains or belts to reach the required traction. For speeds above 2.5 m/s tensioned compensation rope systems should be used;

f) The call assignments will be undertaken by destination control system. The destination call will be set onto an input station (terminal) in the lobby in front of the lifts or in its proximity. Therefore, pushbuttons for call assignment in the car are not required for passenger use. Hidden COP is provided for fireman or special operation. The cars can serve floors with adequate distance directly above each other;

g) The minimum required safety distance depends on contract speed of the lifts. An independent working safety controller guarantees the prevention of a collision in any operating condition;

h) Depending on the type of suspension and shaft dimensions, the drives are distributed in one, two or three machine room levels; and

j) This system is designed for safety integrity level (SIL) 3 as defined in PESSRAL.

NOTE ð Programmable electronic systems in safety related applications for lifts (PESSRAL) is included in the accepted standard [D-5A(21)].

11.7.3 An overview of the system with 2 cabins joined and mounted one upon the other is given below:

a) The lift group must be planned as a single car system with 2 entrances (upper and lower). The cars are joined to operate simultaneously and use the same shaft.

b) Both cars use the same guide rails, counter-weight rails, landing doors, machine, drive, controller system, rope system and safety equipment.

c) The suspension of the cars is dependent on the lift speed and travel height. It can be 1 : 1 or 2 : 1. The suspension of both cars is same.

d) Measures for rope compensation can be designed with compensation chains or belts to reach the required traction. For speeds above 2.5 m/s tensioned compensation rope system should be used.

e) The call assignments will be undertaken by destination control system (DCS). The destination call will be set onto an input station (terminal) in the lobby in front of the lifts or in its proximity. Therefore, pushbuttons for call assignment in the car are not required for passenger use. Hidden COP is provided for fireman or special operation. Depending on the speed, the drives are distributed in one or two machine room levels.

11.8 Firemanôs Lift

Minimum one number of single deck lift (15 persons, 1 000 kg capacity) serving all floors of the building is to be provided meeting all the requirements as per concerned fire authority such as 1 h fire rated landing doors, minimum speed criteria of travel time less than 60 s for travel from the main lobby to the topmost landing (*see* Fig. 30).

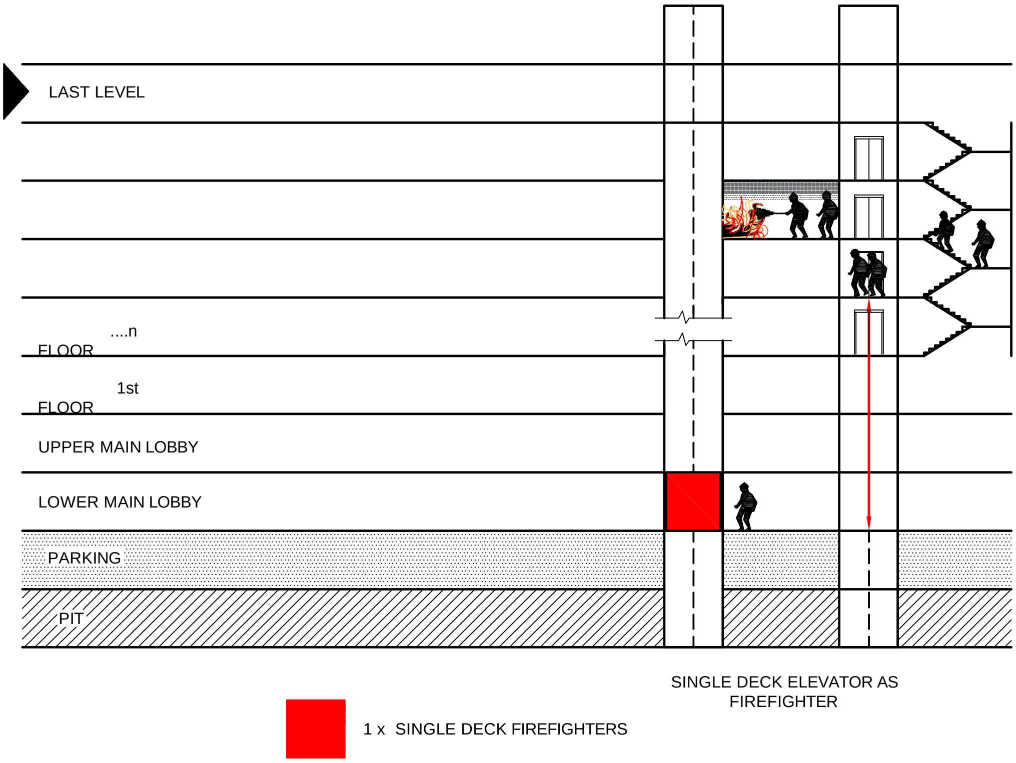
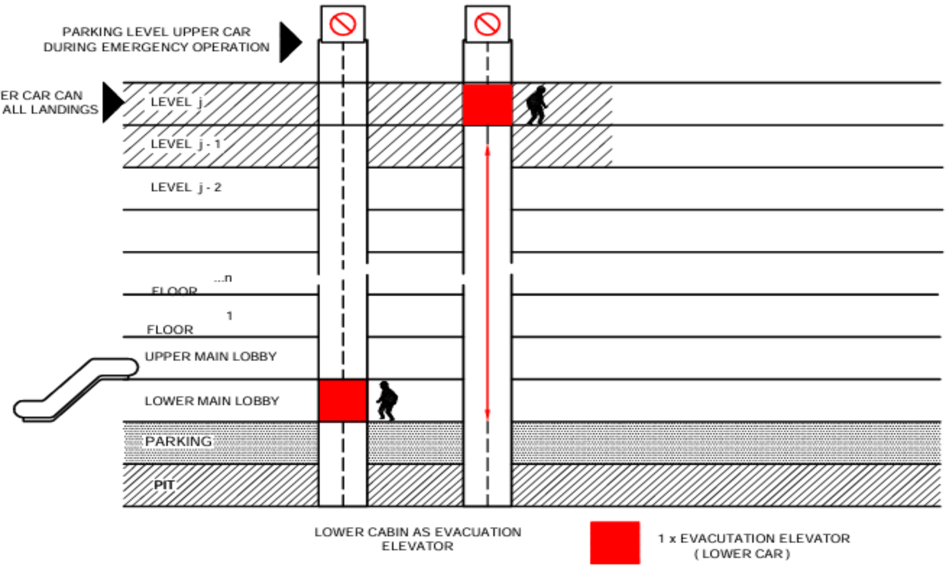

LAST LEVEL
....n
FLOOR
1st
FLOOR
UPPER MAIN LOBBY
LOWER MAIN LOBBY
PARKING
PIT
SINGLE DECK ELEVATOR AS FIREFIGHTER
1 x SINGLE DECK FIREFIGHTERS

FIG. 30 FIREMANôS STRATEGY

11.8.1 *Passenger Evacuation Strategy for* 2 *Cabins Running Independently Inside a Single Shaft*

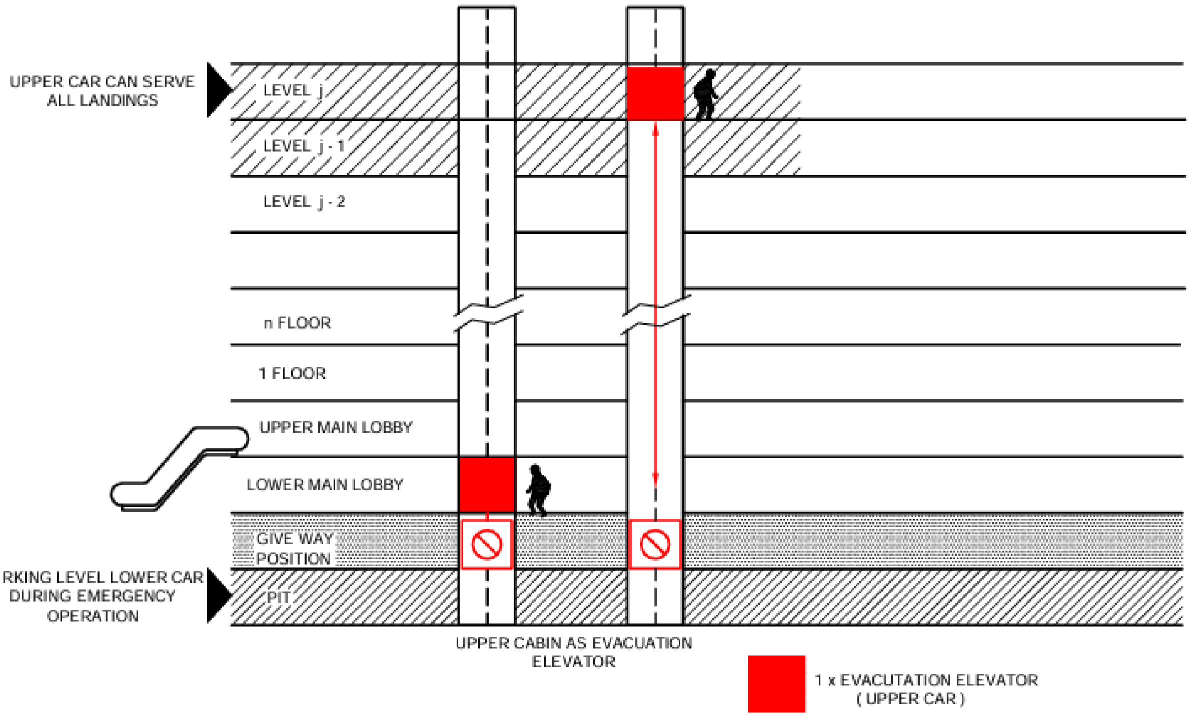
a) Case (I) ð (*see* Fig. 31)


PARKING LEVEL UPPER CAR DURING EMERGENCY OPERATION
LOWER CAR CAN SERVE ALL LANDINGS
LEVEL j
LEVEL j - 1
LEVEL j - 2
...n
FLOOR
1
FLOOR
UPPER MAIN LOBBY
LOWER MAIN LOBBY
PARKING
PIT
LOWER CABIN AS EVACUATION ELEVATOR
1 x EVACUTATION ELEVATOR (LOWER CAR)

NOTE ð OEM to be consulted for suitable depth of the pit.

FIG. 31 GIVE WAY IN LIFT OVERHEAD ROOM FOR UPPER CAR AND OPERATION ONLY WITH LOWER CAR

b) Case (II) ð (*see* Fig. 32)


UPPER CAR CAN SERVE ALL LANDINGS
LEVEL j
LEVEL j - 1
LEVEL j - 2
n FLOOR
1 FLOOR
UPPER MAIN LOBBY
LOWER MAIN LOBBY
GIVE WAY POSITION
PIT
RKING LEVEL LOWER CAR DURING EMERGENCY OPERATION
UPPER CABIN AS EVACUATION ELEVATOR
1 x EVACUTATION ELEVATOR (UPPER CAR)

NOTE ð OEM to be consulted for suitable depth of the pit.

FIG. 32 GIVE WAY IN LIFT PIT FOR LOWER CAR AND OPERATION ONLY WITH UPPER CAR

c) Case (III) ð Without any giveaway, either in pit/overhead, but with 2 firefighter access levels, one on the ground floor (lower main landing), and one on the first floor (upper main landing) so that either of the lifts can be utilized as an evacuation lift.

11.8.2 *Passenger Evacuation Strategy for* 2 *Cabins Mounted One Above the Other and Running Together Inside a Single Shaft*

It can be achieved with 2 firefighter access levels, one on the ground floor (lower main landing), and one on the first floor (upper main landing) so that either of the cabins can be utilized as an evacuation lift.

12 LIFT ENQUIRY OR INVITATION TO TENDER

12.1 General

A period of two to four weeks is normally sufficient for return of tenders. This should be extended, if large numbers of lifts or special requirements are involved.

The enquiry documents should be kept to the essential minimum, and should be strictly confined to material relevant to the lifts works and to the particular project concerned.

When enquiring for and ordering lifts, the particulars given below should be furnished:

a) Type of lift (passenger, goods, service or dumb waiter);

b) Number of lifts required;

c) Capacity/load of lift (s): number of persons (in kg);

d) Rated speed (m/s);

e) Travel (in m) and building height;

f) Floors served (no. of regular openings, emergency openings, blocked openings);

g) Method of control (simplex or group control);

h) Position of machine room (if machine room-less, machine below, hydraulic);

j) Machine room height;

k) Clear overhead/clear top clearance;

m) Pit depth;

n) Sizes of hoist-way (width Ĭ depth), in mm;

p) Position of counterweight;

q) Car size (width Ĭ depth), in mm;

r) Construction, design and finish of car bodywork;

s) Car entrances:
   1) Number of entrances;
   2) Size (width Ĭ height); in mm
   3) Type of door (centre opening, telescopic, 4 panel, vertical bi-parting); and
   4) Whether through opening.

t) Car light;

u) Call indicator;

v) Position indicator in car;

w) Lift landing entrances:
   1) Number of entrances;
   2) Size (width Ĭ height); in mm
   3) Type of door or gates or shutters (for goods lifts) (centre opening, telescopic, 4 panel, vertical bi-parting); and
   4) whether through opening.

y) electric supply:
   1) Power in volts a.c.;
   2) Phase; and
   3) Cycles (wire system).

z) whether neutral wire available for control circuit;

aa) temporary guarding of hoist-way and car cabin;

bb) lighting volts a.c./d.c.;

cc) are premises subject to *Lifts Act and Rules*;

dd) disable friendly requirements [such as voice announcement of floor levels, accessible control panel (good contrast with the background wall, braille, raised letter and font), railing on three sides, two way accessible communication system];

ee) earthquake protection requirements; and

ff) additional items.

12.2 Additional Items

The enquiry should state any additional items required beyond those specified in good practice, such as interface requirements, dismantling of existing lifts, firemanôs control, seismic design consideration, sway/deflection requirements, gravity distortion, etc.

12.3 Finishes

Finishes should be specified at the enquiry stage or provisional sums should be included for them. Finishes to be considered may include interior car finish, false ceiling design, false ceiling lighting, flooring material and weight, blower, ventilation details, car wall cladding details (weight to be considered), multimedia display details (like screen type, size, location, etc), door cladding details, transom details (flushed with the wall, material type, etc). *See also* good practice [D-5A(3)].

12.4 Inclusions and Exclusions

A number of peripheral items are associated with lifts installation, of which some should always be provided by the builder and some are best included by the manufacturer. The requirements vary to some extent with the type of installation.

It is important that the limits of responsibility are clearly understood, and the enquiry documents should be specific in this respect.

The lifts manufacturer should include such items mentioned in **12.1**.

The lifts manufacturer should exclude the supply and fixing of the items or as per the contract conditions as follows:

a) Builder's work such as forming lift well, pit and machine room, and building wall inserts;
b) Machine room floor including any reinforcement necessary for load bearing;
c) Hoisting hook/lifting beam fixing, where necessary;
d) Any necessary tanking, lining or reinforcement of the pit;
e) Diving beams for multiple wells and inter well pit screen (or as per the contract);
f) Trap door;
g) Intermediate beams for bracket fixing;
h) Door cladding (or as per the contract);
j) Cutting away and making good;
k) Working lights/permanent electricity supplies; and
m) Site painting of steel work other than lift material (if any).

For more detailed discussion of the requirements for site preparation and work by other trades, reference should be made to good practice [D-5A(6)] and to other relevant clauses of this Subsection.

Facilities for the use of the main contractor's crane should be provided to assist in installing heavy equipment in addition to other unloading facilities on site in the course of erection.

The main contractor should be instructed to include these facilities in his own quantities.

Where the lift manufacturer agrees to use mobile platforms in place of lift well scaffolding, the general contractor should provide 400/440 V 3-phase and 200/220 V single-phase supply in the lift shaft to operate such equipment, the supply to terminate at the position in the lift well required by the lift manufacturer.

These mobile platforms are limited in use for erection personnel and the transportation of light equipment only, but use of crane will also be necessary to assist in the installation of the heavy machinery and also in the initial installation of the mobile platform equipment.

12.5 Site Programme

The enquiry should indicate as accurately as possible the contract programme as it affects the manufacturer, in particular the target date for completion, construction schedule, site preparedness, the availability of crane for hoisting, coordination details (with other contractors like BMS interfacing, CCTV interfacing, etc).

13 ACCEPTANCE OF TENDER AND SUBSEQUENT PROCEDURE

13.1 General

The procedure indicated below particularly relates to the most usual case, where the lift manufacturer is the sub-contractor.

13.2 Order

The building owner places an order with the selected contractor for supply and installation of lifts. If alternative schemes have been offered, the order should clearly indicate which has been accepted.

13.3 Programme

The contractor shall submit a detailed programme after acceptance of the order showing his intended method, stages of the works, together with the period of time that has been estimated for each and every stage of progress.

The programme shall cover each lift separately, including dates, such as:

a) date of order of equipment and materials;

b) date of commencement and completion of every stage of the works in line with the building construction programme;

c) date of expected completion of builder's work requirements;

d) date of delivery of equipment and materials to site; and

e) date of requirement of temporary and permanent electricity supply and date of completion, commissioning and testing.

The period between order and delivery of material falls into two stages: first the finalizing of details and secondly the actual production of the equipment which depends on the first stage. Within the first stage, other dates may need to be considered, such as:

1) all relevant building information available;
2) submission of lift manufacturer's drawings;
3) approval of drawings; and
4) final selection of finishes.

13.4 Drawings to be Submitted after Placing of Order

The lift manufacturer shall prepare layout drawings based on the civil/structure drawings, order requirements and submit to building owner within mutually agreed time frame. The same shall be briefed to building owner.

The drawings shall indicate clearly the position and sizes of all holes and cuttings, the loads on beams and structures, and all other requirements in relation to óLift Installationô namely:

a) lift machine room and associated equipment, including sub-floor where appropriate;

b) all structural openings, such as landing entrances (including structural dimensions), ventilation openings, etc;

c) all bases, plinths, channels, holes, grouting-in of fixings, etc;

d) lifting beams or other facilities for supporting lifting tackle in the machine room and lift well, permanent means of access to the lift pit;

e) hoisting facilities and access required for delivery of equipment to the machine room, etc;

f) details of structural steelwork for lift machinery in the lift machine room;

g) details of shaft dividing steelwork for supporting guard brackets, etc and inter-well screens/wall for multiple wells; and

h) method of fixing guide rails.

13.5 Approval of Drawings

The building owner should go through the drawings submitted by lift manufacturer and ensure that it is prepared in line with civil/structural drawing and order requirements provided.

If any addition/alteration is noted in the drawing, the same shall be updated in the drawing by the lift manufacturer and resubmitted to the building owner for approval. The drawing shall be approved by building owner, once it has been clearly understood.

13.6 Selection of Finishes

Where the contract provides for the purchaser's choice of decorative finishes, colours, etc, the decisions should be communicated by the purchaser's representative as early as possible, preferably not later than the time of approval of drawings.

13.7 Electricity Power Supply for Lifts

Operation of the machine requires electrical power supply from a comparatively early stage of installation for the most efficient working, and shall be provided accordingly. Whilst temporary supply may be sufficient for erection purposes, the quality of power should be ensured by provider. Final testing and setting up can only be carried out with the permanent power supply. For this reason, the timely provision of the permanent supplies is important.

14 CO-ORDINATION OF SITE WORK

14.1 Preparatory Work on Site

In accordance with the general arrangement drawing for the lift, the representative of the lift company would brief the building owner or his nominated representative about the preparatory work that is required to be carried out before commencement of the lift installation.

The building owner will ensure that the preparatory work is done in accordance with the general arrangement of lift and also the state lift rules are followed for the construction of the lift shaft as well as machine room. Once the preparatory work is completed, the building owner or his nominated representative, will ask the lift company to cross check and see that everything is in order. The lift installation will start after receiving all necessary statutory approvals applicable as per the state laws.

The representative of lift manufacturer shall check the lift shaft and bring the shortfalls, if any, to the notice of the building owner till the preparatory work is completed in compliance with the requirement of lift supplier. The following works shall be completed by the building owner before commencement of lift erection.

14.1.1 *Machine Spaces/Head Room*

a) Adequate ventilation for machine room with rain protected windows or louvers with exhaust fans or air-conditioning system so that the ambient temperature of the machine spaces is maintained between + 5 ÁC and + 40 ÁC (taking into account the heat dissipated by the equipment, ambient temperature, humidity, direct sunlight, air quality and air tightness of buildings due to energy saving requirements);

b) Suitable access door preferably with louvers to machine spaces with RCC steps or mild steel staircase with hand railing (not applicable for MRL);

c) Machine spaces access door shall be of ms, in two panels, hinged type construction, opening outward and clear entrance not less than 1 000 mm wide Ĭ 2 000 mm high with proper locking arrangement. Caution notices of 440V and restricted entry shall be marked on the entrance (not applicable for MRL). A trap door with steel enclosure shall be provided for each machine spaces as per GAD (not applicable for MRL).

d) Hoisting beams/load hooks of required lifting capacity in machine room for machine room lift, one directly above the lift shaft and other directly on top of the trap door as specified in the lift general arrangement drawing. The same shall be provided in the slab in the overhead area for machine room less lifts, as specified by the lift manufacturer in their general arrangement drawing. The safe working load (SWL) shall be specified after certification and tagged on the hook/beam in the machine room/ head room;

e) Machine room slab shall be cast after the slab marking for rope pocket holes is done by manufacturers team. Reinforced concrete machine room slab of 230 mm thickness designed to sustain more than 1 000 kg/sqm uniformly distributed load all over its surface in addition to specific load shown in GAD (not applicable for MRL);

f) Machine spaces walls, floor and ceiling to be treated and painted to minimize accumulation of dust (not applicable for MRL);

g) RCC pedestal for fixing the machine bed frame (not applicable for MRL); and

h) Fire extinguisher shall be provided by building contractor to prevent fire accidents.

14.1.2 *Hoistway*

a) Hoistway dimensions mentioned in the GAD shall have minimum clear plumb dimensions in mm and hence actual wall shall not encroach on these dimensions;

b) Hoistway shall be without any projections and recess from headroom to the pit floor;

c) If any projections or recesses are there, then those shall be flushed and levelled on underside to an angle not less than 60Áfrom the horizontal by means of metal plates or cement;

d) Anything not related to lift equipment like service pipes, ventilation ducts, plumbing and mechanical systems, electrical conduits shall not be allowed to run in lift well and machine room;

e) Front wall at the ground floor and top floor shall not be constructed until all lift equipment is set in position;

f) The thickness of lift walls shall be minimum 230 mm in brick or 150 mm in RCC. The walls shall be constructed in consultation with structural engineers or consultant to verify suitability based on lift load/reactions;

g) In case of brick walls, it would be recommended to have concrete solid block at locations where guide rail brackets are to be installed and in the overhead area in case of MRL Lifts. Similarly, in case of structural shaft suitable ISMC/ISMB shall be provided by the builder to fix guide rail brackets at all bracket fixing levels. The lift manufacturer shall provide a drawing indicating the locations of brackets in the lift shaft;

h) Similarly, for fixing the landing entrances, the builder shall provide RCC lintels/RCC beams for fixing landing door header and sill. In case of structural shaft suitable metallic channels shall be provided in the entrance area at lintel and floor level;

j) The shaft in masonry shall be fully plastered and given two coats of white wash or paint;

k) All the structural shafts shall be completely covered and finished in accordance to the local codes before the start of installation;

m) Suitable cut-outs near the entrance area as indicated in the lift general arrangement drawing shall be provided for fixing human interface system like landing operating panel, floor indicator, hall gong and lantern, emergency alarm, fireman switch and other devices like óTHIS CAR NEXTô, group indicators, etc;

n) Scaffolding (bamboo/steel) shall be erected as required by the lift manufacturer with necessary safety measures;

p) Adequate barricading shall be provided on all the lift entrance openings to avoid mishap;

q) Smoke window with louvers shall be provided below overhead slab in the hoistway as per GAD; and

r) Adequate measures shall be taken to prevent water from seeping into the hoistway at all times.

14.1.3 *Pit*

a) Lift well pit floor and side wall of the lift shaft may be plastered and water proofed. Pit shall be free from any water leakage/seepage and debris. Building owner shall ensure the construction of the pit depth in accordance with the speed of the lift as specified by the manufacturer in the general arrangement drawing;

b) Pit floor shall be strong enough to bear the load reactions as per GAD; and

c) Pedestals shall be provided for fixing car and counterweight buffers to bear the reactions as mentioned in GAD.

14.1.4 *Lighting and Power for Installation*

a) Lift shaft shall be provided with permanently installed electric lighting giving at least 50 lux, 1.0 m above the pit floor and above the pit platform (when provided) everywhere a person may stand, work and/or move between the working areas and at least 20 lux in all other areas, excluding shadows created by car or components, even when doors are closed;

b) The lighting to be protected against mechanical damage;

c) The lighting outside each landing to be provided with 50 lux illumination;

d) Adequate power supply (single phase/3 phase) as required by the lift manufacturer, shall be provided for running winch machine and lift machine for scaffold-less installation; and

e) Double earthing shall be provided in the machine room/control panel as required by the manufacturer.

14.2 Delivery of Material

The delivery of the material shall be made based on mutual agreement of the lift manufacturer and the building contractor. It is strongly recommended that the material should be delivered at site only when a suitable dry, lockable and weather-proof storage area is provided by the building contractor; the building shall be ready for installation as per GAD.

The scope of unloading and stacking materials shall be as per mutually agreed terms between the lift manufacturer and the building contractor. While unloading and shifting of materials due care shall be taken by both the parties to ensure safe unloading and shifting of materials.

Suitable equipment like hydra, fork lift, crane and trolleys shall be used for unloading and shifting of lift materials. Building contractor shall ensure safe passage for vehicles carrying materials, up to the storage area.

14.3 Storage

In order to enable efficient material distribution, it is important that the material shall be unloaded from the delivery truck within a distance of 50 m of the storage/unit location and have proper access from unloading area to storage area. The building contractor shall provide the storage area near the installation site, that is within 20 m distance from the installation site. The minimum storage space per lift shall be 35 m^2 and shall be increased adequately in consultation with the lift company for bigger capacity high speed lifts and tall buildings.

The storage room should be dry, well lit, weather protected and should have locking arrangement and provision of a 16 A power point is recommended. The storage area provided by the building owner should have PCC flooring. The storage room shall be kept ready before arrival of material at site and shall remain in possession of installation engineer till the erection of lift is completed and handed over to the owner.

The material shall be stacked in sequential manner, in accordance with the planned activities. The storage area should be provided at a suitable location near the vicinity of the lift shaft preferably above the ground floor level and should remain in possession of the lift supplier till the installation and commissioning work is completed. It is strongly recommended that the location of the store is not changed to avoid material damages.

14.4 Site Meetings

For the successful progress of the work, full cooperation among all agencies is essential. In large sites, regular meetings of such agencies are beneficial for coordination of work efficiently. Programme for the constructional work in that part of the building containing the lift should be made in consultation among all parties concerned.

14.5 Service of Other Trades

The lift erector will require the services of architect, civil, and electrical contractors, and other agencies as the work proceeds, and it is essential that the lift erector should give due notice to the building contractor of the demands to be made on other trades, so that they may plan accordingly. Mutually agreed, periodic meeting to review work progress with agencies concerned would ensure better coordination and efficiency.

14.6 Scaffolding, Fencing, Wherever Provided

Scaffolds and stationary work platforms shall be erected in accordance with adequate safety under the supervision of a competent person. When used, wooden or synthetic planks shall be scaffold-grade or approved by a qualified person for scaffold and stationary work platform use, and the same shall be capable of withstanding 4 times the working load.

The assembly and disassembly of scaffolds and stationary work platforms shall be done using a safety harness, rope grabber and lifeline as required. All temporary lighting shall be so installed so as not to make any contact with the metal frames of the scaffold. Also, the metallic scaffolding shall be double earthed. Prior to start of any lift installation work, all lift landing shall be barricaded adequately, preferably to full height, with display of warning notices informing presence of persons at work. When scaffold less method of installation is used, certified man-riding rope hoist machine shall be used with double fall protection system.

14.7 System Building Sites

If the building programme allows insufficient time for lift erection in conventional fashion after the well is completely built special procedures are needed. This applies particularly to industrial and multi-storeyed buildings. The building contractor should provide a suitable portable cover to the completed portion of the lift well in order to protect the lift erectors working below against the weather and falling objects.

When the top of the well has been reached it is normal to cap it immediately with a precast load bearing floor slab on to which is lowered the pre-assembled machine room equipment. It then remains for the building contractor to complete and weatherproof the machine room as swiftly as possible. On all such projects the close cooperation between the building contractor and the lift manufacturer is essential.

14.8 Connecting to Power Supply

The lift manufacturer should give prior intimation to the building contractor of the date the power supply to the lift is required, so that suitable arrangements for connection should be made.

15 INSPECTION AND ACCEPTANCE PROCEDURE FOR LIFTS

15.1 Reference

This suggested procedure for inspection of lifts is based on good practice [D-5A(2)], [D-5A(15)] and [D-5A(21)] for the traction lift.

15.2 Purpose

To ensure safe operation of new lifts on their completion and before being placed in service, they need to be subjected to acceptance inspection and tests in the field to determine that installation shall conform to the requirements of applicable standards. An inspection and test shall also be carried out on an existing installation after a major alteration.

15.3 General Requirements

These requirements shall be as follows:

a) *Personal safety*:

  1) Use of relevant personal protective equipment is mandatory by the inspector and his support staff at the time of inspection; and
  2) Work should be stopped and correction(s) arrangement, if unsafe conditions are noticed at the installation.

b) *Safety precautions during inspection*:

  1) Inspectors should have a proper working knowledge of the lifts;
  2) They should always ensure that the car is in his control while working on car roof and pit;
  3) They should at all times be alert of moving objects, and when on top of lift car for moving counter weight, hoist-way projection such as beams, adjacent moving cars, cams and other equipment attached thereto or mounted in the hoist-way;
  4) The overhead clearance should always be noted as number of fatal accidents occurs due to cars running into limited overhead spaces while inspections are made from top of the lift cars;
  5) Inspector should never enter in lift pits containing water;
  6) When working in the lift pit the inspector should always note the position of car; and
  7) Clear distance shall be kept from descending counterweight in the hoist-way of the lift being inspected and those in adjoining hoist-way.

15.4 Description of Installation

The following provides a template of typical description of installation:

Site name with details

Length of travel (mm)

Number of floors served

Total: *

Front: *

Rear: *

Car door: Glass/ SS Landing door: Glass / SS

Rated load

Rated speed m/s *

Lift Type : Passenger/Goods
Machine room/Machine room less/hydraulic

Location of machine room (for MR/ hydraulic lifts)

Give a tick mark in the appropriate box

Above well ☐

Below well ☐

At side ☐

Roping Ratio: ________________

Vendor

Job No:

Purchaserôs identification number

Power supply

Permanent ☐

Temporary ☐

Voltage *

Phase *

Frequency *

Wire (3 or 4) *

MCCB rating *

RCD rating *

Are the above entries acceptable

Yes ☐ No ☐

15.5 Visual and Functional Checks

A typical checklist of visual and functional checks involved in the installation of lifts is given in Annex A.

16 MAINTENANCE OF LIFTS

16.1 Maintenance of the lift essentially covers all necessary operations to ensure safe and intended functioning of the installation and its components after completion of the installation and throughout its life cycle. To this effect, regular maintenance of the installation shall be carried out to ensure the safety of the installation, the ability to be maintained without causing injury or damage to health.

16.2 Information to the Owner of the Installation

16.2.1 The need for the owner to keep the installation in a safe operating condition. To fulfil this, owner shall use a maintenance organization with trained manpower, adequate infrastructure, lift spares and complying with the state requirements.

16.2.2 The need for the owner to take care of any state/local regulations and other requirements, where relevant, and their implications on maintenance.

16.2.3 The need for planned maintenance to be carried out by a maintenance organization, at the latest when the installation is put into service or if the installation is to remain unused for a long period of time, before being put into service first time thereafter.

16.2.4 The importance for the owner of the installation to have the same maintenance organization in the case of several installations having common well/spaces and/or machine room/spaces.

16.2.5 The need for the owner of a passenger/goods-passenger lift to keep the two-way means of communication efficient and linked to a 24 h rescue service for the whole of the time that the installation can be used.

16.2.6 The need for the owner to remove the passenger/goods-passenger lift from service when the two-way means of communication is out of order.

16.2.7 The need for the owner to put the installation out of service in case of dangerous situations.

16.2.8 The need for the owner of the installation to inform the maintenance organization, immediately about any perceived abnormal operation of the installation or abnormal change in its direct environment,

a) immediately after putting the installation out of service in the case of a dangerous situation;

b) after any rescue intervention by their authorized and instructed person(s);

c) before any modification related to the installation and/or its environment;

d) before any authorized third-party inspection or works other than maintenance works are carried out on the installation;

e) before taking the installation out of service for a prolonged period; and

f) before putting the installation back into service after a prolonged period of non-operating time.

NOTE ð The owner of the installation should obtain from the company carrying out the relevant modification, the maintenance instructions for the maintenance organization.

16.2.9 The owner needs to inform the access ways to areas reserved to maintenance persons, the need for the owner of the installation to inform the maintenance organization, about:

a) the access ways to be used and fire evacuating procedures from the building;

b) the place where the keys of the reserved areas can be found;

c) if necessary, the persons who shall accompany the maintenance persons to the installation; and

d) if necessary, personal protective equipment to be used in the access ways and, possibly, where such equipment can be found.

The information shall be made available also on site to the maintenance organization.

16.2.10 The need for the owner of the installation to ensure that the name and the telephone number of the maintenance organization are always available to the user of the installation, permanently affixed and clearly visible.

16.2.11 The need for the owner of the installation to ensure that the keys of machine and pulley room doors (trap doors) and of inspection and emergency doors (trap doors) are permanently available in the building and are used only by persons authorized to gain access.

16.2.12 The need for the owner of the installation to provide, in all circumstances, safe access to the building and to the installation for the maintenance organization involved in the rescue of persons.

16.3 Information to the Owner of the Installation Regarding Self-Monitoring

In addition to those examinations and tests which the owner of the installation entrusts to the maintenance organization, there is a need for the owner to carry out periodically, in their own interests, the following:

a) A full ascent and descent travel to assess any changes in the quality of the ride or damage to the equipment. Typical items to be checked to ensure that they are in place, undamaged and functioning correctly are:
   1) landing doors and bottom door tracks;
   2) stopping accuracy;
   3) indicators that are not located in a reserved area;
   4) landing push controls;
   5) car push controls;
   6) door open controls;
   7) two-way means of communication in the car which provides permanent contact with a rescue service;
   9) normal car lighting;
   10) door reversal device; and
   11) safety signs/pictograms.

b) For goods only and service lifts the checks to be carried out are the same, when relevant.

16.4 Information to the Owner regarding Lift Rescue Operations

The information to the owner shall be inclusive of that given in 16.4.1 to 16.4.5.

16.4.1 The need for person(s) authorized by the owner of the installation to rescue trapped passengers to be trained by the maintenance organization.

16.4.2 The need to ensure that the training is appropriate to the specific installation and updated.

16.4.3 The need to ensure his authorized person(s) rescue people only through landing doors.

16.4.4 The need to ensure that the maintenance organization is called when the owner's authorized person(s) is not able to move the car using the manual and/or electric emergency devices.

16.4.5 The need to inform their authorized person(s) about any condition for which only the maintenance organization shall carry out a rescue operation.

The information required for maintenance of lifts, to be known to the owner of the installation is included, as above detailed maintenance guide for lifts is included in accepted standard [D-5A(22)].

ANNEX A

(*Clause* 15.5)

TYPICAL CHECKLIST OF VISUAL AND FUNCTIONAL CHECKS INVOLVED IN THE INSTALLATION OF LIFTS

A-1 MACHINE ROOM

Sl No.	Requirement	Result	Remarks
(1)	(2)	(3)	(4)
i)	There shall be easy access from the top landing to the machine room	Accessible/Not accessible	
ii)	Steps along with handrail for the access to machine room to be provided	Provided/Not provided	
iii)	Machine room access door of M.S, in two panels, hinged type construction, opening outward and clear entrance not less than 1000 mm wide Ĭ 2000 mm high	Provided/Not provided	
iv)	Caution notice of 440 V and restricted entry marked on the entrance	Displayed/Not displayed	
v)	Locking arrangement provided and machine room shall be kept locked	Provided/Not provided	
vi)	The machine room used for the purpose of lift machinery only	Yes/No	
vii)	Machine room walls, floor and ceiling treated and painted to minimize accumulation of dust	Yes/No	
viii)	Machine room shall be maintained clean, without any seepage of water from roof, walls or any other opening	Yes/No	
ix)	The height of the machine room shall not be less than 2 100 mm at working areas	Yes/No	
x)	Machinery spaces and pulley rooms provided with permanently installed electric lighting with an intensity of at least 200 lux at floor level everywhere a person needs to work and 50 lux at floor level to move between working areas	Provided/Not provided	
xi)	Adequate ventilation for machine room with rain protected windows or louvers with exhaust fans or air-conditioning system so that the ambient temperature of the machine room is maintained between + 5 °C and + 40 °C	Yes/No	
xii)	Are the rope openings below the machine closed adequately as required	Yes/No	
xiii)	The hoisting beams or hooks are certified as per the safe working load required and marked	Provided/Not provided	

Sl No.	Requirement	Result	Remarks
(1)	(2)	(3)	(4)
xiv)	Trap door with metal cover to be provided to lift the machine to/or from the machine room and to be located vertically below the hook provided in the machine room ceiling	Provided/Not provided	
xv)	Rescue chart pasted in the machine room with proper identification	Yes/No	

A-2 POWER SUPPLY

Sl No.	Requirement		Result	Remarks
(1)	(2)		(3)	(4)
i)	Incoming power supply to be 415 V Ñ 10 percent or as specified in the contract agreement		R-Y : _________ Y-B : _________ R-B : _________ Ok/Not Ok	
ii)	Neutral ð Earth voltage	Idle condition within (0 to 3) V	Value: _______ Ok/Not Ok	
iii)	Neutral ð Earth voltage	Running condition within (0 to 3) V	Value: _______ Ok/Not Ok	
iv)	Separate supply with MCB	Three phase supply	Provided/Not provided	
		Single phase supply (for car lighting and hoistway lighting)	Provided/Not provided	
v)	Check whether the power cables are connected with lugs for termination		Connected/Not connected	
vi)	The correct capacity main switch (with lock out tag out provision) with protective device, provided as per the requirement, separately for lift power, light for machine room and hoistway. Three pin sockets with switch provided		Provided/Not provided	
vii)	Double grounding conductor of correct size is provided on the main switch. Earthing of lift motor, control panel, overspeed governor switch, etc provided		Provided/Not provided	
viii)	Hoistway lighting provided at least 50 lux,1 m above the pit floor and above the pit platform (when provided), everywhere a person can stand, work and/or move between the working areas and at least 20 lux in all other areas, excluding shadows created by car or components, even when doors are closed		Provided/Not provided	

Sl No.	Requirement	Result	Remarks
(1)	(2)	(3)	(4)
ix)	Residual current protective device (RCD) with rated residual operating current not exceeding 30 mA (not applicable to main drive) provided	Provided/Not provided	

A-3 MACHINE AND BRAKE ASSEMBLY (FOR TRACTION LIFTS)

Sl No.	Requirement	Result	Remarks
(1)	(2)	(3)	(4)
Make:	*Sl No.*:	*Rating*: _________________	
i)	The motor is smooth in operation without overheating	Satisfactory/Unsatisfactory	
ii)	The gear box (if provided) is smooth and without any oil leakage except little oozing	Satisfactory/Unsatisfactory	
iii)	The condition of machine grooves is such that the ropes/CSB do not slip when the traction sheave stops normally	Satisfactory/Unsatisfactory	
iv)	Is the machine fixation as per the installation manual	Yes/No	
v)	Are the electrical connections of the machine routed and well tightened	Yes/No	
vi)	Are the machine isolation pads installed correctly (if applicable)	Yes/No	
vii)	Ropes/elastomeric coated steel belts fixed by suspension means in the machine room are fixed as required and locked with nuts and split pins.	Yes/No	
viii)	Clear vertical distance of at least 300 mm is available above rotating equipment	Yes/No	
ix)	The lift provided with braking system which operates automatically in the event of loss of: a) the main power supply b) the supply to the control circuits	Provided/Not provided	
x)	The machine, governor, etc, identified with the correct contract number	Yes/No	
xi)	The manual brake release device is available and easily accessible	Yes/No	
xii)	Guards provided for moving parts such as machine sheave, etc to protect against pinching hazard	Provided/Not provided	

A-4 CONTROLLER

Sl No.	Requirement	Result	Remarks
(1)	(2)	(3)	(4)
Type:	*Sl No.*:	*Wiring drawing No*:	
i)	The controller fixed as per the GAD (general arrangement drawing)	Yes/No	
ii)	The controller identified with the correct contract number	Yes/No	
iii)	The controller should have an easy access to open and close with lock	Yes/No	
iv)	The required warning stickers pasted	Provided/Not provided	
v)	All extra cables neatly arranged	Yes/No	
vi)	Are the battery terminals covered	Yes/No	
vii)	The field and controller wiring properly routed	Yes/No	
viii)	The control panel wiring is neatly grouped and the insulation of wires is not more than one Mega Ohm with 500 volt megger	Yes/No	
ix)	Logbook maintained in up-to-date condition	Maintained/Not maintained	

A-5 OVER SPEED GOVERNOR

Sl No.	Requirement	Result	Remarks
Make:	*Model*:	*Sl No*:	*Tripping speed*:
i)	Is the correct over speed governor provided and installed as per layout	Yes/No	
ii)	The sticker/painted indication represents the down direction of rotation which will facilitate the safety gear actuation	Yes/No	
iii)	Check whether the OSG is calibrated and sealed	Yes/No	
iv)	The governor is aligned, and the rope passes through the holes without any obstruction	Yes/No	
v)	The governor rope runs free is not in contact with any object in the hoist way	Yes/No	
vi)	The governor tripping mechanism is free and clean	Yes/No	
vii)	The electrical switch is provided and operates in both the directions	Yes/No	
viii)	All fixation bolts are provided and adequately tightened	Yes/No	

A-6 GENERAL INSPECTION ON CAR ROOF

Sl No.	Requirement	Result	Remarks
Instructions before entering to the car top: a) *Allow the lift to move in down direction from the top terminal landing with no load* b) *Stop the lift from the controller by changing to maintenance mode, such that easy access to enter the car top from the top terminal landing* c) *Switch on the shaft lighting* d) *Use the door open key to open the top terminal landing door* e) *Switch on the car top stop switch from the landing to enable the 'STOP' mode* f) *Switch on the light on car top* g) *Switch to maintenance mode from the car top before entering the car top* h) *Put Stop switch to Run position and press UP/DN and common button to move the car UP or down in maintenance speed*			
i)	Car top guard rail on car roof to be provided of 0.70 m where the distance between car and hoistway wall is > 0.30 m and < = 0.50 m; is 1.10 m where the distance exceeds 0.50 m and not required if the distance is < 0.30 m	Provided/Not provided	
ii)	The car roof has been provided with toe board of 100 mm and non-slip working area	Provided/Not provided	
iii)	Car roof has sufficient strength to resist a minimum force of 2 000 N at any position on an area of 0.30 m Ĭ 0.30 m without permanent deformation	Yes/No	
iv)	Lighting with proper protection is provided on the car roof of at least of 50 lux intensity, 1.0 m above the car roof	Provided/Not provided	
v)	Emergency light on car top with minimum intensity of 20 lux for 1 h operation and alarm initiation device provided	Provided/Not provided	
vi)	Wires and trunking are properly routed and does not hinder with any maintenance related equipment	Yes/No	
vii)	The car fan/blower is properly fixed with isolation	Yes/No	
viii)	Three pin plug sockets with switch is available and is in working condition	Yes/No	
ix)	The emergency stop switch is positioned not more than 0.75 m from the landing	Yes/No	
x)	Check whether the top car clearance meets the requirement Value required: ________________	Value measured: ______ Ok/Not Ok	
xi)	Overhead dimension in W Ĭ H Ĭ D Value required: ________________	Value measured: ______ Ok/Not ok	
xii)	If overhead height is less, then the indication to be provided with zebra painting in the overhead	Provided/Not provided	

Sl No.	Requirement	Result	Remarks
xiii)	Floor levelling switches are fixed as per requirement	Yes/No	
xiv)	Rope/CSB hitches on car roof are fixed as required and locked with nuts and split pins	Yes/No	
xv)	Car sheave; if available; is adequately guarded from accidental contact	Yes/No	
xvi)	The junction box is fixed securely and all wires are adequately protected	Yes/No	
xvii)	The car shoe liners/rollers are fixed as per requirement and adjusted properly	Yes/No	
xviii)	Oil tank are provided and fixed with proper oil levels	Yes/No	
xix)	Engagement of the car door coupler with the landing door at every landing	Ok/Not ok	
xx)	Engagement of shaft limit switches	Ok/Not ok	
xxi)	The governor rope and linkage is correctly connected to the car	Yes/No	
xxii)	The guide rail clips are fixed as per requirements and in the correct directions	Yes/No	
xxiii)	The safety gear assembly and connecting rod should be free from external disturbances	Yes/No	
xxiv)	The safety switches have been verified for correct operation during travel	Yes/No	
xxv)	The safety gear linkages is checked for operation and actuation of switches	Yes/No	
xxvi)	Clearance between the car door coupler and the landing sill to be as per the manufacturer design at every landing	Ok/Not ok	
xxvii)	Clearance between the landing rollers with the car sill to be as per the manufacturer design at every landing	Ok/Not ok	

A-7 PIT INSPECTION

Sl No.	Requirement	Result	Remarks
Instructions before entering to the pit: a) *Allow a person on the car top and ask him to move the lift to the topmost landing* b) *Open the bottom terminal landing door with door open key* c) *Switch on the pit stop switch from outside the pit* d) *Enter into the pit using ladder or from access door*			
i)	It should be clean and dry	Yes/No	

Sl No.	Requirement	Result	Remarks
ii)	Pit access door to be provided, if pit depth exceeds 2 500 mm. Either an access door or a ladder inside the well to be provided, where pit depth does not exceed 2 500 mm	Pit depth = mm Pit access door/ Ladder provided/ Not provided	
iii)	Oil trays are available at the bottom of each guide rail	Provided/Not Provided	
iv)	Pit stop switches to be provided, accessible from the lowest landing. When pit depth > = 1.6 m, two pit switches, one accessible from lowest landing and other from pit floor to be provided	Provided/Not Provided	
v)	Pit stop switches to be verified with the electrical circuit such that lift should not move further after the activation of pit stop switches	Ok/Not OK	
vi)	Inspection control station is permanently installed in the pit. If more than one inspection control station is switched to óInspectionô, it shall not be possible to move the car from any of them, unless the same push buttons on the inspection control are operated simultaneously	Provided/Not Provided Ok/Not Ok	
vii)	Counterweight screen should be provided and fixed, except where rope compensation sheave is provided	Provided/Not Provided	
viii)	Buffers provided for bottom limit of travel of car and counterweight are correctly fixed and not in bent condition. PU buffers not to be in degenerated condition	Ok/Not Ok	
ix)	The governor tension pulley is fixed at the correct height from the pit floor as per the manufacturer recommendation	Ok/Not Ok	
x)	The electrical switch for the tension pulley is verified, if provided	Ok/Not Ok	
xi)	Check whether the bottom car clearance meets the requirement Value required: ______________________	Value measured: ______ Ok/Not Ok	
xii)	Pit lighting to be provided of at least 50 lux,1 m above the pit floor and above the pit platform (when provided), everywhere a person can stand or work	Ok/Not ok	
xiii)	Refuge space to be provided in the pit and signage readable from entrance, indicating allowed number of persons and type of posture to be provided	Provided/Not provided	
xiv)	Is the travelling cable below car secured and correctly fixed and the excess cable is not secured below car	Ok/Not ok	

Sl No.	Requirement	Result	Remarks
xv)	The travelling cable is adjusted and clear of the pit floor with the car at the lowest position	Ok/Not ok	
xvi)	The bottom guide shoes or rollers are fixed as per requirement and adjusted for smooth travel	Ok/Not ok	
xvii)	The car safety gear is properly adjusted as per the installation manual	Ok/Not ok	
xviii)	The compensation chain fixing arrangement is fixed as per requirement	Ok/Not ok	

A-8 EARTHING

Sl No.	Requirement	Result	Remarks
(1)	(2)	(3)	(4)
i)	Separate earth bar to be provided in the machine room	Provided/Not provided	
ii)	Earthing to be done for all controllers and the machine	Yes/No	
iii)	Earthing to be done for the shaft equipment and car top components	Yes/No	
iv)	Earthing from controller to car top components to be linked through the travelling cable	Yes/No	
v)	Routing of the earth from the controller to the main earth bar	Ok/Not ok	
vi)	Connection of the lift earth bar to main earth bar	Ok/Not ok	

A-9 INSPECTION FROM THE LIFT CAR

Sl No.	Requirement	Result	Remarks
(1)	(2)	(3)	(4)
Instructions: a) *No one should be present in the pit as well as on the car top* b) *Make sure the lift is normal mode* c) *Enter the lift car from any of the landing*			
i)	Car inside width Value required: ______________________	Value at site: ________ Ok/Not Ok	
ii)	Car inside depth Value required: ______________________	Value at site: ______ Ok/Not Ok	

Sl No.	Requirement	Result	Remarks
(1)	(2)	(3)	(4)
iii)	Height below false ceiling Value required: ______________________	Value at site: ________ Ok/Not Ok	
iv)	Door opening width Value required: ______________________	Value at site: ________ Ok/Not Ok	
v)	Door opening height Value required: ______________________	Value at site: ________ Ok/Not Ok	
vi)	Car capacity to be displayed inside the lift car	Yes/No	
vii)	Safety warning plate to be displayed (*see* Note)	Yes/No	
viii)	Functioning of car display	Functioning/ Not functioning	
ix)	The stopping accuracy of the car shall be ± 10 mm. If during loading and unloading levelling accuracy of ± 20 mm is exceeded, shall be corrected to ±10 mm	Ok/Not Ok	
x)	DO button and DC button functional check: For power operated door: 1) Press the DO button at level - Door should open 2) Press the DO button during running - Door should not open 3) While closing press the DO button at level - Door should open 4) DC button at level when the door is in open condition - Door should close	Functioning/ Not functioning	
xi)	*For manual operated door:* 1) Lift should not move if any of the door car/landing in open condition 2) If door is opened during run, lift should stop and should not move further	Functioning/ Not functioning	
xii)	Car alarm functions even though there is no power supply to the lift	Functioning/ Not functioning	
xiii)	Functioning of intercom (*see* Note)	Functioning/ Not functioning	
xiv)	Functioning of car call buttons and landing call buttons (*see* Note)	Ok/Not ok	

Sl No.	Requirement	Result	Remarks
(1)	(2)	(3)	(4)
xv)	Provision of fan/blower and its operations	Provided/ Not provided	
xvi)	Provision and working of permanently installed cabin lights that are continuously illuminated except when the car is parked with doors closed. Illumination shall be 100 lux	Provided/ Not provided	
xvii)	Emergency light provided shall come on automatically upon failure of the normal car lighting supply. Shall be capable of illumination intensity of at least 20 Lux for 1 h	Provided/ Not provided	
xviii)	Provided with ventilation apertures on the upper and lower parts of the car with imperforate car doors	Provided/ Not provided	
xix)	Doors are verified for smooth opening and closing at each level	Ok/Not Ok	
xx)	Riding comfort ð No appreciable jerk shall be noticed at the time of travelling, stopping/starting in the car	Ok/Not OK	
xxi)	Car door protective device shall automatically initiate re-opening of the power operated car door(s) in the event of person crossing the entrance during the closing movement	Ok/Not OK	
xxii)	Lift should not move for any safety failure	Ok/Not Ok	
xxiii)	Provision of grab bars inside the lift car (*see* Note)	Provided / Not provided	
xxiv)	Provision of buffer rail (applicable only for service lifts) at the rear panel of the lift car	Provided / Not provided	

NOTE ð Lifts open to public use shall also be inspected for requirements as per good practice [D-5A(3)], including those relating to lift closing time, finishes of interior surfaces, etc.

A-10 INSPECTION FROM THE FLOOR LANDINGS

Sl No.	Requirement	Result	Remarks
(1)	(2)	(3)	(4)
i)	Provision and functioning of landing door de-locking at every landing	Functioning/Not functioning	
ii)	Condition of landing door at every floor	Ok/Not ok	
iii)	Functioning of landing display at every floor	Functioning/Not functioning	
iv)	Functioning of landing call button	Functioning/Not functioning	
v)	Functioning of duplex/group operation at every landing (if applicable)	Functioning/Not functioning	

A-11 RESCUE OPERATIONS

Sl No.	Requirement	Result	Remarks
(1)	(2)	(3)	(4)
i)	Is the automatic rescue device (ARD) installed and operating as per the instructions	Yes/No	
ii)	An audio-visual indicator is provided inside the lift car to alert the passenger(s) trapped inside the car that the lift is on emergency power or there is a mains power failure and they are being rescued	Yes/No	
iii)	Is the stopping accuracy of ± 40 mm achieved during the automatic rescue operation	Yes/No	
iv)	ARD operate in case of failure of any one phase, or any two phases or all the three phases. It also operates during phase reversals (in non-VF type lifts where phase failure relays are installed)	Yes/No	
v)	Emergency light is at least operational till the end of the ARD operation)	Yes/No	

A-12 FIRE OPERATION

Sl No.	Requirement	Result	Remarks
(1)	(2)	(3)	(4)
i)	Phase I a) When the fireman switch is activated, all the landing calls to be inoperative and the car shall report to the evacuation floor and the lift doors to be in opened condition b) If the lift is moving away from the evacuation floor, then it shall reverse its direction at the nearest floor landing without opening its door, and return back to the evacuation floor and remains there itself with the doors open	Functioning/ Not functioning	
ii)	Phase II (if applicable) a) It will be started once after the completion of Phase I along with the fireman switch in ON position b) In Phase II, lift should not respond to landing call and when the car call button is pressed, the door should start closing. If the button is released before the full close of doors, then the doors should open automatically c) After the full close of door, the lift should move on to the floor of registered car call d) The doors should only open if the open button is pressed after reaching the level. If the open button is released before the full open, then the doors should reclose automatically	Functioning/ Not functioning	

A-13 INSPECTION FOR HYDRAULIC LIFTS

Sl No.	Requirement	Result	Remarks
(1)	(2)	(3)	(4)
Instructions before inspecting hydraulic lift: a) *Do not open or tighten the parts of a pressurized system* b) *Make sure that the energy source has been locked and tagged before starting the work* c) *Ensure that there is no pressure* d) *The car must be at the lowest position* e) *The piston must be at the bottom* f) *The shut-off valve must be closed* g) *Press the emergency lowering valve to release all system pressure*			
a)	Check that the oil level in the tank covers the motor-pump system (minimum 20 mm over the motor) when the cylinder is in upper end position and the oil level is 70/80 mm under the tank edge, when the cylinder is in lower extra travel position	Found Ok/Not ok	
b)	Check visually the connection pipe sealing, the joints of the flexible hoses and rigid pipes	Found Ok/Not ok	
c)	Check the rapture valve intervention by loading the car with rated load uniformly distributed and over-speeding the descending car	Found Ok/Not ok	
d)	Is the oil temperature, same as room temperature after the rapture valve intervention	Ok/Not ok	
e)	Check protection against accidental operation of emergency lowering valve	Ok/Not ok	
f)	When the main shut off valve is closed, activating the hand pump, the pressure on the manometer has to increase up to the adjusting valve	Ok/Not ok	
g)	Check the provision of motor thermistor	Provided/Not provided	
h)	Any abnormal noise during normal drive, both in UP and DN direction travel	Ok/Not ok	
j)	Check the working of electrical anti-creep system	Ok/Not ok	
k)	Emergency lowering with battery backup provided and working	Provided/Not provided	
m)	At least one electrically retractable pawl is provided, designed in its extended position to stop the downward moving car against fixed supports	Provided/Not provided	
n)	Check visually, the integrity of the hydraulic system after applying 200 percent full load pressure applied between the non-return valve and the jack for 5 min (observe for any leakage/drop in pressure)	Ok/Not ok	

A-14 SAFETY DEVICES

Sl No.	Requirement	Result	Remarks
(1)	(2)	(3)	(4)
Instructions: a) *The lift is in idle condition and the following safety devices get activated, then it should not move further* b) *If the lift is in running condition and the following safety devices get activated, then the lift shall stop and should not move further*			
i)	OSG ð Over speed governor	Functioning/ Not functioning	
ii)	Car door contact	Functioning/ Not functioning	
iii)	Landing door contact	Functioning/ Not functioning	
iv)	Car top stop switches	Functioning/ Not functioning	
v)	Pit stop switches	Functioning/ Not functioning	
vi)	Functioning of screen sensors and door safety edge: 1) Door should reopen, if we cut the screen 2) Door should reopen, if it hit any object	Functioning/ Not functioning	
vii)	Check whether the car and counterweight buffers installed as per the requirement	Yes/No	
viii)	Functioning of limit switches so as lift should not travel beyond the limit	Functioning/ Not functioning	
ix)	Brake on its own shall be capable of stopping the machine when the car is travelling downward at rated speed and with the rated load plus 25 percent	Ok/Not Ok	
x)	Ascending car overspeed Protection provided to detect overspeed of the ascending car and cause the car to stop or at least reduce its speed	Functioning/Not functioning	
xi)	Provision to prevent or stop unintended car movement away from landing with landing door not in the locked position and the car door not in the closed position. Stopping distance shall not exceed 1.20 m from the landing where the unintended car movement has been detected	Functioning/ Not functioning	
xii)	Safety gear test: 1) Lift car safety gear to be tested in down direction with 100 percent rated load in the lift car (during maintenance it shall be tested only in inspection speed), with test tripping arrangement 2) If provided, counterweight safety gear to be tested in up direction of lift car with no load with test tripping arrangement	Stopping distance: ________ Ok/Not ok	

Sl No.	Requirement	Result	Remarks
(1)	(2)	(3)	(4)
	3) Lift stopping distance depends upon the tripping speed of the governor and shall be within the range as per the Indian Standard		

A-15 STOPPING ACCURACY AND RUNNING CLEARANCE TEST

Instructions:

a) *The stopping accuracy shall be within ±10 mm of the finished floor level*

b) *The running clearance between the lift car threshold and landing door sill should be 35 mm*

No. of floors: ____________________

Floors (Landing)	Stopping Accuracy		Running Clearance		
	UP	DN	LH	Centre	RH
1st					
2nd					
3rd					
4th					
5th					
6th					
é					
é					
Result Ok/Not ok					

A-16 LOAD TEST

Sl No.	Load in Percent	Direction of Travel	Voltage	Current
			V	A
(1)	(2)	(3)	(4)	(5)
Instructions: a) *With balanced load, the current value in both the up and down directions to be same* b) *Check the current only after the lift reaches its rated speed*				
i)	No load	UP		
		DN		
ii)	Balance load	UP		
		DN		
iii)	Full load	UP		
		DN		

LIST OF STANDARDS

The following list records those standards which are acceptable as ógood practiceô and óaccepted standardsô in the fulfilment of the requirements of this NBCS. The latest version of a standard shall be adopted at the time of enforcement of this NBCS. The standards listed may be used as a guide in conformance with the requirements of the referred clauses in this NBCS.

	IS No.	*Title*
(1)	IS 17900 (Part 1) : 2022	Lifts for the transport of persons and goods: Part 1 Safety rules
(2)	IS 17900 (Part 2) : 2022	Lifts for the transport of persons and goods: Part 2 Design rules calculations examinations and tests of lift components
(3)	IS 4963 : 2025	Accessibility in built environment for older adults and persons with disabilities ð Requirements (*second revision*)
(4)	IS 12615 : 2018	Line operated three phase a.c. motors (IE Code) óefficiency classes and performance specification (*third revision*)
(5)	IS 1950 : 1962	Code of practice for sound insulation of non-industrial buildings
(6)	IS 14665 (Part 2/Sec 1 and Sec 2) : 2000	Electric traction lifts: Part 2 Code of practice for installation, operation and maintenance, Section 1 Passenger and goods lifts, Section 2 Service lifts
(7)	IS 15105 : 2021	Design and installation of fixed automatic sprinkler fire extinguishing systems ð Code of practice (*first revision*)
(8)	IS 732 : 2019	Code of practice for electrical wiring installations (*fourth revision*)
(9)	IS 3043 : 2018	Code of practice for earthing (*second revision*)
(10)	IS 17518 (Part 2) : 2021/ ISO 3008-2 : 2017	Fire-resistance tests: Part 2 Lift landing door assemblies
(11)	IS/IEC 60529 : 2001	Degrees of protection provided by enclosures (IP Code)
(12)	IS 17805 (Part 20) : 2024 ISO 8102-20 : 2022	Electrical requirements for lifts escalators and moving walks: Part 20: Cyber security
(13)	IS 14665 (Part 3/Sec 1 and Sec 2) : 2000	Electric traction lifts: Part 3 Safety rules, Section 1 Passenger and goods lifts, Section 2 Service lifts
(14)	IS 2551 : 1982	Danger notice plates (*first revision*)
(15)	IS 15785 : 2007	Installation and maintenance of lifts without conventional machine rooms ð Code of practice
(16)	IS 15259 : 2002	Installation and maintenance of home lifts ð Code of practice
(17)	IS 15330 : 2020	Requirements of lifts for persons with disabilities (*first revision*)
(18)	IS 17900-7-7	Lifts for the transport of persons and goods: Part 7 Lifts for special applications, Section 7 Lifts under seismic conditions (*under prepration*)
(19)	IS 17615 (Part 1) : 2021/ ISO 18738-1 : 2012	Measurement of ride quality : Part 1 Lifts elevators

	IS No.	*Title*
(20)	IS 17106 (Part 1) : 2019/ ISO 22201-1 : 2017	Lifts (elevators), escalators and moving walks — Programmable electronic systems in safety-related applications: Part 1 Lifts (elevators) (PESSRAL)
(21)	IS 17900 (Part 5) : 2026	Lifts for the transport of persons and goods: Part 5 Guide for inspection of lifts
(22)	IS 17900 (Part 6) : 2022	Lifts for the transport of persons and goods: Part 6 Guide for maintenance of lifts

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NATIONAL BUILDING CONSTRUCTION STANDARDS

PART D BUILDING SERVICES

SECTION 5 INSTALLATION OF LIFTS, ESCALATORS, MOVING WALKS AND POWER-DRIVEN PARKING SYSTEMS

5B ESCALATORS AND MOVING WALKS

BUREAU OF INDIAN STANDARDS

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FOREWORD

This NBCS (Part D/Subsection 5B) covers the requirements for planning and design, installation, operation, maintenance, and inspection of escalators and moving walks to ensure safe movement of people with satisfactory performance.

This Section was first published in 1970 and was subsequently revised in 1983, 2005 and 2016 as a part of National Building Code of India. This Section covers the requirements for installation of lifts and escalators in buildings. This Section should be read with Part F 'Fire and Life Safety' of this NBCS from fire safety requirements point of view. The major changes in the first revision of 1983 were addition of outline dimensions of different types of lifts and detailed requirements of escalators in buildings. Emphasis was laid on coordination between the engineer/architect and the lift manufacturer to arrive at the number and position of lifts for attaining optimum efficiency in serving the building with safety.

The significant changes with respect to lifts incorporated in the 2005 revision, included the addition of new clauses/recommendations on the building management system; addition of new clauses on fireman's lift, infrared light curtain, safety and Braille button for blind people and updation of provisions as per the revised standards on lifts on which this Section was based.

In the 2016 revision, the erstwhile Section 5 on lifts and escalators was divided into two Subsections namely:

a) 5A Installation of lifts; and

b) 5B Installation of escalators and moving walks.

This Subsection 5B addresses exclusively the provisions related to the installation of escalators and moving walks, which have been increasingly provided in buildings. It covers comprehensive provisions on all aspects, including requirements for planning and design, installation, operation, maintenance, and inspection of escalators to ensure the safe movement of people with satisfactory performance. This Subsection also covers the provisions on moving walks.

In this revision, this publication has been renamed as National Building Construction Standards (NBCS).

As a result of technical developments in the subject of escalators and moving walks, the experience gained since implementation of 2016 version of this NBCS and feedback received as well as the revision of related Indian Standards on the subject, a need was felt to revise this Subsection. The significant modifications made in this revision of the subsection include amongst others, the following key changes:

a) The terminology has been updated addressing maintenance aspects and electrical safety system.

b) The requirements of power supply including protection devices have been elaborated, in **6.5.3**.

c) Fire protection requirements for the installations have been elaborated, in **7**.

d) Technical requirements for outdoor escalators/moving walks and semi- outdoor escalators/moving walks have been included in **9.2** and **9.3**.

e) Inspection check list has been revised, under **14.6.2**.

f) Annex A on typical escalator site checklist/inspection list has been considerably revised.

g) Annex B on typical check list for functional tests on safety switches and devices has been revised.

The information contained in this Subsection is largely based on the following Indian Standards/Special Publications:

IS 732 : 2019	Code of practice for electrical wiring installations (*fourth revision*)
IS 3043 : 2018	Code of practice for earthing (*second revision*)

IS 4591	Escalators and moving walks:
(Part 1/Sec 1) : 2020	Safety requirements (*first revision*)
(Part 1/Sec 2) : 2020	Guide for planning and selection (*first revision*)
(Part 1/Sec 3) : 2020	Inspection and test (*first revision*)
(Part 2) : 2022	Guide for maintenance
CEA : 2023	Central Electricity Authority Regulation: 2023
SP 30 : 2023	National Electrical Code of India 2023

All standards, whether given herein above or cross-referred to in the main text of this Subsection, are subject to revision. The parties to agreement based on this Subsection are encouraged to investigate the possibility of applying the most recent editions of the standards.

Assistance has also been derived from the following publications in the revision of this Subsection:

> IBC 2024 International Building Code, International Code Council, Washington, USA
>
> CIBSE Guide D : Transportation Systems in Buildings, 2025, The Chartered Institution of Building Services Engineers, London, U.K.
>
> EN 115-1 : 2017 Safety of escalators and moving walks — Part 1: Construction and installation

As the regulation of land development and buildings is a State subject and is dealt by the States and local bodies such as urban local bodies within their jurisdiction through building regulatory documents like building regulations, building byelaws, and fire regulations, this document is voluntary in nature and is non-binding. The implementation depends on adoption by concerned parties or stipulations in a contract or by appropriate adoption by the concerned authorities.

For deciding whether a particular requirement of this Subsection is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 'Rules for rounding off numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this Subsection.

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Important Explanatory Note for Users of this NBCS

In any Part/Section of this NBCS, where reference is made to **'good practice'** in relation to design, constructional procedures or other related information, and where reference is made to **'accepted standard'** in relation to material specification, testing, or other related information, the Indian Standards listed at the end of the Part/Section shall be used as a guide to the interpretation.

At the time of publication, the editions indicated in the standards were valid. All standards are subject to revision and parties to agreements based on any Part/Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

In the list of standards given at the end of a Part/Section, the number appearing within parentheses in the first column indicates the number of the reference of the standard in the Part/Section. For example:

a) Good practices [D-5B(1)] refers to the Indian Standard(s) referred to in serial number (1) of the list of standards given at the end of this Part/Subsection, that is, SP 30 : 2023 'National Electrical Code of India 2023', IS 732 : 2019 'Code of practice for electrical wiring installation (*fourth revision*)', IS 3043 : 2018 'Code of practice for earthing (*second revision*)'.

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART D BUILDING SERVICES

SECTION 5 INSTALLATION OF LIFTS, ESCALATORS, MOVING WALKS AND POWER-DRIVEN PARKING SYSTEMS

5B ESCALATORS AND MOVING WALKS

1 SCOPE

1.1 This NBCS (Part D/Subsection 5B) covers the essential requirements for planning, installation, operation, maintenance, and inspection of escalators and moving walks to ensure safe movement of people with satisfactory performance.

1.2 This Subsection gives information that should be exchanged among the architect/engineer, the consulting engineer and escalator/moving walk manufacturer from the stage of planning to installation including maintenance.

2 TERMINOLOGY

For this Subsection, the following terms and definitions apply.

2.1 General Terms Relating to Escalators and Moving Walks

2.1.1 *Angle of Inclination* — Maximum angle to the horizontal in which the steps, the pallets, or the belt move.

2.1.2 *Operational or Service Brake* — Brake that usually acts on motor shaft and used to stop an escalators/moving walk under all normal conditions or under certain fault conditions.

2.1.3 *Balustrade* — Part of the escalator/moving walk which ensures the user's safety by providing stability, protecting from moving parts and supporting the handrail.

2.1.4 *Balustrade Decking* — Transverse member of the balustrade which meets the handrail guidance profile, and which forms the top cover of the balustrade.

2.1.5 *Brake Load* — Load on the step/pallet/belt for which the brake system is designed to stop the escalator/moving walk.

2.1.6 *Comb* — Pronged section at each landing that meshes with the grooves of the steps/pallets.

2.1.7 *Comb Lighting* — Small flush light panels located in the skirt panels on both sides of the escalators/ moving walk unit at both upper and lower landing and immediately adjacent to the comb teeth to illuminate the comb and step tread and assist passengers boarding and alighting the escalators/moving walk.

2.1.8 *Comb Plate* — Platform at each landing to which the combs are attached.

2.1.9 *Comb Plate Switch* — Switch in safety circuit that opens when excessive force is detected in vertical and/or horizontal direction on the comb or comb plate of escalators/moving walk.

2.1.10 *Comb Teeth* — Series of teeth which ride the grooves of the escalators/moving walk step tread as the step passes underneath and are designed to allow them to break-off if a wedging action should occur at their point of contact with step tread.

2.1.11 *Auxiliary or Emergency or Safety Brake* — Mechanically operated brake which operates automatically to stop a fully loaded escalator if the drive chain breaks. It is typically situated on one side of the main drive shaft.

2.1.12 *Emergency Stop Switch* — Separate stop button usually located in adjacent walls, columns or within the balustrade providing the facility to stop the escalator/moving walk, in the event of emergency.

2.1.13 *Inspection Door* — Means of access to equipment areas and other spaces pertaining to an escalators/moving walk installation such as machinery spaces, etc, and with access usually restricted to authorized persons.

2.1.14 *Electrical Safety Devices* — Part of a safety circuit consisting of safety switches and/or fail-safe circuits.

2.1.15 *Escalator* — Power-driven, inclined, continuous moving stairway used for raising or lowering persons in which the user carrying surface (for example, steps) remains horizontal.

NOTE — Escalators are machines even when they are out of operation and shall not be considered or used as fixed staircases.

2.1.16 *Exterior Panel* — Part of the exterior side of the enclosure of an escalator or moving walk.

2.1.17 *Handrail* — Power-driven moving rail for persons to grip while using the escalator or moving walk.

2.1.18 *Interior Panel* — Panel located between the skirting or lower inner decking and the handrail guidance profile or balustrade decking.

2.1.19 *Lower Inner Decking* — Profile that connects the skirting with the interior panel when they do not meet at a common point.

2.1.20 *Lower Outer Decking* — Profile that connects the exterior panels with the interior panel.

2.1.21 *Machinery* — Escalator or moving walk machine(s) mechanisms and associated equipment.

2.1.22 *Machinery Spaces* — Space(s) inside or outside of the truss where the machinery as a whole or in parts is placed.

2.1.23 *Maximum Capacity* — Maximum flow of persons that can be achieved under operational conditions.

2.1.24 *Moving Walk* — Power-driven installation for the conveyance of persons in which the user carrying surface remains parallel to its direction of motion and is uninterrupted (for example, pallets, belt).

NOTE — Moving walks are machines even when they are out of operation and shall not be considered or used as a fixed access.

2.1.25 *Newel* — End of the balustrade.

2.1.26 *Nominal Speed* — Speed in the direction of the moving steps, pallets, or the belt, when operating the equipment under no load condition (that is, without persons), stated by the manufacturer as that for which the escalator or moving walk has been designed.

NOTE — Rated speed is the speed the escalator/moving walk moves under rated load conditions.

2.1.27 *Pit* — Recess in the floor to receive that portion of the lower landing and the lower end of the incline section which occurs below the floor line when there is no floor under the escalator such as in a basement.

2.1.28 *Rated Load* — Load which the equipment is designed to move.

2.1.29 *Rise* — Vertical distance between the upper and lower finished floor levels.

2.1.30 *Safety Circuit* — Part of the electric safety system consisting of electrical safety devices.

2.1.31 *Skirting* — Vertical part of the balustrade interfacing with the steps, pallets, or belt.

2.1.32 *Skirt Deflector* — Device to minimize the risk of trapping between the step and the skirting.

2.1.33 *Electrical Safety System* — Safety related part of the electrical control system as an arrangement of safety circuits and monitoring devices.

2.1.34 *Maintenance* — All the necessary operations to ensure the safe and intended functioning of the installation and its components after the completion of the installation, throughout its life cycle. *See* **15.1** for details.

2.1.35 *Maintenance Organization* — Company or part of company where competent maintenance person(s) carry out maintenance operation on behalf of the owner of the installation.

2.1.36 *Competent Maintenance Person* — Designated person, suitably trained, qualified by knowledge and practical experience, provided with necessary instructions, and supported within their maintenance organization to enable the required maintenance operations to be safely carried out.

2.1.37 *Manufacturer* — Entity who takes responsibility for the design, manufacture and placing on the market the machinery of escalators or moving walks.

2.1.38 *Installer* — Entity who takes responsibility for the design, manufacture, installation and placing on the market of escalator/moving walk.

2.1.39 *Installation* — Completely installed escalator or moving walk.

2.1.40 *Owner of the Installation* — Person who has the power of disposal of the installation and/or takes the responsibility for its operation and use.

2.2 Terms Related to Performance Requirements of Escalators and Moving Walks

2.2.1 *Acceleration* — Rate of change of velocity. It is expressed in m/s^2.

2.2.2 *Ride Quality* — Sound levels and vibration of the steps/pallet, relevant to passenger perception, associated with escalator or moving walk operation.

2.2.3 *Sound Pressure Level* (L_p) — Ten times the logarithm to the base 10 of the ratio of the square of the sound pressure to the square of the reference sound pressure.

NOTE — The reference sound pressure level is 20 µPa (2×10^{-5} Pa).

2.2.4 *Velocity* — Rate of change of displacement. Velocity is reported as speed and direction of travel. It is given in metre per second (m/s).

2.2.5 *Vibration* — Variation with time of the magnitude of acceleration. It is expressed in metre per second square (m/s^2).

3 GENERAL

3.1 Conformity with Act and Rules

3.1.1 The installation of escalators and moving walks has been governed in states by different Acts and Rules, as applicable, which are intended to ensure safe installation and operation of the same.

3.1.2 The installation shall be generally carried out in conformity with relevant Act and Rules wherever they are in force.

3.1.3 It is the responsibility of the owner of the premises where the escalators and moving walks will be installed, to obtain necessary permission from the Authority before and after the erection of escalators and moving walks and for their subsequent operation.

3.1.4 A license for public use is a safety provision issued by state authorities under applicable Act and Rules, wherever they are in force.

3.2 Conformity with *Indian Electricity Act* and Rules

All electrical work in connection with installation of escalators and moving walk shall be carried out in accordance with the provisions of *Electricity Act,* 2003 Central Electrical Authority (Measures relating to Safety and Electric Supply) Regulations, 2023 and accepted standards [D-5B(1)] as amended up to date along with the rules and regulations framed thereunder and shall also comply with the other provisions of Part D 'Building Services, Section 2 Electrical and Allied Installations' of this NBCS.

3.3 Conformity with Indian Standards

All materials, fittings, appliances, etc, used in electrical installation shall conform to Indian Standard specifications, wherever these exist. In case of materials for which Indian Standard specifications do not exist, the materials shall be approved by the competent authority. The installation shall be according to best practices as in the accepted standards [D-5B(1)].

3.4 Conformity with Fire Regulations

The installation shall be carried out in conformity with the state fire acts/local fire regulations, wherever they are in force *See also* Part F 'Fire and Life Safety' of this NBCS for guidance purpose.

3.5 Safety Design Considerations and Selection of Escalator and Moving Walks

The design consideration for type and selection of escalator and moving walk shall be based on following criteria:

a) *Location* — To ensure reliability, it is important to have design specifications to suit environmental conditions;

b) *Physical Requirements* — Physical factors like the vertical and horizontal distance to be spanned shall be considered. The ability of the building infrastructure to support the heavy components is also a critical physical concern;

c) *Type of Segment and Traffic Patterns* — The design consideration depends on segment type. Some typical segments are transit systems like metro, airport, shopping malls, hotels, etc. Traffic patterns shall also be anticipated in escalator and moving walk design. The carrying capacity of an escalator system shall match the expected peak traffic demand;

d) *Safety Considerations* — Escalators and moving walks shall not be subjected to abuse, misuse, and negligence. There are a few potential hazards, both from escalators and moving walks themselves and those hazards that users may bring with them, which include loose clothing, type of footwear (especially soft footwear), carried goods and trolleys. The severity of these hazards may increase when used by vulnerable groups of people, such as the old, very young and those with impaired mobility. Proper design risk assessment and control are all critical to ensure reliability and, above all safety; and

e) *Aesthetic Preferences* — To be suitably decided between the parties concerned.

3.6 Maintenance

The considerations relating to maintenance shall be as follows:

a) The escalator or moving walk installation should receive regular cleaning, lubrication, adjustment, and adequate servicing by authorized competent persons at such intervals as the type of equipment and frequency of service demand. It is desirable and normal for the escalator or moving walk supplier to be entrusted with the servicing during the guarantee period of new equipment;

b) In order that the escalator or moving walk installation is always maintained in a safe condition, a proper maintenance schedule shall be drawn up in consultation with the manufacturer and rigidly followed. Provision of a logbook to record all items relating to general servicing and inspection is recommended. Any accident arising out of operation or maintenance shall be duly reported to the Authority in accordance with the rules laid down;

c) Escalators and moving walks are required by statutory regulations to be examined at regular intervals as specified by Acts and Rules, by a competent person. The company entrusted with maintenance contract shall have valid license to maintain the escalators and moving walks. The persons assigned for maintenance work shall be appropriately qualified and experienced as required by statutory Acts and Rules;

d) Companies and organizations responsible for the safe use of escalator and moving walks should ensure that their employees are adequately instructed and informed about the safe use of the escalator or moving walk and the hazards arising from their unsafe use and are familiar with emergency procedures; and

e) Proper barricading shall be done to ensure that the open pits of escalator shall be reached/accessed by only the maintenance team. The maintenance service provider shall be responsible for placing of the barricades and signages before start of the maintenance work.

3.7 Energy Efficiency and Sustainability

The following technologies shall be encouraged for reducing power consumption by using energy efficient equipment and behavioural changes:

a) As an option, escalators/moving walk should not run when there are no passengers to move. In this stop mode, only the control system and the passenger detection system are kept running. Another option is to reduce the speed to match the passenger demand, thus reducing energy consumption using variable voltage variable frequency (VVVF) drives, which provide very smooth, almost imperceptible speed transitions;

b) Energy saving LED lamps for lighting in place of conventional lamps;

c) Improvement in total power factor of the motor drive of an escalator or moving walk at the isolator connecting equipment to the building's electrical supply circuit; and

d) Adoption of materials and practices that are environmentally friendly and sustainable shall be promoted.

4 DESIGN GUIDELINES FOR ESCALATORS AND MOVING WALKS

4.1 Escalators are desirable where the movement of people, in large numbers at a controlled rate in the minimum of space, is involved, for example, railway stations, shopping centres/malls, airports, etc. These encourage people to circulate freely and conveniently. Inclined moving walks are preferable where trolley movement is expected between levels, like department stores, airport, etc.

Typically, horizontal moving walks are used where medium to long distance travel is involved such as airports/metro stations/exhibition halls.

4.2 As the escalators and moving walks operate at a constant speed, serve only two levels, and have a known maximum capacity, the traffic study is rather easy, provided the population to be handled in a given time is known. It is easy to predict the rate at which the population can be handled.

Depending on the location of project and the expected tenancy, architect/owner shall provide the expected footfall in weekdays/weekends/special occasions (holidays, sale, etc) to the designer to consider the peak footfall while providing escalators.

Figure 1 shows the brief idea about the steps to be followed for arriving at appropriate escalator and moving walk solution for an application.

Based on Fig. 1, type, and location of building, expected population, and the serving floor details are required to work on the preliminary traffic analysis for escalators and moving walks.

For selection, installation and location of escalators and moving walks, the design of escalators and moving walks fall into four distinct duty categories, as shown in Table 1.

When deciding the duty category, following points shall be considered:

a) The duration and magnitude of peak demands that the equipment might be subjected to; and

b) The number of passengers using the escalators or moving walks per day.

NOTE — Select an escalator or moving walk appropriate for intended duty. If in doubt specify a more robust escalator or moving walk, as applicable.

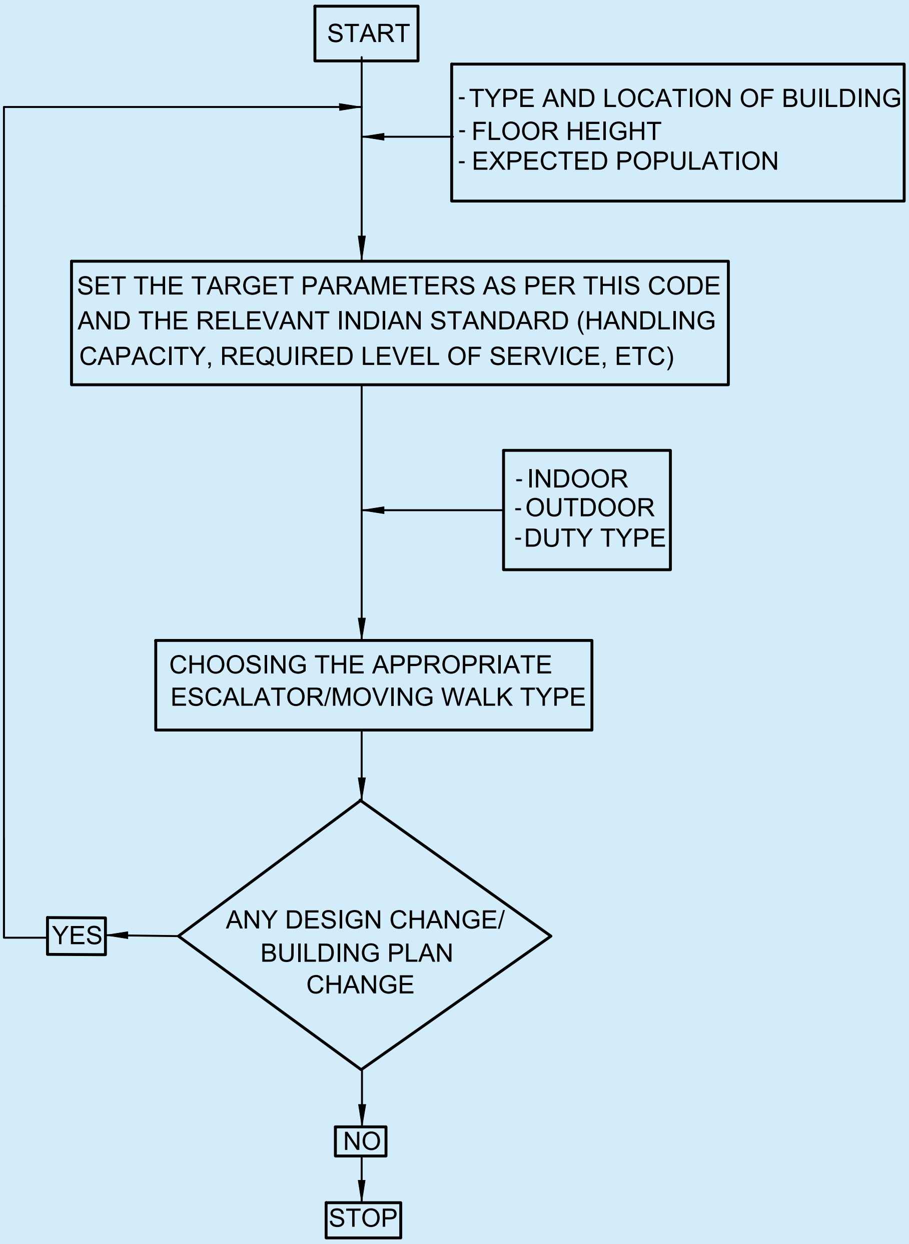

START
- TYPE AND LOCATION OF BUILDING
- FLOOR HEIGHT
- EXPECTED POPULATION
SET THE TARGET PARAMETERS AS PER THIS CODE AND THE RELEVANT INDIAN STANDARD (HANDLING CAPACITY, REQUIRED LEVEL OF SERVICE, ETC)
- INDOOR
- OUTDOOR
- DUTY TYPE
CHOOSING THE APPROPRIATE ESCALATOR/MOVING WALK TYPE
ANY DESIGN CHANGE/ BUILDING PLAN CHANGE
YES
NO
STOP

FIG. 1 TYPICAL FLOWCHART ON PRELIMINARY DESIGN

Table 1 Escalator Duty Categories

(*Clause* 4.2)

Sl No. (1)	Duty Category (2)	Typical Usage (Passengers/Day) (3)	Typical Locations (4)
i)	Light	Up to 3 000	Shops, museums, libraries, leisure facilities and multiplexes
ii)	Medium	Up to 10 000	Department stores, shopping centres, domestic airports and railway stations
iii)	Heavy	Up to 20 000	Major railway and metro stations, major international airports and critical locations such as underground railway systems
iv)	Intensive	Over 20 000	Same as heavy category, but at a higher usage

4.3 The most common rated speed of escalators is 0.5 m/s although speeds of 0.65 m/s and 0.75 m/s are available. Most escalators run at one speed only, although some escalators running in energy saving mode can switch to the higher speed on traffic detection.

Step widths of 600 mm, 800 mm and 1 000 mm for escalators are available, the latter allowing two columns of passengers to be carried.

Angle of inclination of an escalator from the horizontal shall not exceed 30°, but for rises not exceeding 6 m and rated speed not exceeding 0.5 m/s the angle of inclination is permitted to be increased up to 35°.

The rated speed of the escalator shall not exceed:

a) 0.5 m/s for an escalator with an angle of inclination of more than 30° but within 35°; and

b) 0.75 m/s for an angle of inclination up to 30°.

For normal peak periods, the recommended handling capacities for design purposes should be taken as 3 200 to 6 400 persons per hour depending upon the width of the escalator.

The number of persons that may be theoretically carried by the escalator in 1 h can be calculated as follows:

1) The density factor (k) considers the step occupancy levels according to step width. For determination of theoretical capacity, it is assumed that one step with an average depth of 0.4 m can carry 1 person for a step width of 0.6 m, 1.5 persons for a step width of 0.8 m and 2 persons for a step width of 1.0 m;

2) The theoretical capacity then is: 3 600 × (rated speed in m/s × k)/0.4

   where

   k = 1, 1.5, or 2 for 0.6, 0.8 and 1.0 m step widths respectively.

c) Some values calculated as per the above are given in Table 2:

Table 2 Theoretical Escalator Handling Capacity

(*Clause* 4.3)

Sl No.	**Step/Pallet Width** m	**Nominal Speed** m/s		
		0.5	0.65	0.75
		Persons/hour	Persons/hour	Persons/hour
(1)	(2)	(3)	(4)	(5)
i)	0.6	4 500	5 850	6 750
ii)	0.8	6 750	8 775	10 125
iii)	1.0	9 000	11 700	13 500

4.4 The handling capacity (C_e) of a standard escalator with a step depth of 400 mm is: $C_e = 150\ V\ k$

where

V = speed along the incline in m/s; and

k = average density of people (persons per escalator step).

The density factor (k) considers the step occupancy levels. From experience, practical values of k that have been found satisfactory are:

a) For 600 mm steps:

k = 0.5 (one person per two steps of 600 mm);

b) For 800 mm steps:

k = 0.75 (one and half persons per two steps of 800 mm); and

c) For 1000 mm steps:

k = 1.0 (one person per step of 1 000 mm).

Table 3 gives guidance to practical escalator handling capacities based on the densities assumed above in person per hour and horizontal speeds in meters per second.

Table 3 Practical Escalator Handling Capacity

(*Clause* 4.4)

Sl No.	Step/Pallet Width m	Nominal Speed m/s 0.5 Persons/hour	0.65 Persons/hour	0.75 Persons/hour
(1)	(2)	(3)	(4)	(5)
i)	0.6	2 250 [3 600*]	2 925 [4 400*]	3 375 [4 900*]
ii)	0.8	3 375 [4 800*]	4 388 [5 900*]	5 063 [6 600*]
iii)	1.0	4 500 [6 000*]	5 850 [7 500*]	6 750 [8 200*]

*IS 4591 values are shown in parentheses, which assumes passenger densities averaging k = 0.75, 1.00, 1.25 respectively and suggests maximum values.

4.5 Moving walks can be horizontal or inclined. Horizontal moving walks are typically used for medium/long range travel in airports, exhibition centres and railway stations. Inclined moving walks are typically used for short range travel in shopping centres, stores and railway stations.

Inclinations range from 6° to 12°, although the safest maximum inclination is generally considered to be 10°. The typical running speeds for horizontal moving walks are 0.5 m/s, 0.65 m/s and 0.75 m/s. For moving walks with an inclination greater than 6°, the nominal speed shall be limited to 0.5 m/s. The speed is measured in the direction of movement of the pallets.

Nominal widths for moving walks up to an inclination of 6° are 800 mm, 1 000 mm and 1 400 mm and above 6° are 800 mm and 1 000 mm. A width of 1 400 mm allows two columns of passengers and the possibility for some passengers to walk along the moving walk.

The use of suitably designed shopping trolleys and baggage carts on moving walks is permitted. Shopping trolleys or baggage carts which are chosen for use on a moving walk shall be specified between the baggage cart manufacturer and the moving walk manufacturer. If non-specified shopping trolleys or baggage carts are available in the moving walk area, there is a serious risk of misuse. It is necessary to prevent access to the moving walk entrance. The width of the shopping trolley or baggage cart and its contents shall be at least 400 mm less than the nominal pallet/belt width. Passengers shall be able to leave the moving walk, even if shopping trolleys or baggage carts are on the moving walk.

Table 4 provides the theoretical values of handling capacity in person per hour of a moving walk.

4.6 Table 5 gives guidance to practical moving walk handling capacities in person per hour assuming a density of 2.0 persons/m^2.

Table 4 Theoretical Moving Walk Handling Capacity

(*Clause* 4.5)

Sl No.	**Pallet Width** m	**Horizontal Moving Walk (0° Inclination)**			**Inclined Moving Walk For (Nominal Speed 0.5 m/s**		
		Nominal Speed (m/s)			Inclination		
		0.5	0.65	0.75	6°	10°	12°
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	0.8	3 000	3 700	4 400	3 000	3 700	3 000
ii)	1.0	3 800	4 600	5 400	3 700	3 700	—
iii)	1.4	5 100	6 400	7 700	5 100	—	—

Table 5 Practical Moving Walk (Horizontal and Inclined) Handling Capacity

(*Clause* 4.6)

Sl No.	**Step/Pallet Width** m	**Nominal Speed** m/s		
		0.5 Persons/hour	0.65 Persons/hour	0.75 Persons/hour
(1)	(2)	(3)	(4)	(5)
i)	0.8	2 880 [4 800*]	3 648 [5 900*]	4 320 [6 600*]
ii)	1.0	3 600 [6 000*]	4 560 [7 300*]	5 400 [8 200*]
iii)	1.4	5 000 [--------*]	6 350 [-------*]	7 560 [-------*]

*IS 4591 values are shown in parentheses.

NOTES

1 Use of shopping trolleys and baggage carts will reduce the capacity by approx. 80 percent.

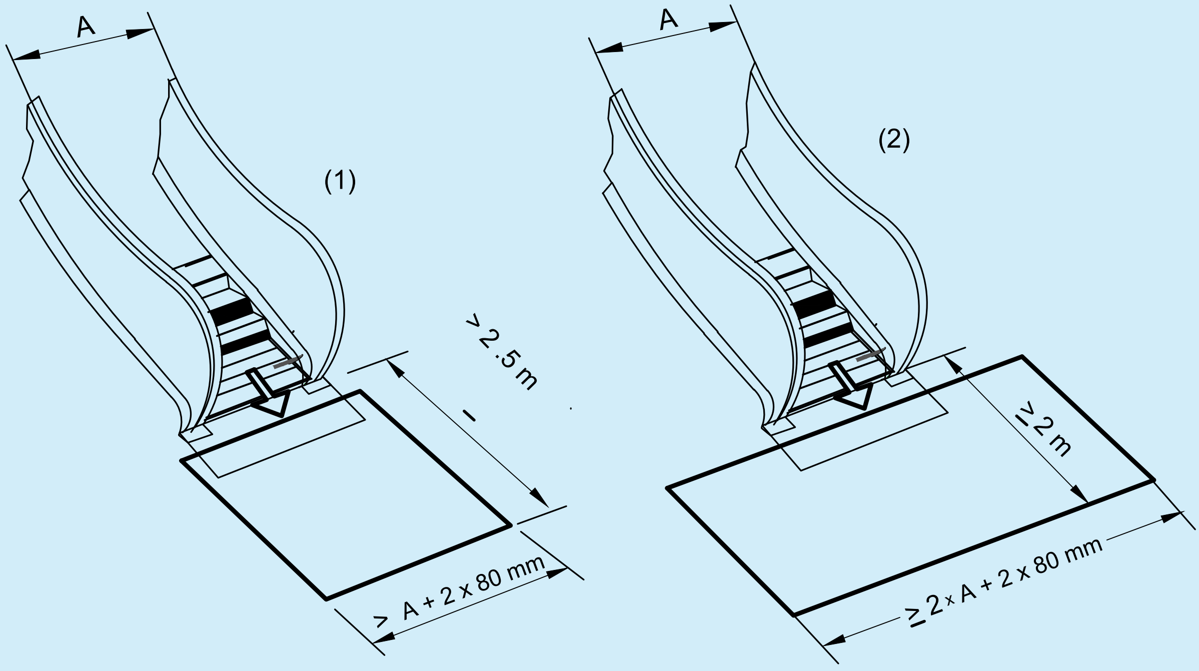
2 For moving walks with a pallet width in excess of 1.0 m the capacity is not increased as users need to hold the handrail, the additional width is to principally enable the use of shopping trolleys and baggage carts.

5 ARRANGEMENT AND PLANNING DIMENSIONS

5.1 Escalators are typically used for short range of movement between adjacent floors. They are usually situated in an obvious circulation path making it easy for pedestrians to board them. Escalators and moving walks should only be accessed from adjacent corridors/walkways, landing and lobby areas, where people do not obstruct other pedestrian circulation routes. Space should be available to accommodate queuing at the boarding point.

It is especially important that the boarding and alighting areas adjacent to an escalator or moving walk are not part of another circulation route, to provide a safe area for passengers to board and alight at landings. The area of this space is defined as a distance between the handrails plus 160 mm, multiplied by a depth of 2.0 m to 2.5 m, depending on the configuration of escalator or moving walk.

Figure 2 illustrates the above clause with option 1 being a 2.5 m landing depth and option 2 being 2.0 m landing depth. Where successive units are installed, each successive escalator or moving walk should have its own individual unrestricted area. For succeeding escalators and moving walks the depth of an unrestricted area shall be determined in each individual case depending on, for example, type of use (persons only or persons with transport devices, number of intermediate exits, relative orientation, and theoretical capacity).



(2 A)

(2 B)

Key

A = Distance between outer edge of handrail

Option 1 >> unrestricted area >= 2.5 m from end of balustrade and width >= A+(2*80) mm

Option 2 >> unrestricted area >= 2.0 m from end of balustrade and width >= (2*A) +(2*80) mm

FIG. 2 UNRESTRICTED FREE SPACE

Where the exit of the escalator or moving walk is blocked by structural measures (for example shutters, fire protection gates, removable barriers), an additional STOP button for emergency situations shall be provided:

a) within reach from inside the escalator/moving walk at 2.00 m to 3.00 m before the steps/pallets reach the comb intersection line; and

b) Between 200 mm below and 400 mm above the handrail, measured from the top of the handrail to the middle of the actuator of STOP button.

NOTE — STOP button shall be with protection to prevent nuisance activation for example shroud guard. STOP switch with cover is not permitted.

Figure 3 illustrates the position of additional STOP button.

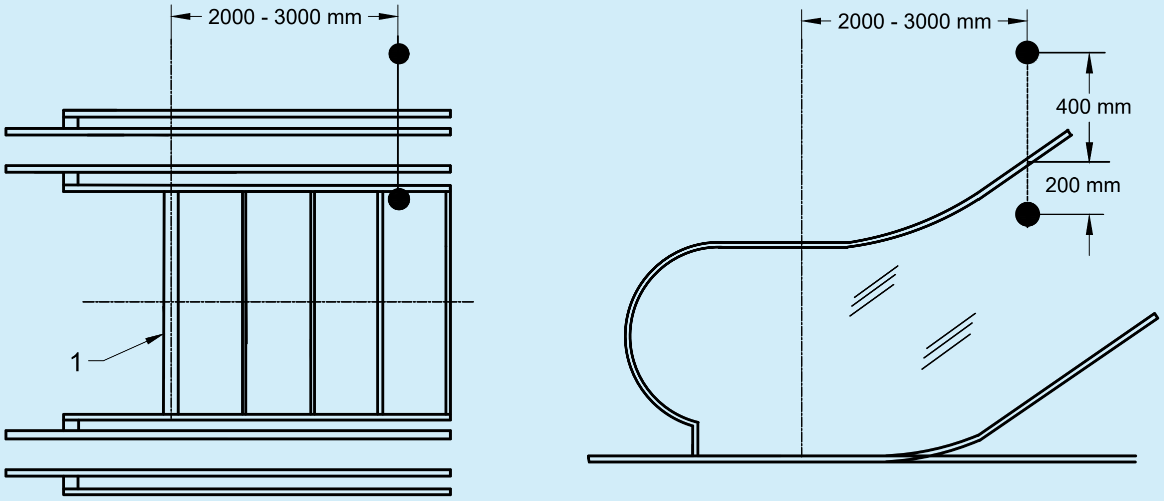


FIG. 3 LOCATION AND DISTANCE OF ADDITIONAL STOP BUTTON

The position of the shutters, fire protection gates, removable barriers, etc shall be protected with a contact in the safety circuit. As soon as the doors close, the escalator or moving walk should stop.

Escalators occupy more space than stairs to accommodate their inclination. There are few standard escalator arrangements as shown in Fig. 4. Type (a) and type (b) provide efficient circulation by providing the shortest transition path and time from one escalator and the next. Type (b) requires larger structural opening than type (a) and type (c) and present users with a higher risk of falling into the void. Type (c) is typical of a store as it allows the store to lengthen the circulation route past goods for sale. This configuration also takes up free space.

Some moving walks are adopted to receive and lock on shopping/baggage trolleys. In these cases, the unrestricted area at the landing should be increased to at least 5 m and number of flat/horizontal steps at the boarding and alighting points increased. The most significant effect is the increased footprint required for the equipment. Shopping/baggage trolleys are not permitted on escalator.

To encourage pedestrian confidence and to assist efficient and safe boarding/ alighting of escalators, the start and end of escalator should present a few horizontal/flat steps. At least two flat steps are provided for escalators speeds up to 0.5 m/s; at least three flat steps for speeds above 0.5 m/s and up to 0.65 m/s for escalator having rise more than 6 m; and at least four flat steps for speeds above 0.65 m/s. In locations where it is anticipated that escalators may be used by persons with impaired mobility or heavy passenger traffic, additional flat steps should be considered.

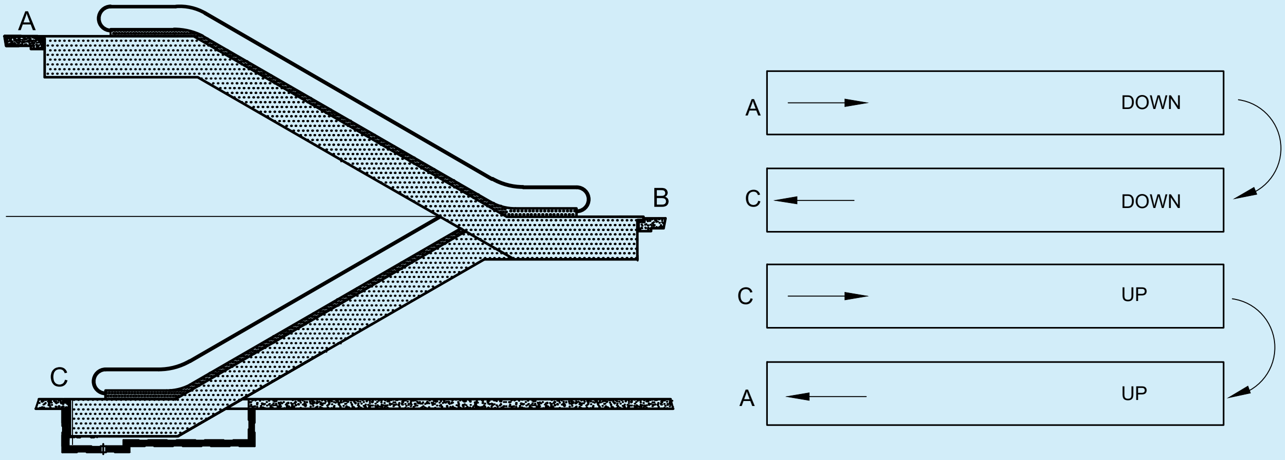
5.2 Ensuring Accessibility for All Users

5.2.1 The accessibility requirements shall be complied with.

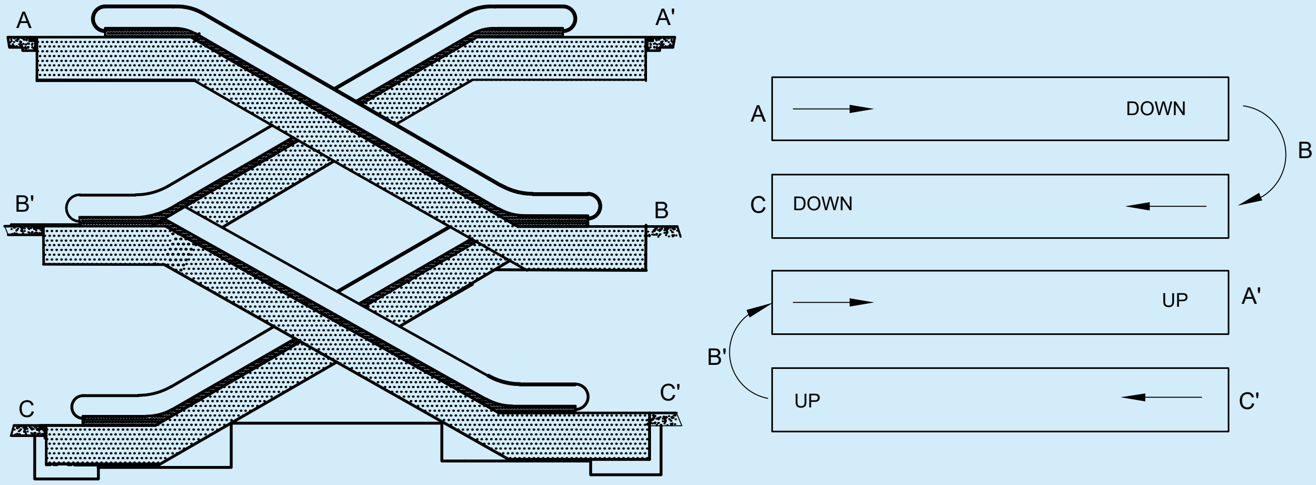
5.2.2 The location of escalators and moving walks should be considered in relation to the position of adjacent fire protected lift shafts and lobbies, staircases, and their associated areas of rescue assistance, as at the time of an emergency these become non-functional. A surface of the escalator and moving walks should contrast visually with the approach and there should be audible signals or pre-recorded messages that indicate the start and finish of the escalator to help visually impaired people.

For important reasons of safety, special warning notices and tactile warning indicators shall be provided at the top and bottom of escalators. Escalators shall not be considered as the accessible route. Persons with locomotor disability cannot use them. Hence a lift should also be installed as an alternative accessible route.

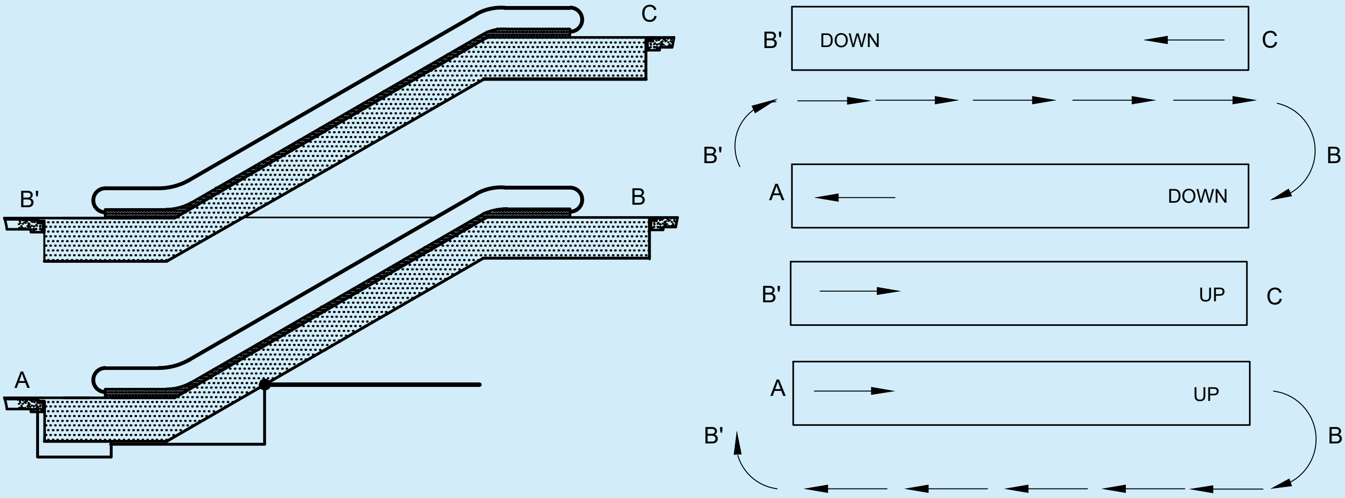
For moving walks, the maximum inclination should be up to 6° for use by people with disabilities. People with disability may find it difficult to use moving walks. Hence, alternative like an accessible battery cart, may be provided to them in appropriate cases. Moving walks shall be free of projecting objects and obstacles up to a height of 2 100 mm. A minimum level of illumination of 100 lux shall be provided on moving walks.


A
B
C
A
DOWN
B
C
DOWN
C
UP
B
A
UP

4 A PARALLEL


A
A'
B'
B
C
C'
A
DOWN
B
C
DOWN
UP
A'
B'
UP
C'

4 B CRISS CROSS


C
B'
B
A
B'
DOWN
C
B'
B
A
DOWN
B'
UP
C
A
UP
B'
B

4 C WALK AROUND

FIG. 4 ESCALATOR CONFIGURATION

6 SPACE REQUIREMENT

6.1 Free Space for Users

6.1.1 The clear height above the steps of the escalator or pallets or belt of the moving walk at all points shall not be less than 2.30 m (*see* X4 in Fig. 5 and Fig. 7). The clear height shall extend to the end of the newel.

NOTE — The clear height of 2.30 m should also be applied to the unrestricted area.

6.1.2 To prevent collision, a minimum free area around the escalator or moving walk is defined as per Fig. 5. The height X12, measured from the steps of the escalator or the pallets or the belt of the moving walk shall be at least 2.10 m (*see* X12 in Fig. 5). The distance between the outer edge of the handrail and walls or other obstacles (*see* Y10 in Fig. 5) shall under no circumstances be less than 80 mm horizontally and 25 mm vertically below the lower edge of the handrail (*see* Y12 in Fig. 8). The area is permitted to be smaller, if by appropriate measures, the risk of injury is minimized.

6.1.3 For escalators arranged adjacent to one another either parallel or criss-cross, the distance between the handrails shall be not less than 160 mm (*see* Y11 in Fig. 5).

6.1.4 Where building obstacles may cause injuries, appropriate preventive measures shall be taken.

At floor intersections and on criss-cross escalators or moving walks, a vertical deflector of not less than 0.30 m in height, not presenting any sharp cutting edges, shall be placed above the handrail level and extend at least 25 mm below the lower edge of the handrail, for example, as an imperforate triangle (*see* X5 in Fig. 7 and Fig. 9).

It is not necessary to comply with these requirements when the distance Y9 between the outer edge of the handrail and any obstacle is equal to or greater than 400 mm (*see* Fig. 5).

6.1.5 In the case of successive escalators and moving walks with intermediate landing without exits, they shall be electrically interlocked to run in same direction and shall have the same transportation capacity. They shall also be electrical interlocked to stop the escalator carrying passengers into the intermediate landing without exits if the escalator carrying passengers away from the landing stops.

6.1.6 Where it is possible for people to come into contact with the outer edge of a handrail at a landing and may be drawn into a hazardous situation, such as toppling over a balustrade, appropriate preventive measures shall be taken (for example, *see* Fig. 6).

Some examples are:

a) Prevention of entry into the space by the placement of permanent barriers.

b) Increasing the height of the building structure of the fixed balustrade in the hazard area by at least 100 mm above the handrail level and positioned between 80 mm and 120 mm from the outer edge of the handrail.

The placement of permanent barriers shall be towards the newel end in the area where the handrail becomes flat after the curved portion of the newel. The permanent barriers shall be designed to prevent injury to travelling passengers.

6.1.7 The surrounding space of the escalator or moving walk shall be illuminated, especially in the vicinity of the combs.

NOTE — Information should be exchanged between the manufacturer and the customer.

6.1.8 It is permissible to arrange the lighting in the surrounding space and/or at the installation itself. The intensity of illumination at the landings including the combs shall be related to the intensity of illumination of the general lighting in the area. The intensity of illumination shall be not less than 50 lux at the comb intersection line measured at floor level.

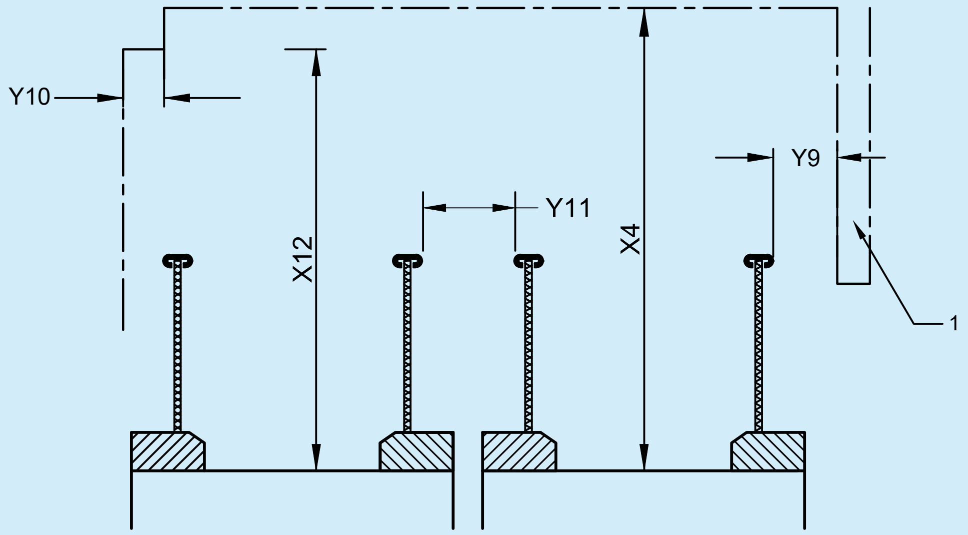
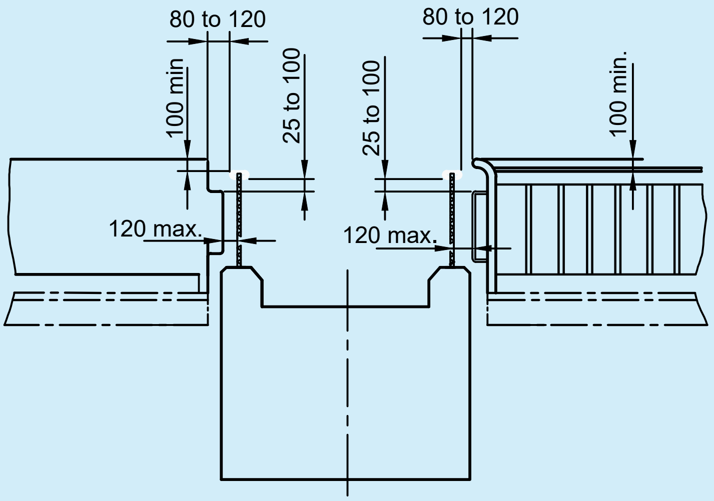

Y10
X12
Y11
X4
Y9
1

FIG. 5 CLEARANCES BETWEEN BUILDING STRUCTURE AND ESCALATOR / MOVING WALK


80 to 120
80 to 120
100 min
25 to 100
25 to 100
100 min.
120 max.
120 max.

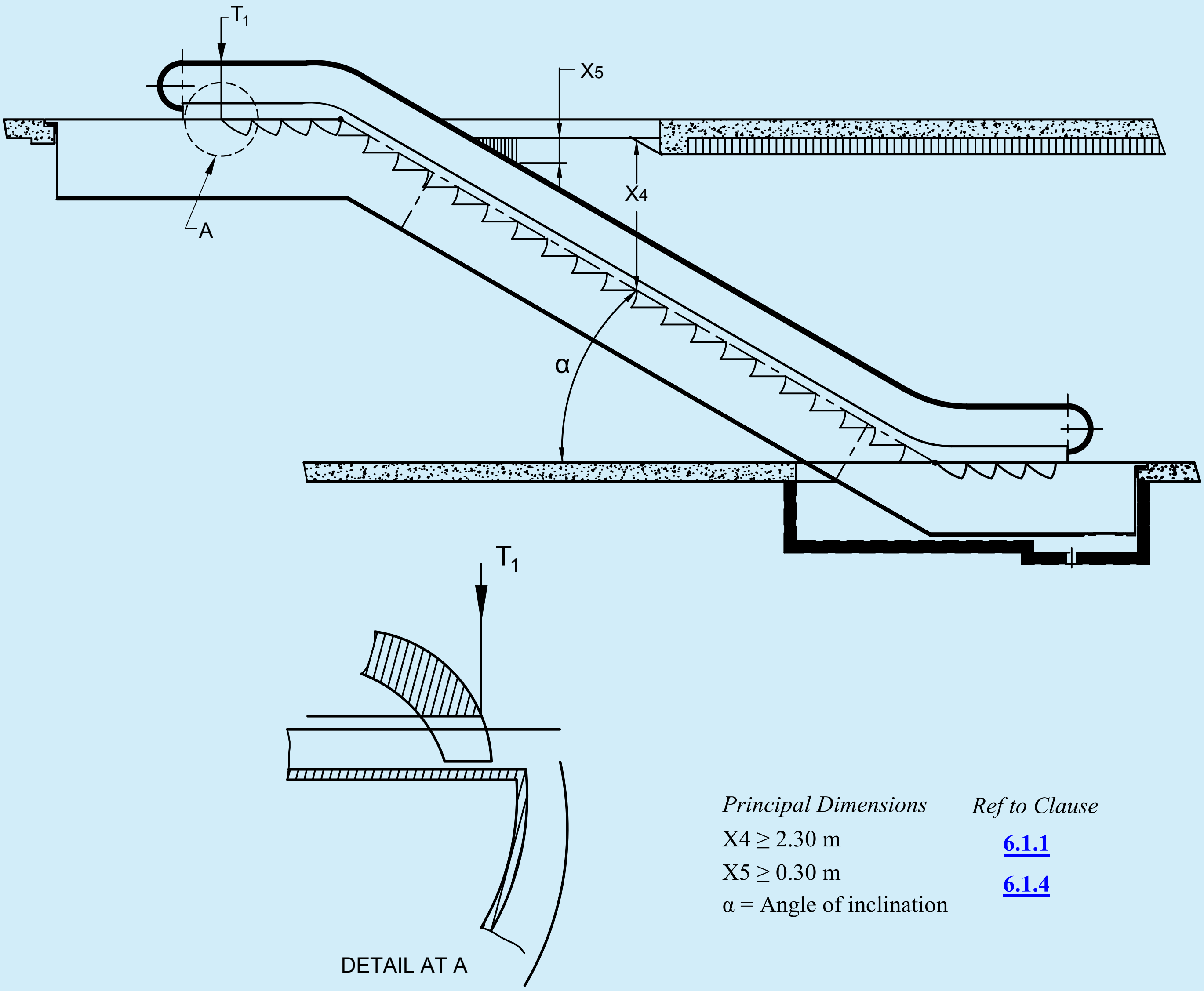
All dimensions in millimetres

FIG. 6 EXAMPLE OF BARRIERS AT LANDINGS

Key

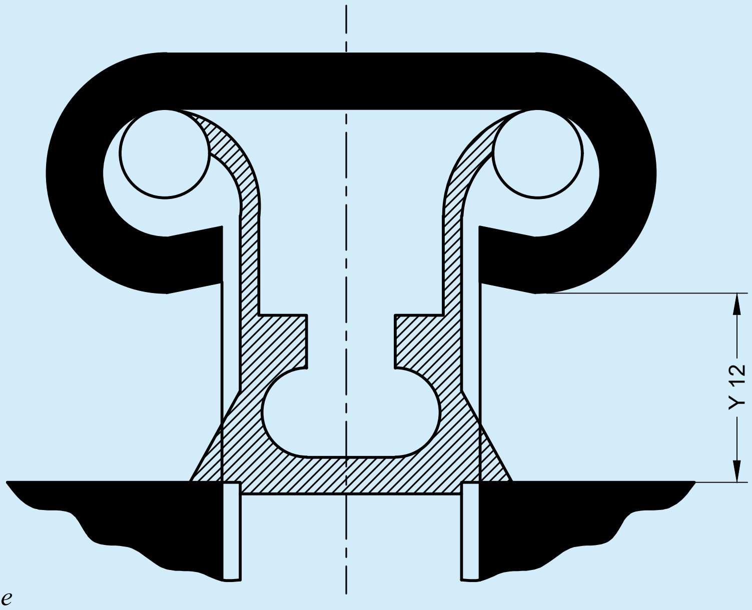
1 Obstacle (for example, Column)

Sl No. (1)	*Principal Dimensions Clause* (2)	*Ref to Clause* (3)	*Principal Dimensions Clause* (4)	*Ref to Clause* (5)
i)	Y9 ≥ 400 mm [Sl No. (xxii) of Annex A]	6.1.4	X4 ≥ 2 300 mm [Sl No. (xix) of Annex A]	6.1.1
ii)	Y10 ≥ 80 mm [Sl No. (xx) of Annex A]	6.1.2	X12 ≥ 2 100 mm [Sl No. (xxii) of Annex A]	6.1.2
iii)	Y11 ≥ 160 mm [Sl No. (xxi) of Annex A]	6.1.3	–	–



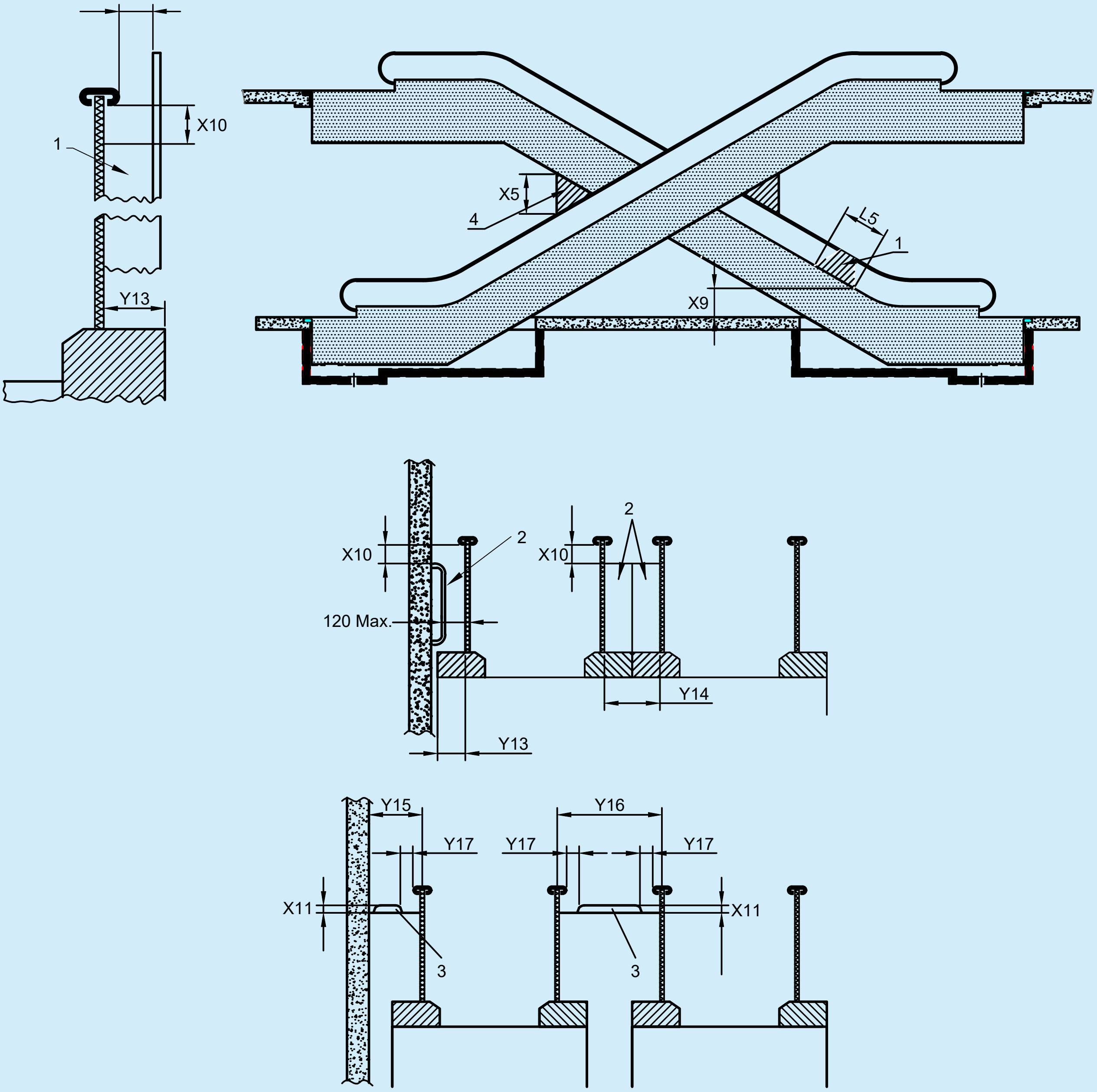
Principal Dimensions	*Ref to Clause*
X4 ≥ 2.30 m	6.1.1
X5 ≥ 0.30 m	6.1.4
α = Angle of inclination	

FIG.7 ESCALATOR (ELEVATION), PRINCIPAL DIMENSIONS



Principal Dimensions	*Ref to Clause*
Y12 ≥ 25 mm	6.1.2

FIG.8 HANDRAIL (SECTIONAL VIEW)


X10
1
Y13
X5
4
L5
1
X9
X10
2
120 Max.
X10
2
Y14
Y13
Y15
Y16
Y17
Y17
Y17
X11
X11
3
3

Key

1) Anti-climbing device (*see* 6.3)
2) Access restriction device (*see* 6.3)
3) Anti-slide device (*see* 6.3)
4) Vertical deflector (*see* 6.1.4)

Principal Dimensions	*Ref to Clause*
Y13, Y14, Y15, Y16	6.3
Y17 ≥ 100 mm	6.3
X5 ≥ 0.30 m	6.1.4
X9 = (1 000 ± 50) mm	6.3
X10 = 25 mm to150 mm	6.3
X11 ≥ 20 mm	6.3
L5 ≥ 1 000 mm	6.3

FIG. 9 ANTI-MISUSE DEVICES

6.2 Machinery Spaces Outside the Truss

The following shall be ensured:

a) A safe access for persons to machinery spaces shall be provided;

b) Machinery spaces shall be lockable and only accessible to authorized persons;

c) Machinery spaces shall be provided with permanently installed electric lighting on the following basis;

  1) Minimum of 200 lux at floor level in working areas;

  2) Minimum of 50 lux at floor level in access routes leading to these working areas.

d) Emergency lighting shall be installed to allow the safe evacuation of all personnel working in any machinery space.

NOTE — Emergency lighting is not intended for continuation of maintenance or other activities.

e) The dimensions of machinery spaces shall be sufficient to permit easy and safe working on equipment, especially the electrical equipment. These shall be provided at least at a clear height of 2.00 m at working areas, and a clear horizontal area in front of the control panels and the cabinets. This area is defined as follows:

1)	Depth, measured from the external surface of the enclosures	At least 0.70 m;
2)	Width, the greater of the following values	0.50 m or the full width of the cabinet or panel.

A clear horizontal area of at least 0.50 m × 0.60 m for maintenance and inspection of moving parts at points where this is necessary.

f) The clear height for movement shall not be less than 1.80 m. The access ways to the clear spaces shall have a width of at least 0.50 m. This value may be reduced to 0.40 m where there are no moving parts. This full height for movement is taken to the underside of the structural roof beams and measured from both:

  1) the floor of the access area; and

  2) the floor of the working area.

g) In machinery spaces the clear height shall under no circumstances be less than 2.0 m;

h) 3 pin plug with socket for the maintenance propose; and

j) Machinery spaces shall not accommodate equipment not related to the escalator or moving walk.

6.3 Balustrade

Balustrades shall be installed on each side of the escalator or moving walk. The dimensions of the balustrade shall be as follows:

In the inclined section the vertical height X1 from step nose or pallet surface or belt surface to top of the handrail shall not be less than 0.90 m and not exceed 1.10 m (*see* Fig. 10).

The balustrades shall have no parts on which a person will normally stand.

Appropriate measures shall be taken to discourage people from climbing on the outsides of the balustrade if there is a danger of people falling from them.

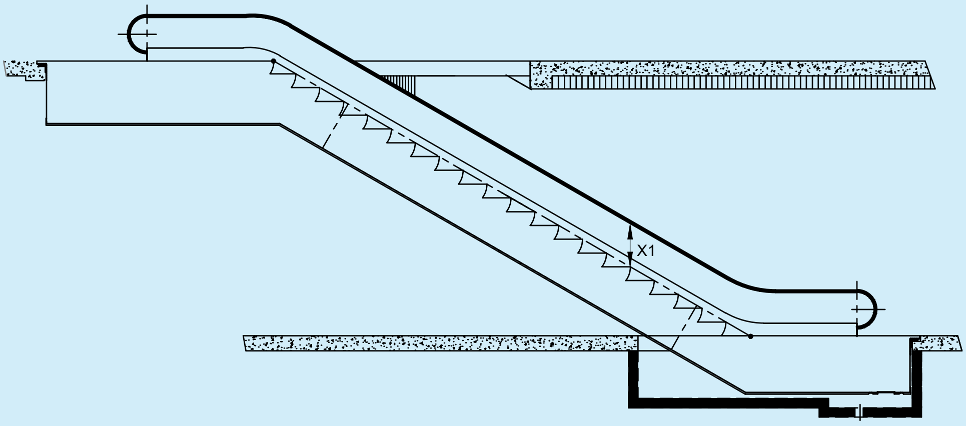
To ensure this, on escalators and moving walks, devices (*see* 1 in Fig. 9) shall be provided on the lower outer decking at a point 1 000 mm ± 50 mm above the floor level (*see* X9 in Fig. 9) where the bottom of the device intersects with the balustrade decking and shall extend to a length L5 of at least 1 000 mm parallel with the balustrade decking where no stepping is possible. The device shall extend to at least a height in line with the top of the handrail not conflicting with the requirements of Y10 and Y12 (*see* Fig. 5 and Fig. 8).

Where escalators or moving walks are located adjacent to walls, devices (*see* 2 in Fig. 9) to restrict access to the balustrade decking shall be provided at the top and bottom ends of these walls when the lower outer decking width Y13 exceeds 125 mm. On adjacent parallel arrangements, this protection shall be provided when the combined balustrade decking width Y14 exceeds 125 mm. The device shall extend to the height X10 (*see* Fig. 9).

All exposed fastener heads for the devices should be of the vandal resistant type.

Where handrail level balustrade decking are provided between escalators/inclined moving walks and adjacent walls, anti-slide devices (*see* 3 in Fig. 9) shall be provided on the balustrade decking when the distance Y15 between the structure of the building (wall) and the centreline of the handrail is greater than 300 mm. These devices shall consist of objects fastened to the balustrade decking, no closer than 100 mm to the handrail (*see* Y17) and spaced no greater than 1 800 mm apart. The height X11 shall be not less than 20 mm. The devices shall have no sharp corners or edges (*see* Fig. 9).

The above mentioned also applies to adjacent escalators/inclined moving walks when the distance Y16 between the centrelines of the handrails is greater than 400 mm.



Principal Dimensions 0.9 m ≤ X1 ≤ 1.10 m

FIG. 10 ESCALATOR (ELEVATION) , PRINCIPAL DIMENSIONS

Exposure of one or both sides of escalators over a void, and the changes made to the balustrade/handrail design on escalators, can increase risks to users. The placement and type of escalator may introduce hazards, particularly when exposed over a void, leading to risks of falling at two areas:

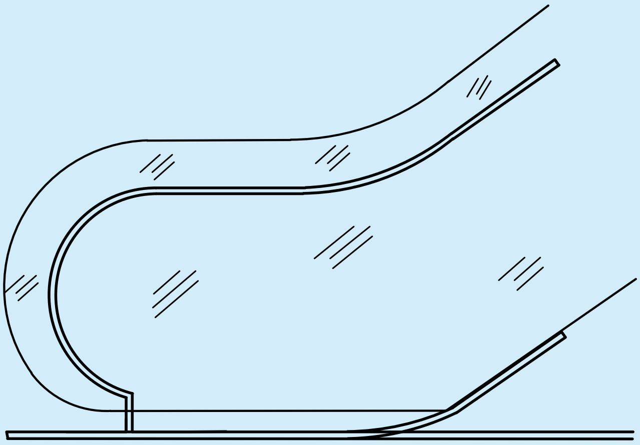
a) *Escalator and Moving Walk Landings* — There is a risk for people to come into contact with the outer edge of a handrail and be drawn into the void; and

b) *Escalator and Moving Walk Balustrades* — There is a risk for people to trip or accidentally overbalance and topple into the void.

A risk assessment should be conducted to identify hazards, potential misuse, affected individuals, and necessary preventive measures. Some examples of misuse are - sitting, standing, sliding on the handrail, holding onto the handrail from outside the balustrade, being lifted onto the handrail, walking up, and sliding down the decking.

Balustrades should balance fall risk and passenger support. Balustrade with 1 100 mm height offer firm grip and better fall protection than 900 mm. To mitigate falling risks, following risk mitigation measures shall be considered:

1) Avoiding voids to remove the hazard;
2) Using 1 100 mm high balustrades if voids are present; and
3) For escalators exposed over a void, falling risks increase, and additional protection beyond the handrail and balustrade may be needed. Where escalators are not bounded totally by adjacent walls or partitions and are therefore exposed over a void on one or both sides, persons are at risk of falling a substantial height. The building architects/developers might need to make provision of additional protection beyond the handrail and balustrade. Glass enclosures, shields, or additional guard rails shall be installed as shown in Fig. 11 if high balustrades alone are insufficient.



(SIDE VIEW)

FIG. 11 TYPICAL ARRANGEMENT OF ESCALATOR LANDING WITH GLASS BALUSTRADE

NOTE — Based on the risk assessment carried out, fixing of external guarding, if required, shall be undertaken with professional consultation to ensure that the integrity of the escalator truss or balustrade is not compromised.

6.4 Installation

The following needs to be planned and carried out on site to ensure easy installation of escalators and moving walks.

6.4.1 *Installation Timing*

To prevent damage to the escalator during the construction phase, the timing of installation and assembly should be as close as possible to the opening date. It should, however, proceed completion of the floor to dispense with the need to take further measures to protect floor coverings. Ensure that the provisional floors along the transport route in the building may comfortably cope with the load weight.

6.4.2 *Transport to the Assembly Site*

A suitable unloading area shall be available in front of the building. The access routes to the building shall be level and negotiable by heavy duty rollers. Along the entire transport route to the assembly site, the free height shall not be less than the minimum specified in the manufacturer plan (also goes for pipes and other attachments fitted by others to the ceiling structure).

6.4.3 *Access Openings, Transport Route and Load Capacity*

Normally, escalators are moved in through openings at the side of the building at ground level. Optionally, suitable roof openings should be provided, to bring the escalators by crane. It is important that the route to the assembly location within the building is free of obstacles and level, and the ceiling can support a load. Otherwise, the appropriate weight distribution shall be catered to.

6.4.4 *Special Delivery*

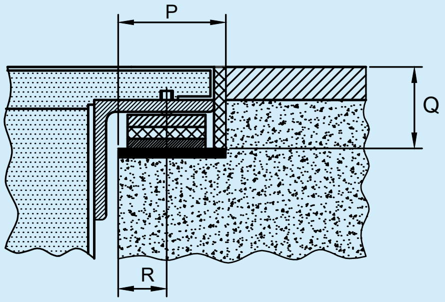
Some escalators are so long that they should be installed in sections. In this case, the escalator may have to be manufactured in split form and assembled on site.

6.4.5 *Ceiling Openings*

Manufacturer should notify the location and size of the required ceiling openings on the installation drawing. Builder shall supervise the precise implementation of these openings.

6.4.6 *Top and Bottom Supports*

While designing the support recess, the support loads shall be considered. They are shown on the installation drawing given by the manufacturer. At those locations where the supports of escalator (or moving walk) will be placed, the support shall be able to bear the weight of the escalator including traffic load. When preparing the supporting structures, the measurements indicated on manufacturer's installation plans shall be precisely adhered to (*see* Fig. 12).



NOTE - P, Q, R ARE BASED ON MANUFACTURER'S DRAWING

FIG. 12 TOP AND BOTTOM SUPPORTS

6.4.7 *Intermediate Supports*

Intermediate supports are needed on escalators with a considerable travel height (recommended above 5 000 mm) and on long moving walks. If the intermediate support is required, the manufacturer shall provide the location and load on intermediate support to the customer irrespective of the segment for which the escalator is provided, to include the additional space required in the construction plan (*see* Fig. 13).

6.4.7 *Intermediate Supports*

Intermediate supports are needed on escalators with a considerable travel height (recommended above 5 000 mm) and on long moving walks. If the intermediate support is required, the manufacturer shall provide the location and load on intermediate support to the customer irrespective of the segment for which the escalator is provided, to include the additional space required in the construction plan (*see* Fig. 13).

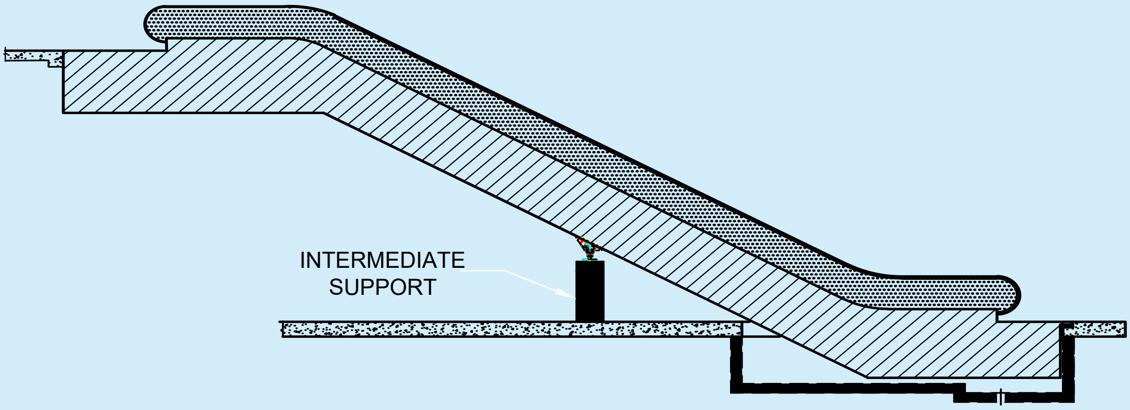

INTERMEDIATE
SUPPORT

FIG. 13 INTERMEDIATE SUPPORTS

6.4.8 *Hoisting Arrangement*

It shall be ensured that pick-up points for hoisting and supporting the escalator shall be fitted securely during assembly. These should be located exactly above the centre of the supporting points. For systems with several supporting structures, plan for additional pick-up points above the intermediate supports. All pick-up points shall be capable of taking a load strain (*see* Fig. 14).

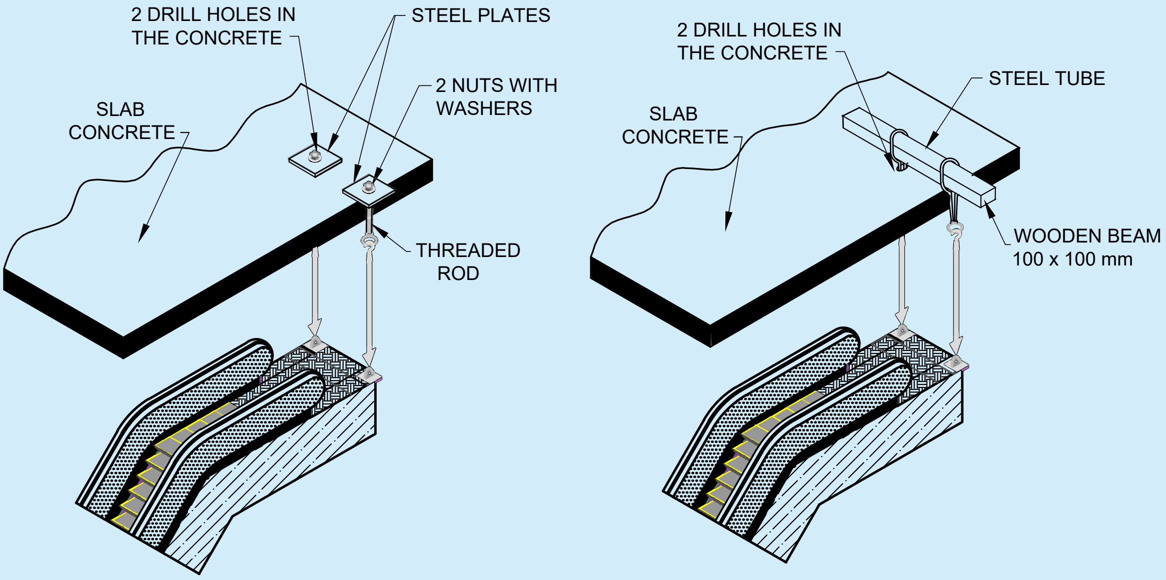

2 DRILL HOLES IN
THE CONCRETE
STEEL PLATES
2 NUTS WITH
WASHERS
SLAB
CONCRETE
THREADED
ROD
2 DRILL HOLES IN
THE CONCRETE
STEEL TUBE
SLAB
CONCRETE
WOODEN BEAM
100 x 100 mm

FIG. 14 PICK-UP POINTS

6.4.8.1 *Installation with a frame*

If no assembly holes can be provided, the escalators and moving walks should be lifted to their final location by means of special sturdy girder construction. In this case, ceiling load strain shall bear the capacity as per the manufacturer's instruction.

6.4.8.2 *Installation with lifting gear*

Holes with a 100 mm diameter are to be made through the ceiling, according to manufacturer instructions. These are used by installation team for fixing the lifting gear. In this way escalator or moving walk is simply lifted upwards from floor to floor. The load strain of every pick-up point shall be maintained as per the manufacturer instruction.

6.4.8.3 *Installation with crane assembly*

Where a suitable roof opening is available, or the site is located outdoor, lift the escalator or moving walk by crane and place it on the supports provided. The builder is responsible for ensuring for all local authority approvals.

6.4.8.4 Permanent hoisting hooks shall be provided by the builder in the top slab for hoisting the escalator as per the load requirement.

6.4.9 *Sprinkler Piping*

An optional safety feature is the installation of a sprinkler piping within the escalator or moving walk (*see* Fig. 15 for typical sprinkler piping arrangement).

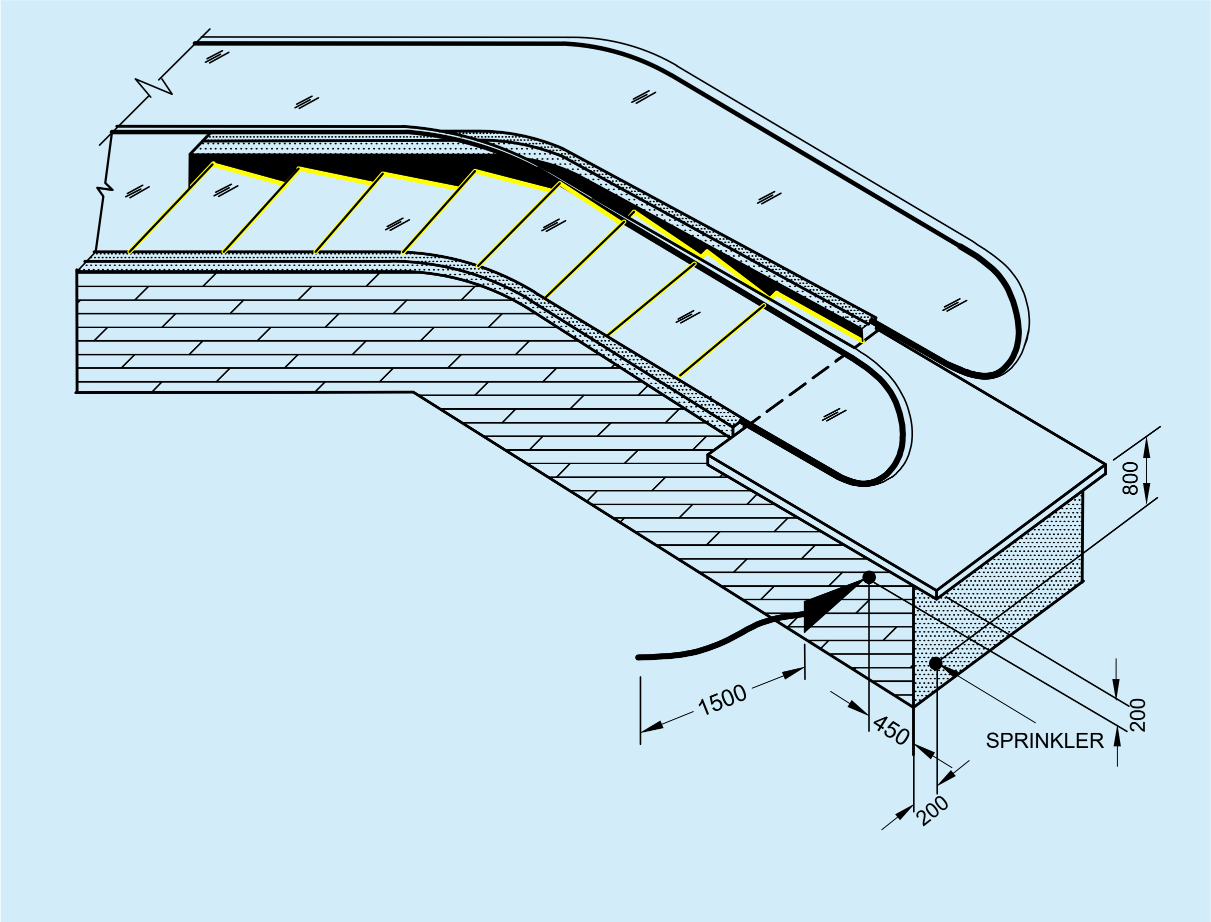


FIG.15 TYPICAL SPRINKLER PIPING ARRANGEMENT

6.4.10 *Oil Separator*

A type-proofed oil separator is essential for escalators and moving walks which are exposed to the weather. At the construction site, a recess shall be provided for the oil separator in the escalator pit.

6.4.11 *Railings*

In the threshold areas of the escalators, railings should be installed by the builder. The distance to the escalator handrail from railing shall be at least 80 mm. For adjacent escalators, the distance between the edges of the handrails shall be at least 160 mm (*see* Y11 in Fig. 5).

6.5 Electrical Requirement

6.5.1 The electrical installations shall be in accordance with Part D ‘Building Services, Section 2 Electrical and Allied Installations’ of this NBCS and good practice [D-5B (2)].

6.5.2 *Power Supply*

6.5.2.1 The main power supply cables providing the electricity supply from main electrical panel of the building to escalator/moving walk equipment shall be PVC or XLPE insulated, flame retardant type, armoured cables. The cables shall be terminated in the main switchgear panels/distribution box using cable glands such that the armour of the cables shall be positively connected to the metal body of switchgear panels/distribution box. For each escalator/moving walk, one $415\ \text{V}^{+6\ \text{percent}}_{-10\ \text{percent}}$, 3-phase, 4-wire, 50 Hz supply and one $230\ \text{V}^{+6\ \text{percent}}_{-10\ \text{percent}}$, 1-phase, 3-wire, 50 Hz supply shall be provided outside the escalator/moving walk in the vicinity of the machine or in the return stations, or in the vicinity of the control devices. Main switchgear shall be capable of breaking the supply to the motor, to the brake releasing device and to the control circuit in the live conductors.

The electric lighting and the socket outlets shall be independent of the power supply to the machine being fed either by a separate cable or a branch cable which is connected before the main switch of the escalator or moving walk. It shall be possible to break the supply of all phases by means of a separate switch. This switch shall not cut the supply to the socket outlets or to the lighting circuits while the escalator/moving walk is switched off for inspection and maintenance. Size of the three-phase and single-phase cables shall be as specified by the manufacturer.

When separate supplies are provided for auxiliary equipment, such as, heating, balustrade lighting and comb lighting, it shall be possible to switch them off independently. The corresponding switches shall be located close to the main switch and be marked unambiguously.

6.5.2.2 The escalator/moving walk sub-circuit from the meter room should be separate from other building services. Each equipment should be capable of being isolated from the mains supply. This means of isolation shall be with lock out and tag out facility. The electric supply cables shall run in a route safe from fire.

6.5.2.3 All electrical supply lines and apparatus in connection with the escalator/moving walk installation shall be so constructed and shall be so installed, protected, worked, and maintained that there may be no danger to persons therefrom.

6.5.3 *Protection*

It is important that earthing should ensure efficient and fast operation of protective device, in the case of earth faults. Escalators or moving walks may be provided with or without variable voltage and variable frequency (V3F) drives. Due to its principle of operation, the V3F drive produces leakage current greater than 3.5 mA. Therefore, the cross-section of earthing conductor should be at least the cross-section of the active conductors and at least 10 mm^2. As an alternative, two ground conductors with the same cross-section as the active conductors (if < 10 mm^2) may be used in parallel.

Suitable overcurrent protection device (MCB/MCCB) and residual current device (RCD) shall be provided outside the escalator/moving walk in the vicinity of the machine or in the return stations or in the vicinity of the control devices.

Protective measure of protective equipotential bonding and automatic disconnection of supply is intended to provide protection against shock and/or fire hazard. The choice of protective device, depends on the earthing network that is TN-S, TN-C-S, TT.

Residual current device (RCD) shall be required in case of fault protection against indirect contact or in case of TT network. When RCD is used, circuit shall also be protected by overcurrent protective device that is standalone RCD shall not be used.

6.5.3.1 *MCB and RCD in 3-phase circuit:*

a) Irrespective of whether the escalator or moving walk is with or without V3F, MCB of characteristics ‘D’ shall be used.

b) *RCD with V3F* — Special type of residual-current circuit breaker appropriate for this application should be used having following characteristics:
   1) Suitable for use with a frequency converter;
   2) Universal-current-sensitive (Characteristic *B*);
   3) Short-time delayed tripping (Type *S*);
   4) Tripping current at nominal frequency: 300 mA; and
   5) Tolerant against leakage currents of up to 2 000 mA at higher frequencies.

c) *RCD without V3F* — RCD with below specifications shall be used:
   1) Type *A* or *AC* — details to be provided by manufacturer;
   2) Non-delayed; and
   3) Tripping current: 100 mA

Alternatively, residual current circuit breaker with overcurrent protection (RCBOP) which meets above specifications may be provided.

NOTE — RCD/RCBO is mandatory in case of TT network.

6.5.3.2 *Over current protective device in the 1-phase circuit*

For the lighting circuit, miniature circuit breaker (MCB) of characteristics 'C' shall be provided. In addition, RCD of the following specification shall be provided:

a) Pulse-current-sensitive (Characteristic *A*);
b) Non-delayed;
c) Tripping current: 30 mA; and
d) Rated current: 16 A.

Alternatively, RCBO which meets above specifications may be provided.

7 FIRE PROTECTION

Fire protection and building requirement differ with the application/use of building. For specific requirements for fire protection, Part F 'Fire and Life Safety' of this NBCS should be referred. It is recommended that escalators and moving walks are made of non-combustible material that do not create additional hazard in case of fire.

To limit the danger caused by overheating, ventilation for the rooms/spaces that contain the motors and gears shall be provided. These areas may contain fire alarm systems, extinguishing systems, and sprinkler heads if the equipment is adequately protected from incidental damage and do not create additional dangers for maintenance personnel to operate. In case sprinklers are used, their integration and fixation into the escalator and moving walk shall be done by taking into consideration the special needs of the machine.

Accumulation of materials (such as grease, oil, dust, paper) represent a fire hazard. Therefore, it should be possible to clean the underside enclosure. If such cleaning is not possible, other precautions (such as installation of sprinkler system) shall be provided to avoid the fire hazard. Outer and inner decking, truss, pallets/steps, track system shall be according to Class 3 of accepted standards [D-5B(3)]. In case of fire, upon receiving the signal, the escalator operation should stop immediately. It is recommended that as far as possible, escalators and moving walks are not used in case of emergency situations.

Escalator wellways may be equipped with a fire shutter(s), operated by an activation of temperature and smoke detectors, and shuts off the wellway of a floor and prevent the spread of fire up through the building.

8 MINIMUM TECHNICAL AND SAFETY REQUIREMENTS

8.1 General

The safety requirements of escalators and moving walks shall comply with good practice in accordance with this Subsection. Certain escalators and moving walks are subject to special operational and environmental conditions.

8.2 Supporting Structures (Truss) and Enclosure

The truss shall be designed to safely sustain steps and running gear in its guides. All mechanically moving parts of the escalator or moving walk shall be completely enclosed within imperforate panels or walls. Exceptions are the accessible steps, the accessible pallets, the accessible belt, and that part of the handrail available for the user. Apertures for ventilation are permitted. However, it shall not be possible to pass a straight rigid rod 10 mm in diameter through the enclosure and to touch any moving part through a ventilation aperture.

Angle of inclination of an escalator from the horizontal shall not exceed 30°, but for rises not exceeding 6 m and nominal speed not exceeding 0.5 m/s the angle of inclination is permitted to be increased to 35°.

Rise m	*Speed* m/s	*Angle of Inclination*	
		Standard	Option
≤ 6	≤ 0.5	30°	35°
≤ 6	> 0.5	30°	-
> 6	≤ 0.5	30°	-
> 6	> 0.5	30°	-

The angle of inclination of moving walks shall not exceed 12°.

8.3 Step, Pallet, or Belt

For escalators and moving walks, the nominal width shall not be less than 0.58 m and not exceed 1.10 m. For moving walks with an angle of inclination up to 6°, widths up to 1.65 m are permitted.

8.3.1 *Step Treads and Pallets*

The step depth in the direction of travel shall not be less than 0.38 m. The step height shall not exceed 0.24 m. The surface of the step treads shall have grooves in the direction of the movement, with which the teeth of the combs mesh. They shall be sensibly horizontal in the usable area of the escalator. The step risers shall be cleated, and the surface of the cleat shall be smooth. The ends of the step tread shall mesh with the cleating of the next step riser.

The width of the grooves shall be at least 5 mm and shall not exceed 7 mm. The depth of the grooves shall not be less than 10 mm. The web width shall be at least 2.5 mm but not exceed 5 mm.

8.3.2 *Belts*

The belts shall have grooves in the direction of travel with which the teeth of the comb mesh. The width of the grooves shall be at least 4.5 mm and shall not exceed 7 mm. The depth of grooves shall not be less than 5 mm. The web width shall be at least 4.5 mm but not exceed 8 mm. Splicing of tread way belt shall be such as to provide continuous unbroken tread way surface.

8.4 Driving Machine and Brake

8.4.1 A driving machine shall not drive more than one escalator or moving walk.

8.4.2 The speed of an unloaded escalator shall not deviate by more than ± 5 percent from nominal speed at nominal frequency and nominal voltage.

8.4.3 The driving machine shall be connected to main drive shaft, preferably by non-friction driving elements such as by gear wheels, shaft, coupling, multiplex chain, two or more single chains. Where friction elements are used such as trapezoidal belts (flat belts are not permitted) an auxiliary brake shall be used.

8.4.4 *Braking System*

Escalators and moving walks shall have an operational braking system by means of which they can be brought to rest with a uniform deceleration and maintained stationary; there shall be no intentional delay in the application of the braking system. If the control system starts a braking sequence immediately to bring the escalator/moving walk to a stop, this is not considered as an intentional delay. A device shall be provided to monitor the lifting of the braking system after starting the escalator/moving walk.

Operational braking shall be affected by an electro-mechanical brake or by other means. Where no electro-mechanical operational brake is used, an auxiliary brake shall be provided.

8.4.4.1 *Auxiliary brake*

Escalators and inclined moving walks shall be equipped with auxiliary brake(s) if:

a) the connection between the operational brake and the driving sprockets of the steps/pallets or the drum of the belt is not accomplished by shafts, gear wheels, multiplex chains, or more than one single chain; or

b) the operational brake is not an electro-mechanical brake; or

c) the rise exceeds 6 m; or

d) escalators or moving walks are part of a public transport/service system.

8.5 Steps and Pallets Drive

The steps of escalators shall be driven by at least two chains of which at least one shall be located on each side of the step. The pallets of moving walks may be permitted to be driven by only one chain if the parallel movement of the pallets in the usable area is ensured by other mechanical measures.

8.6 Belt Drive

The belt shall be driven by drums and be tensioned continuously and automatically. Springs working in tension are not permitted for the tensioning device. When weights are used for tensioning, they shall be safely retained should their suspension break.

8.7 Balustrade

Balustrades shall be installed to comply with the requirements of 6.3.

If glass is used for the interior panel, it shall be toughened glass. In case of splinter free one layer safety (tempered) glass, the minimum thickness shall be 6 mm. When multi-layer glass balustrades are used, they shall be laminated toughened glass, the thickness of at least one layer shall also be not less than 6 mm.

8.8 Skirting

The skirting shall be vertical, plain, and sufficiently rigid. Where the skirting of escalators or moving walks is placed beside the steps and pallets or the belt the horizontal clearance shall not exceed 4 mm at either side, or 7 mm for the sum of clearances measured at both sides at two directly opposite points.

Where the skirting of moving walks finishes above the pallets or the belt, the clearance shall not exceed 4 mm measured vertically from the tread surface. Motion of the pallets or the belt in lateral direction shall not cause a gap between the sides of the pallets or the belt and the vertical projection of the skirting.

8.8.1 *Requirements for Skirt Deflectors*

The skirt deflectors shall be designed with rounded edges. Fastening heads and joint connections shall not extend into the path of travel. They shall consist of a rigid and a flexible part (for example, brushes and rubber profiles) and shall be mandatorily provided in the escalators.

8.9 Handrails

Each balustrade shall be provided with a handrail moving on the top of each balustrade, in the same direction and at the same speed, within tolerance of ${}^{+2}_{0}$ percent, as the steps, pallets or belt. Each moving handrail shall extend at normal handrail height not less than 300 mm beyond the line of point of comb plate teeth at the upper and lower landings. Hand or finger guards shall be provided at the points where handrails enter the balustrade.

The width of handrail shall be between 70 mm and 100 mm. The handrail shall be a minimum of 80 mm horizontally and 25 mm vertically away from adjacent surfaces (*see* Fig. 6). The handrail shall be guided and tensioned in such a way that it does not leave its guides during normal use.

8.10 Landing

The landing area (that is, comb plate and floor plate) of escalator shall have a surface that provides a secure foot hold (combs are exempted from this) for a minimum distance of 0.85 m measured from the root of the comb teeth.

8.10.1 *Configuration of Steps, Pallets, and Belts*

8.10.1.1 At the upper and lower landing, the steps of the escalator shall be guided in such a way that the front edges of the steps leaving the comb and the rear edges of the steps entering the comb are moving horizontally for a length of at least 0.80 m measured from point T1 (*see* Fig. 7 and detail A).

8.10.1.2 At the upper landings of moving walks with an inclination of more than 6°, the pallets or belt shall move for a length of at least 0.40 m at a maximum angle of 6° before entering or after leaving the comb.

8.11 Comb Plates

There shall be a comb plate at the entrance and at the exit of every escalator. The comb plate teeth shall be meshed with and set into the tread surface so that the points of the teeth are always below the upper surface of the treads. The comb plates shall be adjustable. Combs shall be easily replaceable.

8.12 Speed Governor

8.12.1 Where speed control devices are used for this purpose, they shall have switched off the escalator before the speed exceeds 1.2 times the nominal speed. This requirement may not be applied if the design prevents the excessive speed.

8.12.2 Escalators and inclined ($\alpha \geq 6°$) moving walks shall be equipped in such a way that they stop automatically by the time the steps and pallets or the belt change from the pre-set direction of travel.

8.12.3 For operation and safety devices, electrical work, precautions and tests, reference may be made to accepted standards [D-5B(3)].

8.13 Inspection Control

Escalators or moving walks shall be equipped with inspection controls to permit operation during maintenance or repair or inspection by means of portable and manually operated control devices. At least one portable control device shall be provided for each escalator or moving walk.

8.14 Information for Use

8.14.1 *General*

All escalators and moving walks are required to be provided with documentation that shall include an instruction handbook relating to use, maintenance, inspection, periodic checks and rescue operations. Information for use shall cover, separately or in combination, transport, assembly and installation, commissioning, use (setting, teaching/programming, operation, cleaning, fault finding and maintenance) of the escalator and moving walk, and, if necessary, de-commissioning, dismantling and disposal.

8.14.2 *Signals and Warning Devices*

8.14.2.1 *Plates, inscriptions, and notices for use*

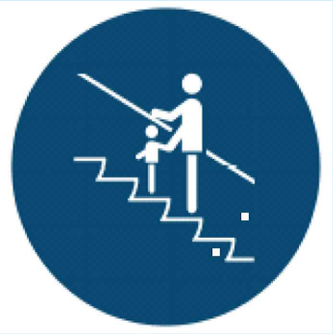
a) *General* — All signs, inscriptions and notices for use shall be of durable material, placed in a conspicuous position and written in clearly legible characters in English as well as in local language.

b) *Safety signs near the entrances of escalators or moving walks* — The following mandatory action signs and prohibition signs for the user shall be fixed in the vicinity of the entrances:

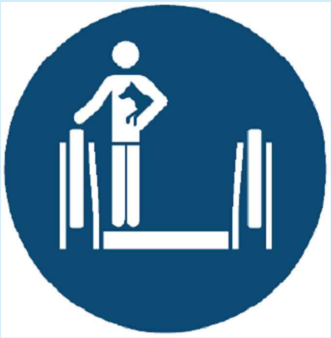
   1) Small children shall be held firmly (*see* Fig. 16);
   2) Pets shall be carried (*see* Fig. 17);
   3) Use the handrail (*see* Fig. 18);
   4) Push chairs not permitted (*see* Fig. 19); and
   5) Soft footwear prohibited (*see* Fig. 20).

When required by local conditions, prohibition signs, for example, 'Transportation of bulky and heavy loads not permitted' and mandatory action signs like 'Use permitted only with footwear', shall be necessitated.

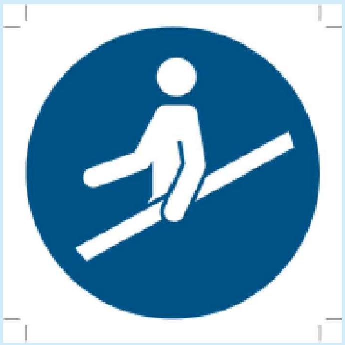
The minimum diameter of the signs shall be 80 mm.



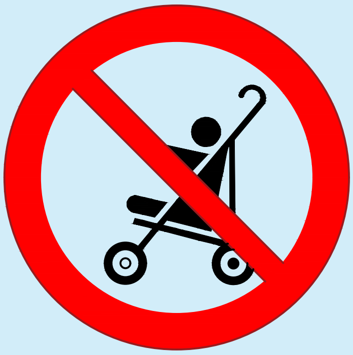
"SMALL CHILDREN SHALL BE HELD FIRMLY"
FIG.16 MANDATORY ACTION SIGN



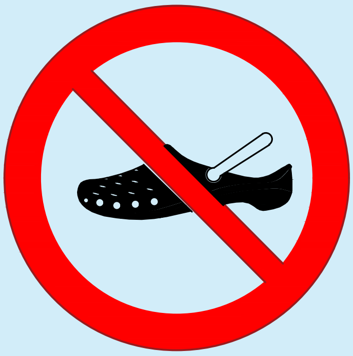
"PETS SHALL BE CARRIED"
FIG.17 MANDATORY ACTION SIGN



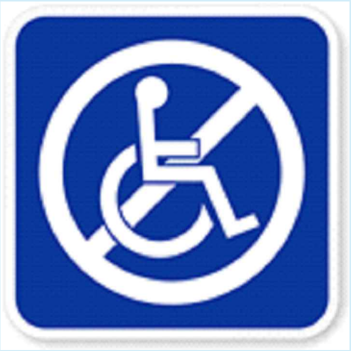
"USE THE HANDRAIL"
FIG.18 MANDATORY ACTION SIGN



"PUSH CHAIRS NOT PERMITTED"
FIG.19 PROHIBITION SIGN



"SOFT FOOTWEAR PROHIBITED"
FIG. 20 PROHIBITION SIGN



"WHEELCHAIR USERS NOT PERMITTED"
FIG. 21

Stop devices shall be colored red either on the device itself or in its immediate vicinity and be marked with the inscription ‘STOP’.

During maintenance, repair, inspection or similar work, the access to the escalator or moving walk shall be barred to unauthorized persons by devices which shall bear the notice ‘NO ACCESS’ or the ‘NO ENTRY’ indicator and be available in immediate area.

NOTE — The safety sign (*see* Fig. 21) shall be affixed prominently near the entrances of escalators or moving walks which are inclined above 6˚.

c) *Instructions for hand winding devices* — If a hand winding device is provided, operating instructions for use shall be available in the vicinity. The direction of travel of the escalator or moving walk shall be indicated clearly.

d) *Notices on the access doors to machinery spaces outside the truss, driving and return stations* — On access doors to machinery spaces outside the truss, and driving and return stations, a notice shall be fixed with the inscription reading, ‘MACHINERY SPACE — DANGER’ and ‘ACCESS PROHIBITED TO UNAUTHORIZED PERSONS’.

9 SPECIAL TECHNICAL REQUIREMENTS

If escalators or moving walks are intended to be operated under special conditions, such as directly exposed to the weather or explosive atmosphere, or in exceptional cases serve as emergency exits, appropriate design criteria, components, material and instructions for use should be used that satisfy the particular conditions.

9.1 Escalators or Moving Walks for Public Transport

For escalators and inclined moving walks for public transport which:

a) are part of a public transport system including entrance and exit points; or

b) are suitable for intensive use, regularly operating for approximately 140 h/week with a load reaching 100 percent of the brake load for a total duration of at least 0.5 h during any time interval of 3 h.

It is recommended to install auxiliary brakes also for rises less than 6 m. Auxiliary brakes shall be mandatory for public transport. The load conditions and additional safety features should be agreed to between the manufacturer and the owner reflecting the traffic levels which exist.

9.2 Semi Outdoor Escalator/Moving Walk

Semi-outdoor escalators and moving walks are installed outside the building while they have roofs above them to protect them from rain and snow. Wherever possible, the escalator/moving walks should be placed above the road level, with a ramp, to prevent water on the road directly entering the escalator/moving walk. These escalator/moving walk shall have:

a) Aluminium die-cast step;

b) Outdoor type handrail;

c) Three-layered protective truss painting;
d) Float switch at lower machine room;
e) Cooling fan in control panel box;
f) Control box of IP54 protection rating;
g) Inverter with enclosure of IP54 protection rating;
h) Safety switch IP65 protection rating;
j) Comb heating (temperature below 4 °C) (if applicable);
k) Step/pallet band heating (temperature below 0 °C) (If Applicable);
m) Lubrication: Lifetime lubricated and sealed step chain roller bearings; and
n) Water drainage system.

9.3 Outdoor Escalator/Moving Walk

Fully outdoor escalators and moving walks are installed outside the building without any roof or overhead covers. Wherever possible, the escalator/moving walk should be placed above the road level, with a ramp, to prevent water on the road directly entering the escalator or moving walk. These escalator/moving walk shall have:

a) Aluminium die-cast step;
b) Extrude aluminium floor plate panel;
c) Outdoor type handrail;
d) Hot-Dip galvanized truss (minimum thickness of 85 microns);
e) Zinc plated track and handrail guide;
f) Galvanized steel drive chain cover;
g) Float switch at lower machine room;
h) Control panel box cooling system:
    1) with inbuilt cooling fan; or
    2) with external cooling fan.
j) Control box of IP54 protection rating;
k) Inverter with enclosure of IP54 protection rating;
m) Safety switches of IP65 protection rating;
n) Stainless steel material grade 304 or higher for skirting, outer decking, handrail decking, balustrade (if not glass balustrade);
p) Class E insulation of electromagnet;
q) Class F insulation of motor;
r) Comb heating (temperature below 4 °C) (if applicable);
s) Step/Pallet band heating (temperature below 0 °C) (if applicable);
t) Lubrication-Life time lubricated and sealed step chain roller bearing;
u) Water drainage system;
w) Provision of galvanized drip pans below the step chain throughout the length of chain with catch tray at return station;
x) Automatic lubrication system with lubrication reservoir of adequate capacity;
y) Provision of hose/pipe to drain water from oil/water separator;
z) Provision for prevention of flooding of return station; and

aa) Stainless steel fasteners, wherever provided.

9.4 Measures to Prevent Access of Shopping Trolleys and Baggage Carts

9.4.1 *General*

If there is a reasonably foreseeable risk that shopping trolleys and/or baggage carts may be taken onto escalators or moving walks, adequate measures shall be taken to eliminate risks and access shall be prevented, if the following conditions are given:

a) *For escalators* — Where shopping trolleys or baggage carts are available in the area around; and where shopping trolleys or baggage carts are in an area not close to the escalator, but it is reasonably foreseeable that they are taken onto the escalator.

b) *For moving walks* — Where shopping trolleys or baggage carts are not intended to be used on a moving walk.

9.4.2 *Barriers*

If barriers are used, the following requirements shall be fulfilled:

a) Barrier shall be installed at the entrance only. An installation at the exit is not permitted in the unrestricted area;

b) Design of the barrier shall not create another risk;

c) Free entrance width between ends of the newels and barriers and between barriers itself, shall be at least 500 mm and less than the width of the type of shopping trolley or baggage cart to be used;

d) Height of the barrier shall be between 900 mm and 1 100 mm;

e) Barrier and its fixation should withstand the following load: At a height of 200 mm a horizontal force of 3 000 N applies. This force results from an impact of a chassis of a shopping trolley/baggage cart loaded with 160 kg moving with a speed of 1.00 m/s;

f) Barrier shall be fixed preferably at the building structures. It is also permitted to fix it at the floor plate. In that case, when the defined forces apply, there shall be no permanent deformation and increased/additional gaps; and

g) If the escalator/moving walk is dedicated to operating in both directions, the presence of the removable barrier shall be electrically monitored preventing wrong positioning of the barrier resulting in operation towards the barrier, except when under maintenance condition.

9.4.3 *Fixed Devices*

Where fixed devices such as guiding barriers and/or traffic columns are necessary in the unrestricted area, their design shall not create another risk. The following requirements shall be complied with:

a) Guiding barriers or traffic columns shall have a minimum horizontal distance (radius) of 500 mm to any point of the handrail and shall be positioned outside of the centre line of the handrail;

b) Minimum horizontal distance (radius) to any point of the handrail may be reduced to 300 mm, provided that the guiding barriers or traffic columns are positioned outside of the centre lines of the handrails and an additional barrier is installed between the guiding barriers or traffic columns and the vertical centre line of the balustrade newel;

c) The additional barrier shall have a lateral distance between 80 mm and 120 mm of the handrail outer edge and shall close at least the area between the actual lowest point of the handrail entry into the newel and the balustrade decking profile and shall have filled inlets with gaps less than 25 mm;

d) Minimum horizontal distance (radius) to any point of the handrail may be reduced to 180 mm, provided that the guiding barrier or traffic column is positioned outside of the outer edge of the handrail and an additional barrier is installed between the guiding barrier or traffic column and the vertical centre line of the balustrade newel;

e) The additional barrier shall have a lateral distance between 80 mm and 120 mm of the handrail outer edge and shall close at least the area between the actual lowest point of the handrail entry into the newel and the balustrade decking profile and shall have filled inlets with gaps less than 25 mm; and

f) Minimum horizontal distance (radius) to any point of the handrail may be reduced to 100 mm, provided that the guiding barrier or traffic column is of a round shape and is positioned outside of the outer edge of the handrail and an additional barrier is installed between the guiding barrier or traffic column and the vertical centre line of the balustrade newel.

In addition, the following specific requirements shall apply:

1) Devices and its fixation shall withstand a horizontal force of 1 kN/m applied to the top of the device;

2) Barrier shall be fixed preferably at the building structures. It is also permitted to fix it at the floor plate. In that case, when the defined forces apply, there shall be no permanent deformation and increased/additional gaps;

3) Height of traffic columns shall be at least the height of the handrail level;

4) Height of guiding barriers shall be at least the height of the balustrade decking;

5) If fixed devices are placed inside the unrestricted area, the size of the unrestricted area shall remain the same and in this case be extended in the length; and

6) Guiding barriers and traffic columns are not considered as structural measures that block the exit.

NOTE — For fixed devices in the immediate environment of the unrestricted area these requirements also apply.

9.5 Escalators and Moving Walks Subject to Seismic Conditions

9.5.1 *Structural Requirements*

The requirements given below are applicable:

a) *General* — Escalators and moving walks, if specified to meet specified seismic conditions, shall comply with the relevant safety requirements and/or protective measures as listed below;

b) *Pit/support* — Pit and support conditions are to be secured in that way that the escalator and moving walk under seismic condition is not subjected to constraint. One support should be executed as fixed support and the other supports are to be executed as movable support in horizontal direction. The supporting conditions need to be simply statically determinate;

c) Escalator and moving walk shall be retained on the supports in vertical direction by adequate measures so that the unit shall not jump off the supports under seismic conditions;

d) *Arrangement* — The length and the movability of the escalator and moving walk should be chosen in accordance with the building movement between two storeys of the building. The minimum allowable compensation length of the movable support of the escalator and moving walk has to be chosen same as the maximum allowed storey drift of the building; and

e) *Mechanical safety devices for escalators and moving walks* — If the design of the escalator and moving walk does not allow the safe situation in the pit or support an additional safety device need to be applied so that the escalator and moving walk should not fall off the support.

9.5.2 *Design Requirements*

It is assumed that negotiations have been made for each contract between the customer and the supplier/installer about the peak ground acceleration to be considered. The building designer or owner shall provide the design acceleration which shall be documented in the information. Client and supplier/contractor should agree on one common acceleration value. The acceleration value needs to be communicated between all participants of the contract. The following to be considered in addition to the above:

a) The design of the truss for the escalators and moving walks shall be sufficiently executed for the ambient seismic condition. The structural design shall provide a dissipation capacity to withstand a design-relevant earthquake of the region where it is located;

b) *Drive and control unit* — Machinery [including control cabinet(s) and drive system, machine, main switch(es), and means for emergency operations], free-wheeling switch shall be designed and anchored to prevent overturning and displacement due to the forces imposed on them including forces generated by the design acceleration; and

c) *Electrical installation and other equipment* — In case the building where the escalator and moving walk will be installed is equipped with a seismic detector/sensor, the electrical system of the unit shall provide an interface for the connection and shall stop the escalator and moving walk in case of seismic activity.

9.6 Escalator/Moving Walk Interface with Building Management System (BMS)

Where required, a means to interface, monitor and control be provided by the escalator/moving walk manufacturer, which should become the part of building management system. Following information and controls, but not limited to these, may be provided either through potential free contacts or building automation interface device suitable for providing necessary escalator/moving walk information over accepted communication protocols:

a) *Monitoring signals:*
   1) Power status;
   2) Running up/down (Escalator);
   3) Running forward/backward (Moving walk);
   4) Under maintenance;
   5) Under fault; and
   6) Emergency 'STOP' pressed.

b) *Remote operation* — Escalator or moving walk shall not be started or stopped from remote monitoring station using remote signal, unless the escalator/moving walk operation is visible/monitored from the remote station.

10 PERFORMANCE REQUIREMENTS FOR ESCALATORS AND MOVING WALKS

10.1 It is necessary to have uniformity in the definition, measurement, processing and expression of vibration and noise signals that comprise escalator and moving walk ride quality. The aim of such uniformity is to benefit escalator and moving walk users by reducing variability in the results of ride quality measurements caused by differences in the methods of acquiring and quantifying the signals. Experience indicates that passenger perception and sound pressure levels measured while travelling on an escalator or moving walk may be influenced by the presence of extraneous noise and vibration sources and by acoustic characteristics of the environment in which the unit is installed and operated. Additionally, the proximity of the escalator or moving walk to strong reflecting surfaces such as walls, ceilings or diagonally opposite units may also influence the sound pressure level measured. These influences may cause a sound pressure level measurement to significantly overestimate the sound level emitted exclusively by the unit. To address this issue, this Subsection defines the methodology for measuring vibration and sound pressure level that corresponds to passenger perception and additionally defines the methods that should be used, if further understanding of the result is required to quantify vibration and noise emitted by the unit as compared to the background or environmental contributions.

10.2 Measurement of Escalator and Moving Walk Ride Quality

Escalator and moving walk should be measured in both running directions except where the unit is designed to operate in one direction only. The measurements should be carried out under following conditions where, escalator and moving walk shall:

a) be assembled completely, adjusted and operating in accordance to the requirement;

b) have reached normal operating temperature;

c) be measured in unloaded condition;

d) be measured after starting sequence has been completed. If the unit operates at different speeds, all the speeds shall be measured;

e) have finished star/delta changeover, if used, before starting the measurement;

f) have vibration measurements made by aligning the axis of transducer to the axis of entire escalator or moving walk; and

g) have the noise measured at measuring distance to the floor/surface of steps and pallets of 1.55 m ± 0.075 m.

NOTE — Accepted standard [D-5B(4)] shall be referred for Ride Quality measurements.

11 ESCALATOR AND MOVING WALK ENQUIRY OR INVITATION TO TENDER

11.1 A period of two to four weeks is normally sufficient for return of tenders. This should be extended if large numbers of escalators/moving walks or special requirements are involved. The enquiry documents should be kept to the essential minimum and should be strictly confined to material relevant to the escalators/moving walk works and to the project concerned.

When enquiring for and ordering the escalators/moving walks, the particulars given below should be furnished:

a) Type(s) of escalator/moving walk;
b) Number of escalators/moving walks;
c) Location of escalators/moving walks (indoor or outdoor);
d) Capacity/usage type (persons per hour/heavy duty, medium duty, light duty);
e) Angle of inclination, in degree;
f) Rise (travel), in mm;
g) Nominal speed, in m/s;
h) Step width, in mm;
j) Number of flat steps (2 or 3 or 4);
k) Balustrade details;
m) Construction, design, finishes details;
n) Escalator/moving walk lighting details;
p) Electric supply — power volts a.c./d.c.; phase; cycles; wire system;
q) Proposed date for commencement on site;
r) Additional items, if required;
s) Details of maintenance, schedule and circuit diagram where so specified;
t) Details of voice announcements, visual contrast, tactile indicators and warning signage; and
u) Number of horizontal steps/pallets.

11.2 Additional Items

The enquiry should state any additional items required beyond those specified in accepted standards [D-5B(3)], such as interface requirements, seismic design, etc.

11.3 Finishes

Finishes should be specified at the enquiry stage or provisional sums should be included for them. Finishes to be considered may include step lighting, handrail colour, handrail lighting, balustrade material, step colour, truss cladding details (weight to be considered).

11.4 Inclusions and Exclusions

Several peripheral items are associated with escalators/moving walk installation, of which some should always be provided by the builder, and some are best included by the manufacturer. The requirements vary to some extent with the type of installation.

It is important that the limits of responsibility are clearly understood, and the enquiry documents should be specific in this respect.

The escalators/moving walk manufacturer should include items (as applicable), such as:

a) tracks;
b) drive unit;
c) controller;
d) broken chain detection switch;
e) stop switches at both ends;
f) balustrade;
g) handrail;
h) steps/step drive assembly;
j) saree/skirt guard;
k) step demarcation lights;
m) missing steps;
n) comb plate;
p) flat steps;
q) comb plate switches/skirt switches;
r) floor plate (anti-slip material);
s) truss;
t) guarantee of equipment; and
u) scaffolding for installation.

The escalators/moving walk manufacturer should exclude the supply and fixing of the items (as applicable) or as per the contract conditions as follows:

1) Hoisting hook/beam fixing;
2) Truss cladding;
3) Temporary guarding;
4) Cutting and making goods;
5) Working lights/permanent electricity supplies; and
6) Site painting of steel work.

For more detailed discussion of the requirements for site preparation and work by other trades, reference should be made to relevant provisions of this NBCS and other good practices.

Facilities for the use of the main contractor's crane should be provided to assist in installing heavy equipment in addition to other unloading facilities on site in the course of erection. The main contractor should be instructed to include these facilities in his own bill of quantities.

11.5 Site Programme

The enquiry should indicate as accurately as possible the contract programme as it affects the manufacturer, in particular the target date for completion, construction schedule, site preparedness, the availability of crane for hoisting, co-ordination details (with other contractors like BMS interfacing, CCTV interfacing, etc).

12 ACCEPTANCE OF TENDER AND SUBSEQUENT PROCEDURE

12.1 Order

The owner places an order with the selected contractor for supply and installation of escalator/moving walk.

12.2 The general arrangement drawings supplied by owner with the tender documents,

a) are provided for the supplier's guidance and information when tendering;

b) should the arrangement and dimensions shown be inadequate to properly install the equipment as specified then necessary amendments shall be issued by client; and

c) any amendments issued after the commencement of contract shall be subject to the agreement and approval.

12.3 Layout Drawing

The contractor shall furnish proposed layout giving particulars such as dimensions, steel work requirements and loading imposed on structure. Such drawings shall include following details:

a) Position and sizes of all holes and cuttings;

b) Loads on beams and structure;

c) Escalator/moving walk pits and associated equipment;

d) Requirement of end supports, intermediate support(s) with location and load;

e) Hoisting facilities and access requirement for delivery of equipment;

f) Builder's work; and

g) Power and ventilation requirement.

12.4 Approval of Layout Drawing

The contractor shall commence actual production of equipment after approval of drawings submitted by contractor. Where the contract provides for the purchaser's choice of decorative finishes, colours, etc, the decisions should be communicated as early as possible, and preferably not later than the time of approval of drawings.

12.5 Programme of Works

The contractor shall submit a detailed programme showing intended method and stages together with period estimated for each stage. The programme shall include following:

a) date of commencement and completion of every stage of the works in line with the building construction programme;

b) date of expected completion of builder's work requirements;

c) date of delivery of equipment and materials to site;

d) date of requirement of temporary and permanent electricity supply; and

e) date of completion, commissioning and testing.

The contractor shall ensure the work in accordance with the criticality of adherence of installation dimensions and supports as indicated in layout.

12.6 Electricity Supply to Escalators/Moving Walk

Operation of the machine under power is required from a comparatively early stage of installation for most efficient working, and power supply shall be furnished accordingly. Whilst temporary power supply may be sufficient for erection purposes, final testing and setting up should only be carried out with the permanent power supply connected. For this reason, the timely provision of the permanent power supply is important.

13 COORDINATION OF SITE WORK

13.1 Preparatory Work on Site

13.1.1 It is expected for the escalator/moving walk supplier to make periodic visits to the site to check progress on the construction and discuss relevant matters with the owner. The contractor should assure himself that all building work has been completed in accordance with his requirements. Immediately before the time for erection to commence, the contractor should check that site conditions are fit to permit erection to proceed.

13.1.2 Building works to be completed before the erection work, includes the following:

a) Providing adequate access to the well-way to allow for setting the equipment in place;
b) If the project is not ready for placement at the time of delivery, providing dry storage area located close to well-way;
c) Providing protection of all floor openings adjacent to and in the general area of escalator/moving walk;
d) Providing safety compliant stairwell access to floors;
e) Providing clear unobstructed workspace adjacent to well-way;
f) Providing safety compliant overhead and floor opening protection;
g) Providing barricades to prevent the entrance of unauthorized personnel to construction area;
h) Drying and cleaning of pit and floor openings with proper dimensions;
j) Providing properly located supports of adequate strength for the truss at the landings including intermediate supports, if required;
k) Providing suitable floor fill and patching of flooring including floor covering, adjacent to the landing plates of the escalator/moving walk; all floor finishing to be completed after installation of the landing plates; and
m) Providing flooring with little slope in direction outwards of the escalator to prevent ingress of water, etc, into the escalator.

13.2 Delivery of Material

The contractor should advise the owner when equipment is ready for dispatch, so that the owner is able to make arrangements on site to receive and unload as near as possible to the well-way.

13.3 Storage

Adequate provision should be made by the owner for storage, protection and preservation against loss, deterioration of or damage to all material on the site. Attention is drawn to the adverse effect of damp conditions on electrical equipment.

13.4 Site Meetings

The contractor shall coordinate his proposed programme of work with that of the building contractor and all other contractors and sub-contractors to adhere to the latest overall construction programme and to achieve efficient and safe working on site. In large sites, regular meetings of all parties are beneficial for successful progress of work.

13.5 Service of Other Trades

The contractor may require the services of other trades as the work proceeds, and it is essential that the contractor should give due notice to the building contractor of the demands to be made on other trades, so that he may plan accordingly.

13.6 Connecting to Power Supply

The contractor should give prior notice to the owner of the date the power supply is required, so that suitable arrangements for connection can be made. During erection, necessary electrical power shall be provided for illumination, operation of required tools and hoist and for starting, testing and adjustment.

14 INSPECTION AND ACCEPTANCE PROCEDURES

14.1 General

Escalators and moving walks shall be inspected, before their first use; after major modifications; and at regular intervals. Such inspections and tests should be made by a competent person.

14.2 Constructional Inspection and Acceptance Inspection and Test

14.2.1 The constructional inspection and acceptance inspection and test shall be carried out at the jobsite on completion of the escalator or moving walk. During inspection and tests, precautions shall be taken so that escalators or moving walks are not set in motion without the knowledge and consent of the person(s) performing such work.

For the constructional inspection and acceptance inspection and test, the data specified in **14.4** should form part of a pre-completed test sheet. Furthermore, layout drawings, description of the equipment and wiring diagrams (current flow chart with legend or explanations, and a terminal connection chart) which permit a check of compliance with the safety requirements, shall be provided.

The constructional inspection comprises the examination of the completed installation for conformity with the required data and about proper workmanship as specified hereunder.

14.2.2 The acceptance inspection and test comprises,

a) overall visual inspection;

b) functional test;

c) test of electric safety devices regarding their effective operation; and

d) test of the brake(s) of the escalator or moving walk under no load, for compliance with the prescribed stopping distances.

Measurement of the insulation resistance of the different circuits between conductors and earth shall also be done. For this measurement, the electronic components shall be disconnected. This includes a test of the electric continuity of the connection between the earth terminal(s) in the driving station and the different parts of the escalator or moving walk, liable to be live accidentally.

14.3 Inspection and Test after Major Modifications

A major modification is a change of the location, a change of the speed, of the electric safety devices, of the braking system, of the drive, of the control, of the step band, of the truss and of the balustrades. Wherever applicable, the principles set forth for the constructional inspection and acceptance inspection and test should apply to the new environmental conditions, modified components and other components which are affected.

The replacement of parts with parts of same design is not considered to be a major modification.

14.4 Specific Data, Test Reports and Certificates

The following documentation should be held by the manufacturer:

a) stress analysis of the truss or equivalent certificate by a stress analyst;

b) proof by design calculation of sufficient breakage resistance of the parts directly driving the steps, pallets or the belt, for example step chains, racks;

c) calculation of the stopping distances for loaded moving walks together with adjustment data;

d) proof testing of steps or pallets;

e) proof of the breaking strength of the step chain/pallet chain/belt;

f) proof of sliding coefficients for skirting;

g) proof of anti-slip properties of tread surfaces (steps, pallets, floor and comb plates without combs);

h) proof of stopping distances and deceleration values;

j) proof of electromagnetic compatibility; and

k) test certificate for handrail breaking strength (for public service escalators and public service passenger moving walks).

14.5 Escalator Site Checks and Inspection List

Suitable site checklist/inspection list may be used. A typical list is given at Annex A.

14.6 Escalator Commissioning and Acceptance Tests

14.6.1 *Escalator Details*

Typical details to be provided are given below:

a) Name of station :

b) Location :

c) Escalator No. and job No. :

d) Drawing No. :

e) Rise :

f) Type of balustrade : SS/Glass - Tick (√)

g) Manufacturer's Sl No. :

14.6.2 *General Inspection*

A typical general inspection list is given below:

Sl No.	*Item*	*Method/Requirement*	*Result*
(1)	(2)	(3)	(4)
i)	All unwanted material have been removed	Visual check	
ii)	Escalator (including steps, handrails, floor plate, cladding, etc) has been cleaned	Visual check	

Sl No.	*Item*	*Method/Requirement*	*Result*
(1)	(2)	(3)	(4)
iii)	Proper barricading of the area has been done prior to testing	Visual check	
iv)	Emergency signage to be fixed at the emergency stop; safety labels placed at top/bottom newel end	Visual check	
v)	Check provision of 'Danger Sign' plate on the escalator control panel	Visual check	
vi)	Wedge guard/deflector fixed for obstacles such as walls, pillars, floor intersection or criss-cross arrangement of escalators/moving walks	Visual check	
vii)	Clear height of 2.3 m above steps throughout the length of escalator	Measurement check	
viii)	Access restriction guard fixed between parallel escalators	Visual check	
ix)	Permanent barriers at entry and exit with gaps according to code requirement	Measurement check	
x)	Connection of hose/pipe to oil/water separator	Visual check	
xi)	Power cables and earthing provided at drive station	Visual check	

14.6.3 *Electrical Test*

A typical check list of electrical tests is given below:

Sl No.	*Item*	*Test Procedure*	*Recommended Result*	*Instrument / Sl No.*	*Measured Value*	*Result*
(1)	(2)	(3)	(4)	(5)	(5)	(7)
i)	Insulation resistance test	Shall be tested between lines connected together and earth at 500 V d.c.	> 0.5 MΩ (Mega Ohm)			

NOTES

1 Protective earthing of escalator shall be as per clauses 4.2.11.3.1.1 of good practice [D-5B(5)].

2 Verification of the effectiveness of the measures for fault protection by automatic disconnection of supply shall be according to 6.2.3.6 and 6.2.3.7 of good practice [D-5B(5)].

3 Where the current exceeds 10 mA under normal operating conditions, a reinforced protective conductor shall be used according to 5.4.3.7 of good practice [D-5B(5)].

14.6.4 *Functional Tests on Safety Switches and Devices*

A typical check list is given in Annex B

15 OPERATION AND MAINTENANCE

15.1 General

The installation shall be maintained in good working order in accordance with the installer's instructions. To this effect, regular maintenance of the installation shall be carried out to ensure the safety of installation. The safety of an installation shall consider the ability to be maintained without causing injury or damage to health.

Regular maintenance of the installation shall be carried out to ensure the reliability of the installation. The access and the associated environment shall be maintained in good working order in accordance with the installer's instructions.

The instructions for maintenance of an installation shall be provided by the manufacturer, when placed on the market, after risk assessment.

In order that the aim of the maintenance instructions should be achieved, they shall be formulated so that they should be clearly and easily understood by competent maintenance person. The competent maintenance person within the maintenance organization shall be continuously updated.

The installer/manufacturer shall provide maintenance instructions intended for the owner of the installation (*see* **15.3.2**) including the information intended for the maintenance organization (*see* **15.3.3**).

NOTE — The owner of the installation should be informed that the qualification of the maintenance organization is in conformity with the regulation applicable in the location in which the installation operates.

Maintenance aspects include:

a) Lubrication, cleaning, etc;

b) Checks;

c) Passenger rescue operations;

d) The operations of setting and adjustment; and

e) Repair or changing of components which may occur due to wear and tear, and do not affect the characteristics of the installation.

However, cleaning of the external parts of the escalator or moving walk shall not be considered as maintenance.

The following shall not be considered as maintenance operations:

1) changing of major component, such as the machine, even if the characteristics of the new component are the same as the original;
2) replacement of installation;
3) modernization of the installation including changing of any characteristics of the installation (such as load, speed, etc); and
4) rescue operation carried out by fire brigade.

15.2 Elements to be considered for Maintenance Instructions

When preparing the content of the maintenance instructions (*see* **4.3** and **5**) the following elements shall be considered:

a) Specifications and the intended use of the installation (type of installation, performance, etc);

b) Environment in which the installation and its components are installed (weather conditions, vandalism, etc);

c) Any restriction of use;

d) Result of risk assessment (*see* **5**) for every working area and for every task undertaken;

e) Specific maintenance instructions provided by the manufacturer of safety components; and

f) In case of components other than safety components, where maintenance is necessary, the maintenance instructions provided by the manufacturer of these components.

15.3 Information to be Included in the Maintenance Instructions

15.3.1 *General*

The maintenance instructions shall contain information relating to the tasks of both the owner and the maintenance organization, respectively.

15.3.2 *Information to the Owner of the Installation*

The information relating to the tasks of the owner of the installation shall include the following:

a) Need for the owner to keep the installation in a safe operating condition. To fulfil this, the owner shall use a maintenance organization complying with the requirements of this Subsection;

NOTE — It is recommended to inform the owner of the installation about the need to use a maintenance organization with adequate and proper insurance cover provided by an insurance company.

b) Need for the owner to take care of applicable regulation(s) and other requirements, where relevant, and their implications on maintenance;

c) Need for planned maintenance to be carried out by a maintenance organization, at the latest when the installation is put into service or if the installation is to remain unused for a long period of time before first being put into service;

d) Importance for the owner of the installation to have the same maintenance organization in the case of several installations having common well/spaces and/or machine room;

e) Need for the owner to put the installation out of service in case of dangerous situations;

f) Need for the owner of the installation to inform the maintenance organization:

   1) Immediately about any perceived abnormal operation of the installation or abnormal change in its direct environment;

   2) Immediately after putting the installation out of service in the case of a dangerous situation;

   3) After any rescue intervention by their authorized and instructed person(s);

   4) Before any modification related to the installation and/or its environment or use;

   NOTE — The owner of the installation should obtain from the company carrying out the relevant modification the maintenance instructions for the maintenance organization.

   5) Before any authorized third-party inspection or works other than maintenance works are carried out on the installation;

   6) Before taking the installation out of service for a prolonged period; and

   7) Before putting the installation back into service after a prolonged period of non-operating time.

g) Need for the owner of the installation to take into consideration the consequences of the risk assessment carried out by the maintenance organization;

h) Need for the owner of the installation to make sure that the risk assessment for maintenance is carried out:

   1) If the maintenance organization is replaced;

   2) If the use of the building and/or the installation changes;

   3) After a major modification of the installation or of the building; and

   4) If it is the case, after an accident involving the installation.

j) Need for the building owner to ensure, through a risk assessment, that:

1) their premises are safe and free from risk to health as far as is practicable. This includes access to the premises and installation equipment, and articles or substances used according to the regulation for the use of work equipment at the workplace;

2) the persons using the premises are informed about any remaining risks; and

3) any action to be done as a consequence of risk assessment carried out.

Regarding the access ways to areas reserved for maintenance persons, the need for the owner of the installation to inform the maintenance organization, about,

i) the access ways to be used and fire evacuating procedures from the building;

ii) the place where the keys of the reserved areas shall be found;

iii) if necessary, the persons who shall accompany the maintenance persons to the installation; and

iv) if necessary, personal protective equipment to be used in the access ways, and, possibly, where this equipment shall be found.

The information shall be made available also on site to the maintenance organization.

k) Need for the owner of the installation to ensure that the name and the telephone number of the maintenance organization are always available to the user of the installation, permanently affixed and clearly visible;

m) Need for the owner of the installation to ensure that the keys of machine room doors (trap doors) and of inspection and emergency doors (trap doors), if any, are permanently available in the building and are used only by persons authorized to gain access;

n) Need for the owner of the installation to provide, in all circumstances, safe access to the building and to the installation for the maintenance organization involved in the rescue of persons;

p) Need for the owner of the installation to keep the access to working areas and working rooms safe and free for the maintenance persons and to inform the maintenance organization about any hazard or change in the workplace and/or the access ways (lighting, obstructions, ground conditions, etc);

q) In addition to those examinations and tests (for escalators/moving walk) which the owner of the installation entrusts to the maintenance organization, the need for the owner to carry out periodically, in their own interests, include the following:

1) A full travel in both directions, when they exist, to assess any changes in the quality of the ride or damage to the equipment.

2) Typical items to be checked to ensure that they are in place, undamaged and functioning correctly are:

i) all lighting and indicators;

ii) emergency stopping device;

iii) handrails;

iv) skirting/deflector devices;

v) combs;

vi) safety signs/pictograms;

vii) approximation of speed between handrail and steps/pallets;

viii) steps/pallets;

ix) balustrade and panels;

x) head guard and decking; and

xi) safe and unobstructed access to entry and exit areas.

15.3.3 *Information for the Maintenance Organization*

The information relating to the tasks of the maintenance organization shall include the following:

a) Need to carry out the work of maintenance in conformity with the maintenance instructions and based on systematic maintenance checks. After these checks, the maintenance organization shall decide in conformity with the maintenance instructions what is required to be done. A list of typical examples of maintenance checks to maintain the installation is shown in Annex C;

   NOTE — Due to the fact that the components may be different in design and operation, it is therefore not possible to give specific guidelines in this Subsection.

b) Need to update the original maintenance instructions, if the installation changes its intended use and/or the environmental conditions existing on the completion of the installation;

   NOTE — The maintenance organization should be provided by the owner of the installation with the relevant maintenance instructions where modifications are carried out on the installation.

c) Need for the maintenance organization to ensure that a risk assessment for any working area and for any maintenance operation has been carried out considering the installer's maintenance instructions and all information supplied by the owner of the installation;

d) Need for the maintenance organization to inform the owner of the installation about any work to be carried out as a consequence of a risk assessment especially for the access and/or the environment related to the building/installation;

e) Need to carry out a maintenance plan so that preventive maintenance is suitable for the installation and maintenance time is as short as reasonably practicable, without reducing the safety of persons, in order to minimize the non-operational time of the installation;

f) Need to adapt the plan for maintenance to take account of any predictable failures, for example, those due to misuse, mishandling, deterioration, etc;

g) Need to carry out maintenance operations by competent maintenance persons and provided with the necessary tools and equipment;

h) Need to maintain the competency of maintenance persons;

j) Need to carry out the maintenance periodically. In determining the frequency of maintenance interventions, the following non-exhaustive list should be considered:

   1) Operating time and any non-operating periods of time;

   2) Age and condition of the installation;

   3) Location and type of building in which the installation is installed, as well as the needs of the users; and

   4) Local environment where the installation is situated, as well as external environmental elements, for example, weather conditions (rain, heat, cold, etc) or vandalism.

k) Need to provide a 24 h, all year-round call-out service for rescue of persons;

m) Need to keep records of the result of each intervention due to a failure of the installation. These records shall include the type of failures to detect any repetition. They shall be available to the owner of the installation on request;

n) Need to put out of service the installation, if the maintenance organization is aware of a dangerous situation, detected during the maintenance, which cannot be eliminated immediately, and to inform the owner of the installation of the need to keep it out of service until repaired;

p) Need to be organized to provide the necessary spare parts for any repair;

q) Possible need for attendance of a competent maintenance person(s), given reasonable notice, for any inspection carried out by an authorized third party or for building maintenance works to be carried out in the areas reserved for the maintenance organization;

r) Need to inform in due time, the owner of the installation about necessary progressive upgrading of the installation; and

s) Need to organize rescue operations, even with sub-contractor(s), and to make provision for circumstances such as fire, panic, etc.

15.4 Maintenance Contract

It is recommended that the maintenance is carried out by original equipment manufacturer (OEM). Any maintenance contract should include the following at a minimum, to ensure that escalators/moving walk is always maintained/operated in the safe working condition:

a) All batteries used for emergency operations;
b) All safety switches/devices;
c) Handrail system components including handrails;
d) Operational and auxiliary brake; and
e) Combs.

15.5 Risk Assessment

15.5.1 *General*

Before an installation is placed on the market, it is necessary that the installer/manufacturer carries out a risk assessment. Every risk shall be limited as much as reasonably possible by means of safety measures and suitable instructions. The instructions can never replace a safety measure which can be provided to reduce the risk.

It is necessary to determine the different intervention procedures of the maintenance operations and to determine the appropriate safety measures for each of these procedures.
The use of diagnostic systems may support fault finding, improve the maintainability of the installation and reduce the exposure of maintenance persons to hazards.

Safety in maintenance operations of the installation is ensured by adopting safety measures and providing instructions. Safety measures on the installation and in the building shall be provided by the installer and by the owner of the installation, respectively.

For any working area, it is necessary to identify the list of the specific hazards related to health and safety and to carry out a risk assessment for any maintenance operation, including access to the working area.

For this purpose, the following should be considered:

a) Presence of one or more maintenance persons in a working area;
b) Foreseeable actions of persons other than maintenance persons (for example, person switching on or off power circuits and dependent circuits or lighting circuits or trying to use the installation during maintenance operations, etc); and
c) Possible states of the installation (normal or abnormal due to a foreseeable failure of its component parts, external disturbances, disturbance of its power supply, etc).

Annex D gives a list of examples of elements to be considered in any risk assessment for maintenance operations. However, several methods are available for the systematic assessment of risk.

15.5.2 *Information for the Maintenance Organization*

For safe maintenance and to provide relevant instructions, it is first necessary to identify the maintenance operations.

Maintenance operations are:

a) those operations considered necessary for a correct and safe functioning of the installation and its components after the completion of the installation; and
b) those operations considered necessary during the 'life' of some components, determining, as far as possible, the time or condition after which the functioning or the integrity of the component is no longer ensured even if correctly maintained.

In carrying out specific maintenance operations, if it is necessary to neutralize some safety functions (for example, an electric safety device), the hazard identification shall be considered for such a situation.

It is necessary to inform and warn the maintenance persons about: (a) residual risks, that is, those for which risk reduction by design and safeguarding techniques are not there or not completely effective; and (b) risks that arise from the necessary removal of certain guards to carry out specific maintenance operations. The maintenance instructions and warnings shall prescribe the procedures and operating modes intended to overcome these risks and, if it is necessary, to specify personal protective equipment, instruments, tools and provisions to be used.

15.6 Markings, Signs, Pictograms and Written Warnings

If the risk assessment of the maintenance organization indicates that additional specific warnings are required for the purpose of maintenance, these shall be affixed directly on the installation/component or, in the close vicinity, when this is not possible. Markings, signs, pictograms, and written warnings shall be readily understandable and unambiguous. Readily understandable signs and pictograms shall be used in preference to written warnings.

Signs or written warnings carrying only the words ‘DANGER’ shall not be used. Information affixed directly on the installation/component shall be permanent and legible.

Any markings, signs, pictograms, and written warnings affixed on the installation shall be renewed if they become illegible.

15.7 Format of the Maintenance Instruction Handbook

The maintenance instruction handbook for any installation shall contain at the front at least the following:

a) Type of installation, with its serial number, to which the instructions apply;
b) Title of the handbook;
c) Date of issue;
d) Name and address of the installer/manufacturer; and
e) Name of the publisher, when different from the installer/manufacturer.

In the handbook:

1) all units used shall be SI units;
2) all pages shall be numbered; and
3) all references to other documents shall be in full.

Warnings shall state the hazard, the related risks, and the appropriate safety measure.

Type and size of print shall ensure the best possible legibility. Safety warnings and/or precautions shall be emphasised using colours or symbols and/or large print.

Documents giving instructions for maintenance shall be produced in durable form (that is, they shall be able to survive frequent handling) or triplicate copies shall be provided.

15.8 Maintenance Record and Annual Inspection

Maintenance organization is required to maintain a logbook at the equipment to record of maintenance and repair work carried out on the equipment. In addition, the layout diagram and latest wiring diagram is required to be maintained at the equipment by maintenance organization. Maintenance organization is required to carry out annual inspection of the installation and certify that escalator is in safe for operation. Owner of the installation is responsible for ensuring that any deficiencies found during the annual inspection are rectified before the equipment is put back in service.

ANNEX A

(*Clause* 14.5)

CHECK LIST FOR INSPECTION OF ESCALATOR/MOVING WALK AT SITE

Sl No. (1)	Reference No. (2)	Item (3)	OK (4)	Not OK (5)	NA (6)
	1	Escalator/Moving Walk - External			
i)	1.1	General fire protection			
ii)	1.2	Geometry			
iii)	1.3	Handrails			
iv)	1.4	Entrance and exit ends			
v)	1.5	Lighting			
vi)	1.6	Caution signs			
vii)	1.7	Comb-plate			
viii)	1.8	Deck barricade			
ix)	1.9	Steps/Pallets and upthrust device			
x)	1.10	Operating devices			
xi)	1.11	Skirt obstruction devices			
xii)	1.12	Handrail-speed monitoring devices			
xiii)	1.13	Speed			
xiv)	1.14	Balustrades			
xv)	1.15	Ceiling intersection guards			
xvi)	1.16	Step/pallet/skirt clearance panels and performance index			
xvii)	1.17	Outdoor protection			
	2	Escalator/Moving Walk - Internal			
xviii)	2.1	Machinery space access, lighting, receptacle and condition			
xix)	2.2	Stop switch			
xx)	2.3	Controller and wiring			
xxi)	2.4	Drive machine and brake			
xxii)	2.5	Speed governor			
xxiii)	2.6	Broken drive chain and disconnected motor device			
xxiv)	2.7	Reversal stop switch			
xxv)	2.8	Broken step/pallet chain switch			
xxvi)	2.9	Step/pallet upthrust device			
xxvii)	2.10	Missing step/pallet device			
xxviii)	2.11	Step/pallet level device			
xxix)	2.12	Step/pallet, step/pallet chains and trusses			
xxx)	2.13	Handrails			
xxxi)	2.14	Name plate			
xxxii)	2.15	Response to smoke detector			
xxxiii)	2.16	Log card			
xxxiv)	2.17	Pit cleanliness			
xxxv)	2.18	Inspection box			

ANNEX B

(*Clause* 14.6.4)

TYPICAL CHECK LIST FOR FUNCTIONAL TESTS ON SAFETY SWITCHES AND DEVICES

Sl No. (1)	**Check Point** (2)	**Method** (3)	**Value Required** (4)	**Measured Value** (5)	**Result** (6)
i)	Emergency stop switch	Push the button	OK/NOT OK	Top:	
			OK/NOT OK	Intermediate level:	
			OK/NOT OK	Bottom:	
ii)	Direction key switch (Start switch)		OK/NOT OK	Top:	
			OK/NOT OK	Bottom:	
iii)	Traffic bollard		OK/NOT OK		
iv)	Traffic light working	Check for correct movement indication. (Up/Down) visual check	OK/NOT OK	Top:	
			OK/NOT OK	Bottom:	
v)	Provision of comb light	Visual check	OK/NOT OK		
vi)	Sprinkler:				
	a) Connected to main system		Yes/No/NA		
	b) Number of sprinkler heads provided		Yes/No/NA		

ANNEX C

[(*Clause* 15.3.3(a)]

TYPICAL EXAMPLES OF MAINTENANCE CHECKS TO MAINTAIN THE INSTALLATION

C-1 ESCALATORS AND MOVING WALKS

Sl No. (1)	Component (2)	Checks (3)
i)	Controller	Check cabinet is clean, dry and free from dust
ii)	Gear box	Check gear and associated parts Check lubrication
iii)	Drive motor	Check bearings for wear Check lubrication
iv)	Brake	Check braking system Check parts for wear
v)	Auxiliary brake	Check braking system Check parts for wear
vi)	Intermediate gear box	Check gear and associated parts Check lubrication
vii)	Main drive chain	Check for tension and wear Check lubrication
viii)	Step/Pallet chain	Check for tension and wear Check lubrication
ix)	Step/pallet	Check step/pallet and step/pallet wheels for integrity
x)	Conveyor belt	Check for condition and tension
xi)	Drive belt	Check for condition and tension
xii)	Clearances	Check step to step and step to skirting clearances
xiii)	Combs	Check condition Check meshing with steps, pallets or belt
xiv)	Comb plate	Check clearances and operation
xv)	Handrails	Check for free running and condition Check tension Check synchronization between step/pallet band and the handrail
xvi)	Track system	Check for condition and wear Check fixings
xvii)	Safety devices	Check operation
xviii)	Deflector devices	Check condition
xix)	Lighting	Check operation
xx)	Display	Check operation
xxi)	Signs/pictograms	Check condition
xxii)	Balustrade	Check condition of panels Check fixings of interior claddings

ANNEX D

(*Clause* 15.5.1)

EXAMPLES OF ELEMENTS TO BE TAKEN INTO ACCOUNT THE RISK ASSESSMENT FOR MAINTENANCE OPERATIONS

D-1 ESCALATORS/MOVING WALKS

Elements (1)	**Machinery Spaces** (2)	**On Step/Pallet Band** (3)	**Inside Step/Pallet Band** (4)	**Upper and Lower Landing** (5)	**Control Cabinet** (6)	**Machine Room (External Drives)** (7)
Access and entry	R	R	R	R	R	R
Inadequate lighting (including access)	R	R	R	R	R	R
Falls/slips	R	R	R	R	R	R
Falling on machine	NR	R	NR	R	NR	NR
Falling over balustrade	NR	R	NR	R	NR	NR
Contact with moving machinery	R	R	R	R	R	R
Indirect contact with machinery	R	R	R	R	R	R
Crushing and shearing (step to step or comb/step to skirting)	R	R	R	NR	NR	NR
Gaps in balustrade	NR	R	NR	NR	NR	NR
Intersection between floors and/or escalators	NR	R	NR	NR	NR	NR
Persons on the step band	NR	R	NR	R	NR	NR
Safety switches and emergency stopping device(s)	R	R	R	R	R	R
Inspection control	R	R	R	R	R	R
Intersection between fixed and moving parts	NR	R	NR	NR	NR	NR
Unintentional start/stop	R	R	R	R	R	R
Machine moving (other than on power)	R	R	R	R	R	R
More than one maintenance person working	R	R	R	R	R	R
Manual operation	R	NR	R	R	R	R
Falling objects	R	R	R	R	NR	R
Unexpected water/dirt	R	R	R	R	R	R
Contamination by oil and grease	R	R	R	R	NR	R
Dangerous substances	R	R	R	R	R	R
Fire	R	NR	R	NR	R	R
Missing step/pallet	R	R	R	R	NR	NR

'R' = Relevant and 'NR' = Not relevant

LIST OF STANDARDS

The following list records those standards which are acceptable as ‘good practice’ and ‘accepted standards’ in the fulfilment of the requirements of this NBCS. The latest version of a standard shall be adopted at the time of enforcement of this NBCS. The standards listed may be used for conformance with the requirements of the referred clauses in this NBCS.

In the following list, the number appearing in the first column within parentheses indicates the number of the reference in this Part/Section.

	IS No.	*Title*
(1)	SP 30 : 2023	National Electrical Code of India 2023
	IS 732 : 2019	Code of practice for electrical wiring installation (*fourth revision*)
	IS 3043 : 2018	Code of practice for earthing (*second revision*)
(2)	IS 12777 : 1989	Method for classification of flame spread of products
(3)	IS 4591	Escalators and moving walks:
	Part 1/Sec 1 : 2020	Safety requirements *(first revision)*
	Part 1/Sec 2 : 2020	Guide for planning and selection *(first revision)*
	Part 1 / Sec 3 : 2020	Inspection and test *(first revision)*
	Part 2 : 2022	Guide for maintenance
(4)	IS 17615 (Part 2) : 2021/ ISO 18738-2 : 2012	Measurement of ride quality: Part 2 Escalators and moving walks
(5)	IS 732 : 2019	Code of practice for electrical wiring installations (*fourth revision*)

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART D BUILDING SERVICES

SECTION 5 INSTALLATION OF LIFTS, ESCALATORS, MOVING WALKS AND POWER-DRIVEN PARKING SYSTEMS

5C POWER-DRIVEN PARKING SYSTEMS

BUREAU OF INDIAN STANDARDS

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National Building Code Sectional Committee, CED 46

FOREWORD

This NBCS (Part D/Subsection 5C) covers the requirements for planning and design, installation and operation, of car parking systems to ensure efficient operation of system with satisfactory performance.

This Section was first published in 1970 and was subsequently revised in 1983, 2005 and 2016 as a part of National Building Code of India. This Section covers the requirements for installation of lifts and escalators in buildings. This Section should be read with Part F 'Fire and Life Safety' of this NBCS from fire safety requirements point of view. The major changes in the first revision of 1983 were the addition of outline dimensions of different types of lifts and detailed requirements of escalators in buildings. Emphasis was laid on coordination between the engineer/architect and the lift manufacturer to arrive at the number and position of lifts for attaining optimum efficiency in serving the building with safety.

The significant changes with respect to lifts incorporated in the 2005 revision, included the addition of new clauses/recommendations on the building management system; the addition of new clauses on the fireman's lift, infrared light curtain, safety and braille button for blind people and updation of provisions as per the revised standards on lifts on which this Section was based.

In the 2016 revision, the erstwhile Section 5 on Lifts and Escalators was divided into two subsections namely:

5A Lifts

5B Escalators and moving walks

The growing demand for efficient and space-saving parking solutions for passenger cars in urban environments has led to the development of power-driven parking systems in the country that address the requirements of power-driven vehicle parking systems. These systems, which may be either automated or semi-automated, are crucial for optimizing land use in densely populated areas. Recognizing the importance of such systems, in this NBCS, a new subsection 5C 'Power-Driven Parking Systems' has been introduced to provide comprehensive guidelines for the planning, design, installation, operation, maintenance and inspection of parking systems assuming safe and efficient movement of vehicles.

In this revision, this publication has been renamed as National Building Construction Standards (NBCS).

This new Subsection on power-driven parking systems reflects the evolving technological advancements and urban planning needs and its integration within the lifts and escalators related building services chapter underscores the significance of vertical transportation solutions in modern building infrastructure.

The following important provisions are addressed in this new Subsection:

a) *Automated parking systems* — Fully automated car parks allow drivers to leave their vehicles at designated entry points, from where the vehicles are transported and parked automatically. This system minimizes human intervention, reduces parking time and enhances space utilization;

b) *Car lifts and ramps* — In semi-automated systems, the movement of cars depends on the use of car lifts with/without ramps. It is essential to conduct a detailed analysis to determine the optimal number of car lifts required, ensuring that the average car retrieval/parking time does not exceed 3 min; and

c) *Design and safety* — Car lifts are to be designed to accommodate the largest vehicles intended for use, providing adequate space for door opening to facilitate passenger evacuation in case of emergencies. Additionally, designers need to account for potential queues and provide sufficient holding areas for vehicles.

This NBCS (Part D/Subsection 5C) deals with the requirements for planning, design, installation, operation, maintenance and inspection of parking systems so as to ensure safe movement of cars within and out of the building spaces and with satisfactory performance.

Assistance has also been derived from the following publications in the preparation of this Subsection:

IBC 2024	International Building Code, International Code Council, Washington, USA
DIN EN 14010 : 2009-12	Safety of machinery — Equipment for power-driven parking of motor vehicles — Safety and EMC requirements for design, manufacturing, erection and commissioning stages

As the regulation of land development and buildings is a State subject and is dealt by the States and local bodies such as urban local bodies within their jurisdiction through building regulatory documents like building regulations, building byelaws and fire regulations, this document is voluntary in nature and is non-binding. The implementation depends on adoption by concerned parties or stipulations in a contract or by appropriate adoption by the concerned authorities.

For the purpose of deciding whether a particular requirement of this Subsection is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 'Rules for rounding off numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this Subsection.

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Important Explanatory Note for Users of this NBCS

In any Part/Section of this NBCS, where reference is made to **'good practice'** in relation to design, constructional procedures or other related information, and where reference is made to **'accepted standard'** in relation to material specification, testing, or other related information, the Indian Standards listed at the end of the Part/Sec shall be used as a guide to the interpretation.

At the time of publication, the editions indicated in the standards were valid. All standards are subject to revision and parties to agreements based on any Part/Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

In the list of standards given at the end of a Part/Section, the number appearing within parentheses in the first column indicates the number of the reference of the standard in the Part/Section. For example:

a) Good practice [D-5C(1)] refers to the Indian Standard given at serial number (1) of the List of Standards given at the end of this Part 5/ Subsection 5C, that is, SP 30 : 2023 'National Electrical Code of India 2023'.

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART D BUILDING SERVICES

SECTION 5 INSTALLATION OF LIFTS, ESCALATORS, MOVING WALKS AND POWER-DRIVEN PARKING SYSTEMS

5C POWER-DRIVEN PARKING SYSTEMS

1 SCOPE

1.1 This NBCS (Part D/Subsection 5C) covers the requirements for planning, design, installation, operation, maintenance and inspection of permanently installed power-driven vehicle parking systems in buildings so as to ensure safe parking and movement of cars with satisfactory performance. These systems which may be automated or semi-automated are crucial for optimizing land use in densely populated areas.

1.2 This Subsection gives information that should be exchanged among the architect/engineer, the consulting engineer and the car parking solution providers/installers from the stage of planning of installation including up to the functioning and maintenance stage.

2 TERMINOLOGY

For the purpose of this Subsection, the following definitions shall apply.

2.1 General

2.1.1 *Grid* — One or more (sideways) working areas load handling devices standing vertically one above the other.

2.1.2 *Operating Panel* — Stationary or mobile device giving command for parking space request. Signal transmission for mobile controls can be based on different technologies (radio, infrared, RFID, bluetooth, etc).

2.1.3 *Parking Unit* — A parking unit refers to one or several load carriers connected together mechanically and moving as a single entity.

2.1.4 *Parking Equipment Attendant* — A person tasked with operating, cleaning and/or supervising power-driven parking equipment.

2.1.5 *Public Use* — Those parking systems designed and intended for access and use by the general public, as opposed to private or restricted use.

2.1.6 *Series* — One or more load-handling attachments placed horizontally and one behind the other as a multi-row arrangement.

2.1.7 *Transfer Area* — An area within a semi-automatic/fully automatic parking facility into which cars are parked in and/or from which they are removed. Normally only the driver should be allowed to enter in this area.

2.1.8 *Working Area* — Power-operated parking system for motor vehicles and cars, in which the transfer area is the same as the working area. A main vertical and horizontal sliding door (recommended for safety) is located in front of each transfer area which stores and makes the car available again in sequential operation. During the operation of the parking system, access of any personnel is prevented in this working area.

2.2 Terms Relating to Parking Systems

2.2.1 *Automatic Parking System* — A parking system that consists of parking equipment along with its linked ancillary equipment, such as main doors, working area doors and emergency doors all of which operate in an automatic/preprogrammed manner.

2.2.2 *Electromechanical Parking Systems* — A parking system that employs mechanical components such as gears, pulleys, ropes and chains to move vehicles horizontally or vertically into parking positions, often using automated platforms or carriages.

2.2.3 *Hydraulic Parking Systems* — A parking system that utilizes fluid-driven mechanisms, including hydraulic cylinders, to lift and lower vehicles into designated parking spaces, typically allowing for multiple vehicles to be stacked vertically in a compact space.

2.2.4 *Locking Device* — A mechanism that prevents the platform from leaving a defined position within the parking system.

2.2.5 *Puzzle Parking System* — A type of automated parking system in which vehicles are moved on platforms in vertical direction and horizontal direction (similar to a puzzle).

2.2.6 *Safety Switch* — A control switch with one or more break-contact elements connected via non-resilient members, ensuring full contact opening when the actuator is moved through the specified positive opening travel.

2.2.7 *Safety Gear* — A mechanical device designed to stop and hold the platform in case of over speeding with gravity within the parking system.

2.2.8 *Stack Parking System* — A type of parking system which moves the car in up and down position.

2.2.9 *Wheel Track Width* — The distance between the centre lines of the wheels on a single axle of a vehicle.

2.2.10 *Wheel Base* — The distance between the centres of the wheels on the front and rear axles of a vehicle.

2.3 Terms Relating to Semi-Automatic Parking Systems

2.3.1 *Area of Parking* — The area reserved for the car parking system where the system is supported at various load bearing points shall ensure firm support from flooring/ceiling.

2.3.2 *Drive Way* — The front open space in the parking system (minimum 6.0 m in length or the diagonal distance of car + 500 mm) where the car enters in 90° direction into the system.

2.3.3 *Horizontal Movements* — The lateral shifting of vehicles within a parking level, often using automated platforms or conveyors for efficient space utilization.

2.3.4 *Restricted Access* — Access restricted to authorized persons to use the parking facilities and are controlled through access code, magnetic card, key switch, etc.

2.3.5 *Vertical Movements* — The transporting of vehicles between different levels vertically, typically using car lifts or stacker systems to maximize vertical space.

3 GENERAL

3.1 Conformity with Act and Rules

3.1.1 The installation of parking systems, including stack parking, puzzle parking, tower parking and other automated parking systems, is governed by different acts and rules across states, intended to ensure the safe installation and operation of such systems.

3.1.2 The installation shall be carried out in conformity with relevant acts and rules wherever they are in force, ensuring compliance with all safety and operational guidelines.

3.1.3 A license for public use is a safety provision issued by state authorities under applicable acts and rules, wherever they are in force.

3.2 Conformity with the Electricity Act and Rules

3.2.1 All electrical work related to the installation of parking systems shall be carried out in accordance with the provisions of the *Electricity Act*, 2003 and *Central Electricity Authority* (CEA) Regulations as amended up to date, along with the Rules and Regulations framed thereunder. Additionally, the installation shall comply with the provisions of Part D 'Building Services, Section 2 Electrical and Allied Installations' of this NBCS.

3.3 Conformity with Indian Standards

3.3.1 All materials, fittings, appliances, etc used in the installation of parking systems shall conform to Indian Standard specifications wherever these exist. In cases where Indian Standard specifications do not exist, the materials shall be approved by the competent authority (*see* Part B 'Building Materials' of this NBCS). The installation shall adhere to best practices as outlined in relevant standards such as accepted standards [D-5C(1)], [D-5C(2)] and [D-5C(3)].

3.4 Conformity with Fire Regulations

3.4.1 The installation of parking systems shall be carried out in conformity with the applicable state fire acts/rules/local fire regulations, wherever they are in force. The installation shall be carried out in conformity with relevant acts and rules wherever they are in force, ensuring compliance with the same. *See also* Part F 'Fire and Life Safety' of this NBCS for guidance purpose.

3.5 Safety Design Considerations

The design consideration for type and selection of parking systems walk shall be based on following criteria:

a) *Location* — To ensure reliability and longevity, the design specifications of parking systems should suit the environmental conditions of the installation site. Factors such as exposure to weather elements, seismic activity, susceptibility to stagnant rain water/flood prone zone and temperature variations should be considered when selecting and designing a parking system;

b) *Physical Requirements* — The physical characteristics of the site, such as available space and the building's structural capacity, play a crucial role in selecting the appropriate parking system. The system should be designed to accommodate the vertical and horizontal dimensions of the space. The building infrastructure should also be evaluated to ensure it can support the weight and dynamic loads of the components of the parking system, apart from the various external loads, forces and effects (*see* Part C 'Structural Design, Section 1 Loads and Load Effects' of this NBCS);

c) *Type of Segment and Traffic Patterns* — The design and selection of parking systems depend on the type of segment where they will be installed, such as residential buildings, commercial complexes, transit hubs, or public parking facilities. The expected traffic patterns and peak demand should be carefully analysed to ensure that the parking system's capacity matches the anticipated usage, preventing congestion and delays;

d) *Safety Considerations* — Parking systems should be designed and installed with a focus on safety to prevent accidents and injuries. Safety features should include proper load limits, emergency stop functions, and clear signalling systems. Operators and users should adhere to the rules for safe operation, including compliance with all safety signals and instructions outlined in the operation and maintenance manual. Routine inspections should be conducted before operation to confirm the equipment's condition, and overloading should be strictly avoided to prevent mechanical failure and any local buckling damage; and

e) *Aesthetic Preferences* — The aesthetic integration of the parking system with the surrounding environment should be determined in consultation with all relevant stakeholders. This may involve choosing materials, finishes and designs that complement the architectural style of the building or site.

4 PARKING SYSTEMS (OVERVIEW AND SPECIFICATIONS)

4.1 General

Parking systems are essential in urban environments where space is limited and the demand for efficient vehicle storage is high. These systems optimize the use of vertical and horizontal space, ensuring that vehicles are securely and conveniently parked. The choice of a parking system should be based on factors such as the type of vehicles to be parked, the available space, the required capacity and specific site conditions, time taken in parking, maintainability and economy.

4.2 Stack Parking System

An optimized system in which vehicles are stacked vertically is known as stack parking system. Such systems are particularly useful in urban settings where land space is scarce. The stack parking system operates by lifting vehicles and placing them on platforms supported by vertical columns. They are ideal for residential and commercial buildings having limited space and are also suitable for above-ground installations where space constraints prevent extensive horizontal expansion. There are two types of stack parking systems, namely:

a) *Dependent stack parking system* — A vertical parking arrangement where two/three cars are parked one above the other. The lower car should be removed to access the upper car. This system is suitable for both indoor and outdoor installations and offers a cost-effective solution by utilizing a single driving level to create two parking levels (*see* Fig. 1A and Fig. 2A). The dimensions and configurations for two-level and three-level dependent stack parking systems are provided in Table 1.

Table 1 Dimension and Configuration of Dependent Stack Parking System

[*Clause* 4.2(a)]

Sl No.	Dependent System	Minimum Height mm				
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	2 Level parking system:					
	a) Upper level	1 600	1 600	1 600	1 600	1 600
	b) Lower level	1 600	1 700	1 800	1 900	2 000
	c) Combined system	3 400	3 500	3 600	3 700	3 800
ii)	3 Level parking system:					
	a) Upper level	1 600	1 700	1 800	1 900	2 000
	b) Middle level	1 600	1 700	1 800	1 900	2 000
	c) Lower level	1 600	1 700	1 800	1 900	2 000
	d) Combined system	5 300	5 600	5 900	6 200	6 500

b) *Independent stack parking system* — A parking system that allows two/three cars to be parked vertically above each other, with each parking level being independently accessible. This system maximizes space efficiency by providing multiple parking levels on a single driving level, making it an ideal solution for areas with limited space (*see* Fig. 1B and Fig. 2B). The dimensions and configurations for two-level and three-level independent stack parking systems are provided in Table 2.

Table 2 Dimension and Configuration of Independent Stack Parking System

[*Clause* 4.2(b)]

Sl No.	Independent System	Height mm		
(1)	(2)	(3)	(4)	(5)
i)	2 Level parking system:			
	a) Required pit	1 850	2 000	2 250
	b) Upper level	1 650	1 800	2 050
	c) Lower level	1 650	1 800	2 050
	d) Combined system	3 550	3 850	4 350

Table 2 (*Concluded*)

Sl No.	Independent System	Height mm		
(1)	(2)	(3)	(4)	(5)
ii)	3 Level parking system:			
	a) Required pit	3 450	3 750	3 850
	a) Upper level	1 550	1 700	1 750
	b) Middle level	1 550	1 700	1 750
	c) Lower level	1 550	1 700	1 750
	d) Combined system	4 950	5 400	5 550

4.2.1 *Key Features and Components*

The following are the key features and components of stack parking systems:

a) *Vertical support* — Supported on two sides by vertical columns with a pair of slides that hold the platform and allow movement along the columns.

b) *Balancing chain* — A chain fixed at both ends that supports the platform during travel, having sufficient strength to withstand impact loads in case of a sudden fall. This also ensures that platform remains in horizontal position during entire operation.

c) *Locking mechanism* — Lockers positioned on both sides of the vertical columns engage during downward movement. Locking mechanism restricts free fall of platform ensuring safety during entire travel length (*see* Note).

d) *Hydraulic cylinder* — The system uses hydraulic cylinders designed to bear the load of the vehicle on the platform during vertical transportation.

e) *Hydraulic power pack* — A single hydraulic power pack can serve multiple systems, with individual controls for each system.

f) *Non-return valve* — Controls the flow of hydraulic oil in one direction with a self-locking arrangement to prevent accidental movement.

g) *Foundation support* — The system is anchored by RCC foundations (minimum M25 grade) capable of sustaining the pull-out loads exerted through foundation bolts ensuring anchoring depth of (125 mm to 150 mm) and concrete depth of 200 mm.

h) *Ceiling or side supports* — The upper end of the system is supported by either ceiling or side supports.

j) *Four-column support* — The car's weight is transferred to four supporting pillars, typically driven by mechanical traction machines using ropes or chains.

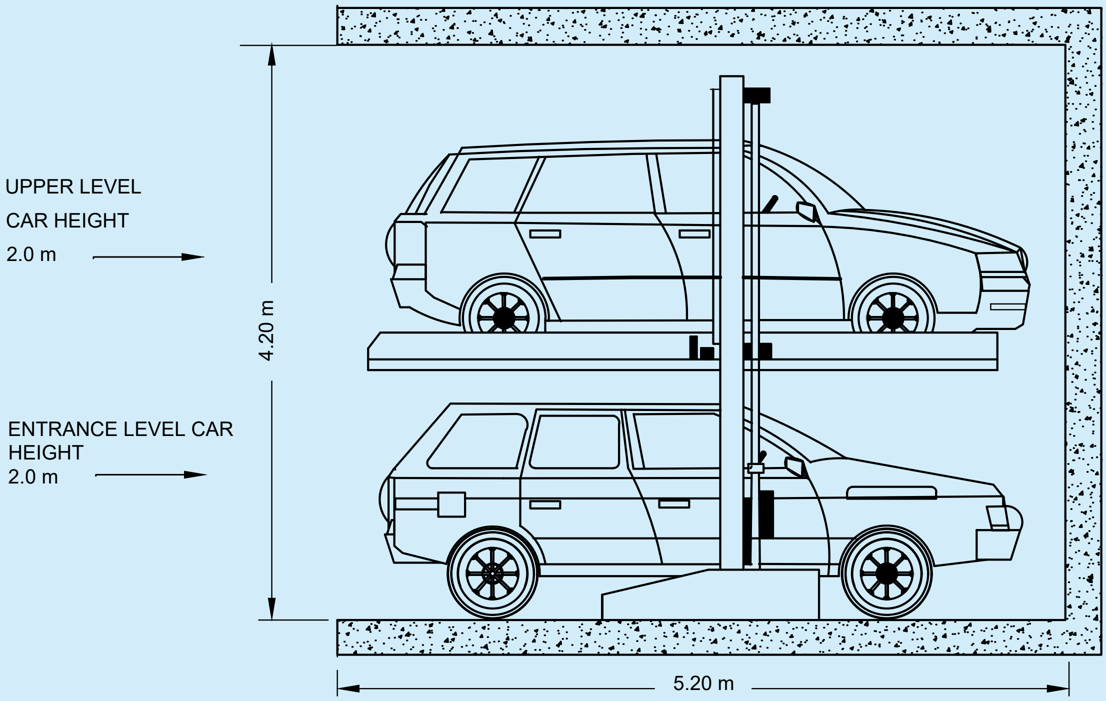
k) *Braking system* — The movement is controlled by brakes, though the system lacks a secondary stopping mechanism if the brakes fail.

m) *Limit switches and sensors* — Limit switches control movement, but over-reliance can lead to accidents. Sensors below the platform detect vehicles, though potential blind spots exist.

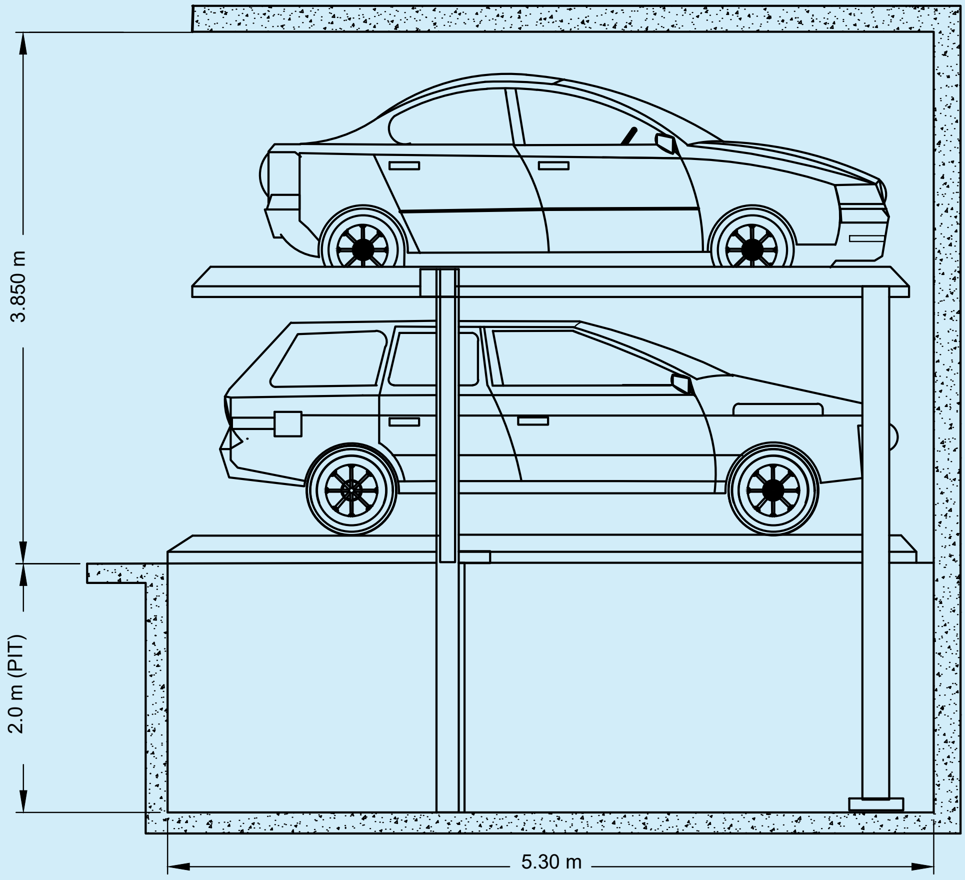
n) *Operational safety* — An emergency safety switch is mandatory for every operating panel. The system requires a 'hold to run' operation to ensure no objects are within the parking area before activation.

p) *Security features* — Each operating device should have a key lock to prevent unauthorized use. The system's components should have an IP rating of 67 for outdoor installations.

NOTE — Until the Indian Standard on the subject is formulated, specialist literature like EN 14010 : 2003 'Safety of machinery — Equipment for power-driven parking of motor vehicles. Safety and EMC requirements for design, manufacturing, erection and commissioning stages' may be referred to.

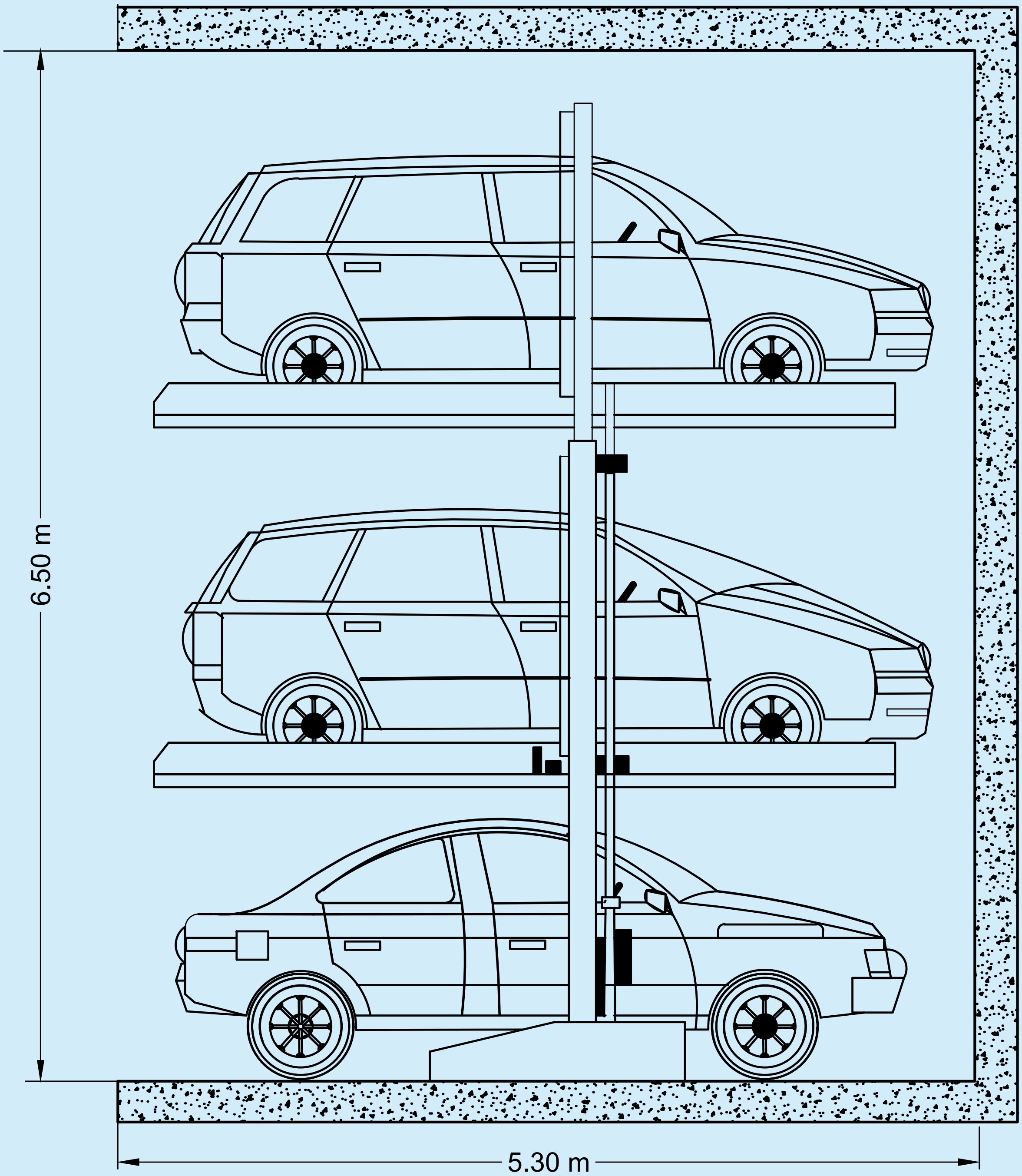

UPPER LEVEL
CAR HEIGHT
2.0 m
ENTRANCE LEVEL CAR
HEIGHT
2.0 m
4.20 m
5.20 m

1 A DEPENDENT TWO LEVEL STACK PARKING SYSTEM (TYPICAL)

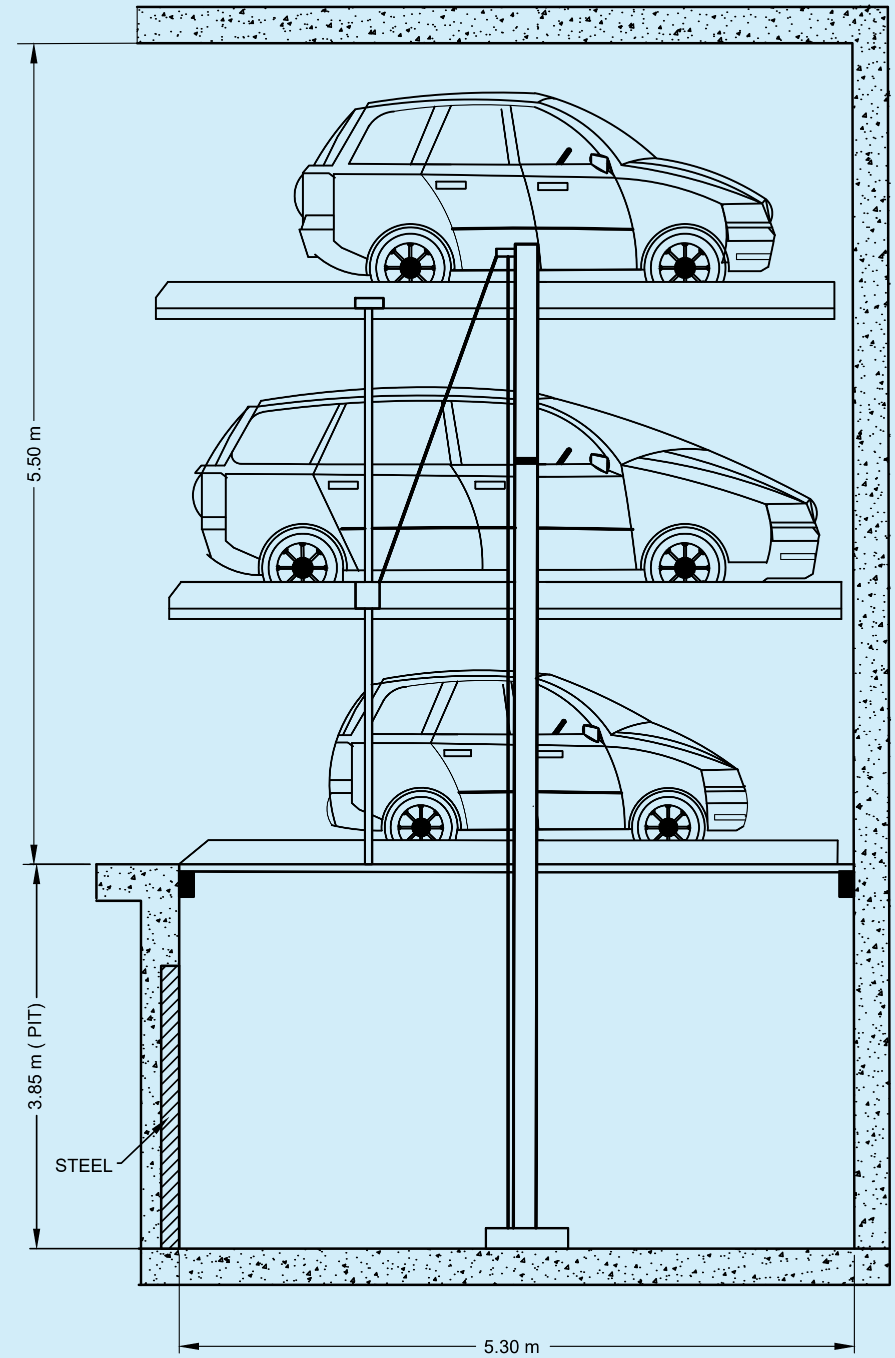

3.850 m
2.0 m (PIT)
5.30 m

1 B INDEPENDENT TWO LEVEL STACK PARKING SYSTEM (TYPICAL)

FIG. 1 STACK PARKING SYSTEM TWO LEVELS



2 A DEPENDENT THREE LEVEL STACK PARKING SYSTEM



2B INDEPENDENT THREE LEVEL PARKING SYSTEM

FIG. 2 STACK PARKING SYSTEM — THREE LEVELS

4.3 Puzzle Parking

Puzzle parking system is a type of semi-automatic parking system designed to maximize parking space efficiency by utilizing a combination of vertical and horizontal movements. The system mechanically arranges vehicles in a grid-like structure to optimize space utilization and minimize the need for manual parking. Figure 3 to Fig. 8 depicts various options of puzzle parking and the essential systems in them. The retrieval time for cars should be maintained within the time range specified in Table 3 to ensure efficient operation and user convenience.

Table 3 Categorization of Retrieval Time

(*Clause* 4.3)

Sl No. (1)	Performance Level (2)	Retrieval Time s (3)
i)	Excellent	≤ 90
ii)	Very good	90 to 100
iii)	Good	100 to 120
iv)	Acceptable	120 to 140
v)	Poor	> 140

NOTE — These are under ideal conditions. However, it may vary depending upon the arrangement of parking systems.

4.3.1 *Key Features and Components*

The features and components of the puzzle parking are described hereunder:

a) *Vertical movement*:

  1) *Geared motor and machine* — The geared motor and machine for vertical movement shall be located at the side or rear of the system. Movement shall be facilitated using ropes or chains; and

  2) *Hydraulic cylinders* — Vertical movement using hydraulic cylinders may be located either vertically or horizontally, depending on the system design.

b) *Horizontal movement* — Horizontal movement shall be controlled by a traction motor utilizing a chain sprocket mechanism.

c) *Safety precautions*:

  1) *Entry to transfer rooms* — Access to transfer rooms should be controlled with sliding doors to ensure safety. Sensors may be used to halt the system in case of obstruction, but reliance solely on sensors may not fully prevent accidents; and

  2) *Flood sensors* — Flood sensors shall be installed in the pit to monitor water levels. A warning hooter shall be provided to alert any potential malfunction in the sump pump system.

d) *Pit requirements:*

  1) *Waterproofing* — The pit shall be waterproofed to prevent water ingress. A sump shall be provided for efficient water removal;

  2) *Condition before installation* — The pit shall be handed over with a whitewash applied prior the installation of the puzzle parking system; and

  3) Entire area to be properly ventilated, illuminated and in hygienic conditions.

e) *Maintenance and inspection* — Regular maintenance and inspection schedules shall be established to ensure all components are functioning correctly and system is in safe working condition.

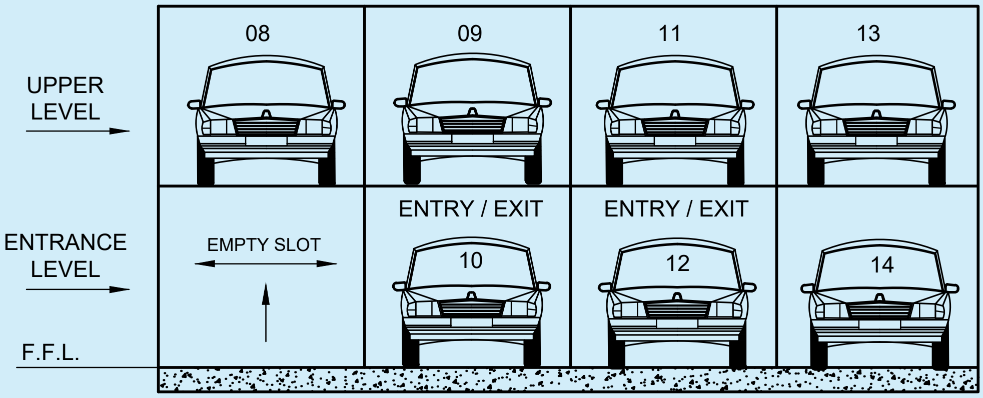
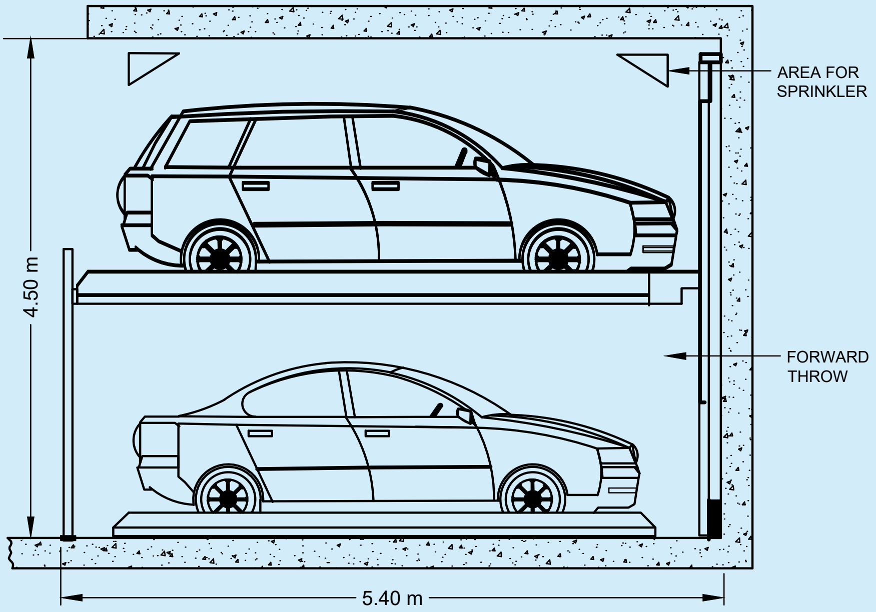
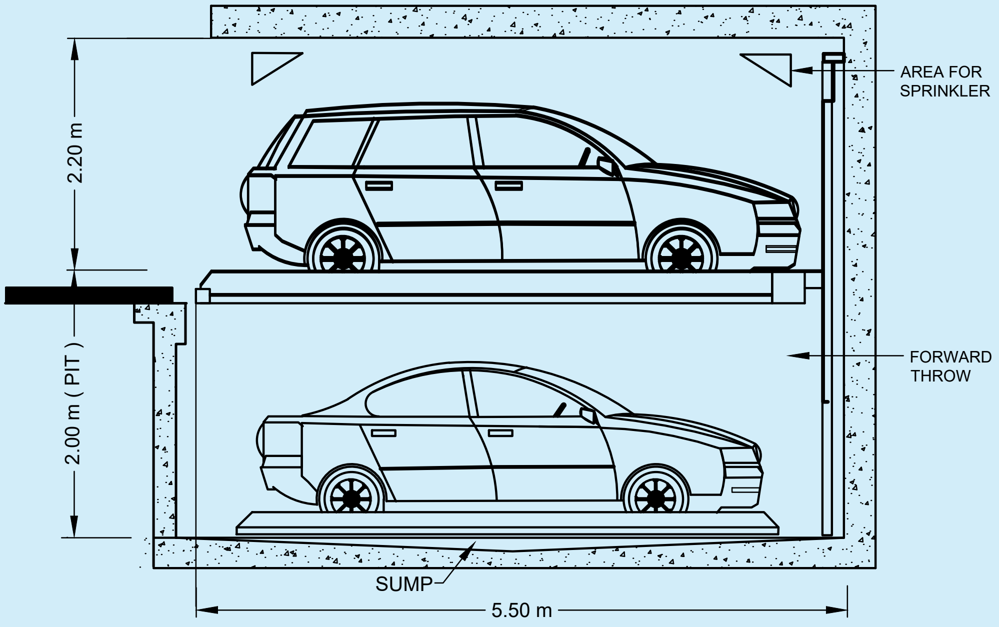

08
09
11
13
UPPER LEVEL
ENTRANCE LEVEL
EMPTY SLOT
ENTRY / EXIT
ENTRY / EXIT
10
12
14
F.F.L.

FIG. 3 SYSTEM SHOWING 2 LEVEL PARKING ABOVE GROUND


AREA FOR SPRINKLER
4.50 m
FORWARD THROW
5.40 m

4A TWO LEVEL INDEPENDENT PUZZLE PARKING SYSTEM


AREA FOR SPRINKLER
2.20 m
FORWARD THROW
2.00 m (PIT)
SUMP
5.50 m

4B TWO LEVEL INDEPENDENT PUZZLE PARKING SYSTEM WITH PIT

FIG.4 CROSS-SECTION SHOWING FREE SPACE FOR SERVICES LIKE FIRE SPRINKLERS

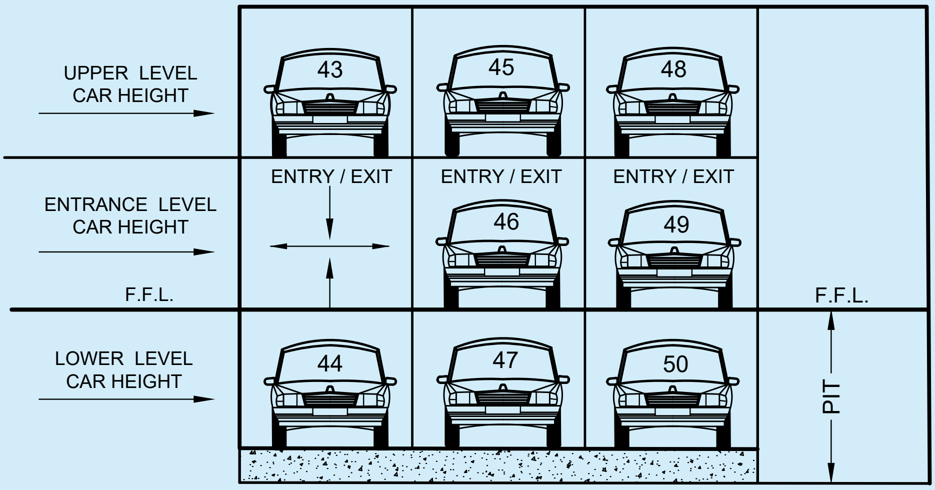

UPPER LEVEL CAR HEIGHT
ENTRANCE LEVEL CAR HEIGHT
F.F.L.
LOWER LEVEL CAR HEIGHT
43
45
48
ENTRY / EXIT
ENTRY / EXIT
ENTRY / EXIT
46
49
F.F.L.
44
47
50
PIT

FIG. 5 SYSTEM SHOWING 3 LEVEL PUZZLE PARKING WITH PIT

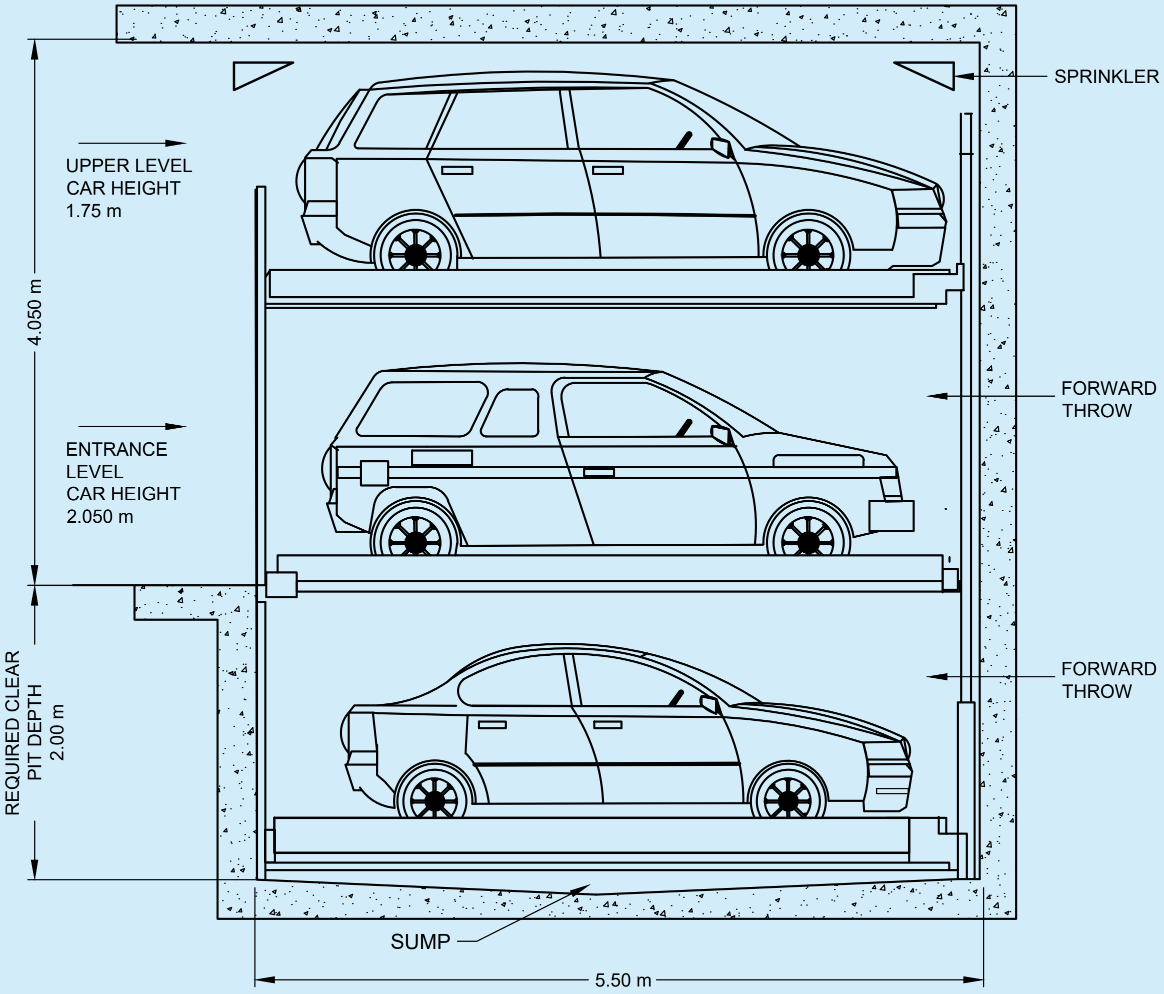
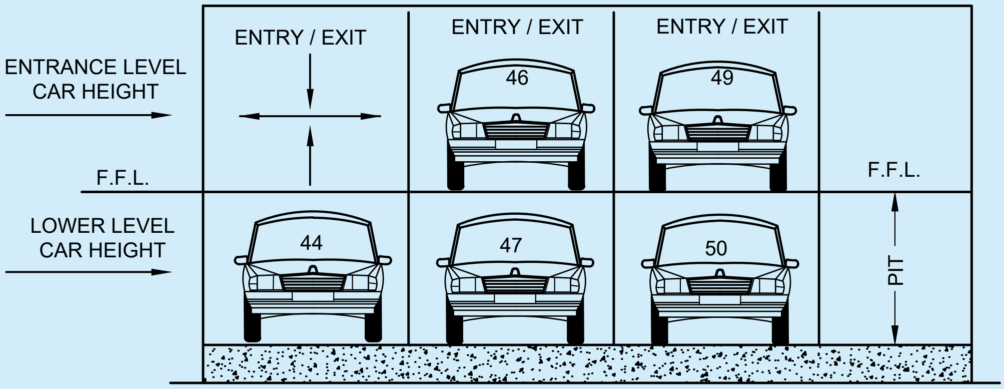
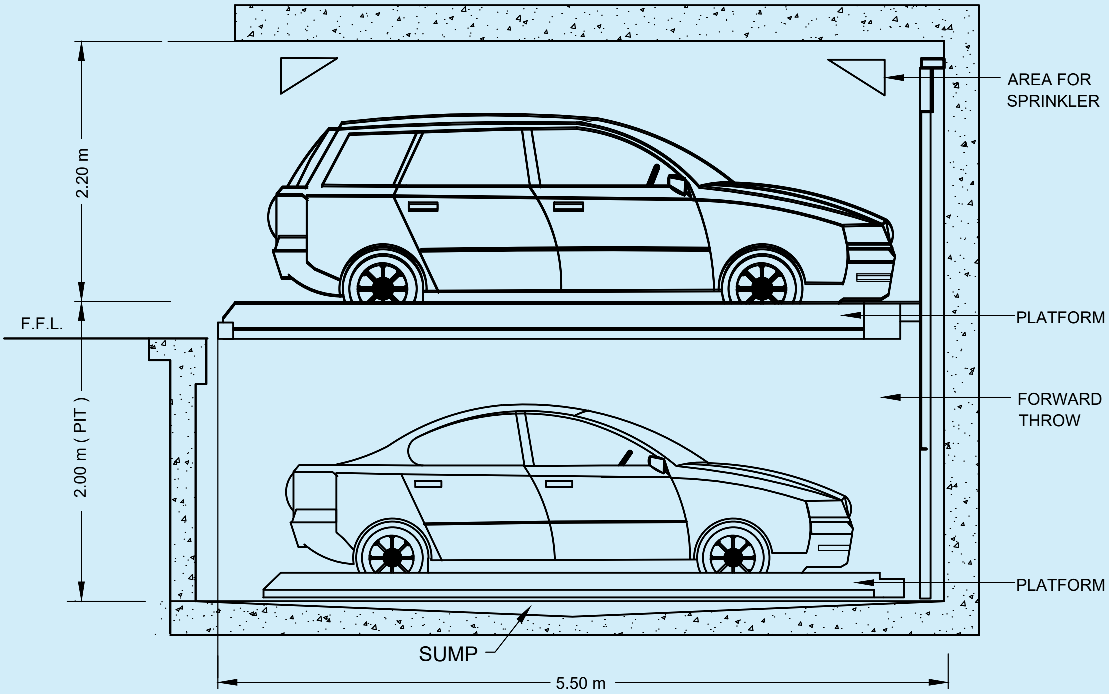

SPRINKLER
UPPER LEVEL CAR HEIGHT 1.75 m
4.050 m
FORWARD THROW
ENTRANCE LEVEL CAR HEIGHT 2.050 m
FORWARD THROW
REQUIRED CLEAR PIT DEPTH 2.00 m
SUMP
5.50 m

FIG. 6 CROSS-SECTION SHOWING FREE SPACE FOR SERVICES LIKE FIRE SPRINKLERS


ENTRY / EXIT
ENTRY / EXIT
ENTRY / EXIT
ENTRANCE LEVEL CAR HEIGHT
46
49
F.F.L.
F.F.L.
LOWER LEVEL CAR HEIGHT
44
47
50
PIT

(FFL - FINISHED FLOOR LEVEL)

FIG. 7 ARRANGEMENT OF PUZZLE WITH PIT


2.20 m
AREA FOR SPRINKLER
F.F.L.
PLATFORM
FORWARD THROW
2.00 m (PIT)
PLATFORM
SUMP
5.50 m

TWO LEVEL INDEPENDENT PARKING SYSTEM WITH PIT

FIG. 8 CROSS-SECTION SHOWING FREE SPACE FOR SERVICES LIKE FIRE SPRINKLERS

4.4 Automatic Tower Parking System — Inside RCC Shaft and Free Standing Structure

Automatic tower parking system is a vertically oriented automated parking system designed to efficiently utilize space by stacking vehicles in a slender tower. The system combines mechanical and automation technologies to transport vehicles to the designated parking spots within the tower. Foundation shall be evaluated as per structural stability norms (*refer* Part C 'Structural Design, Section 2 Soils and Foundations' of this NBCS). Free standing tower, shall be enclosed within RCC framework for better stability.

4.4.1 *Key Features and Components*

The following shall be applicable:

a) *System configuration* — The system features a central lift with various configurations including 1/1, 1/2, 1/3, 2/2, 2/3 and 3/3 arrangements, as illustrated in the system's design, *see* Fig. 9.

b) The lift facilitates the vertical transportation of vehicles to different levels within the tower.

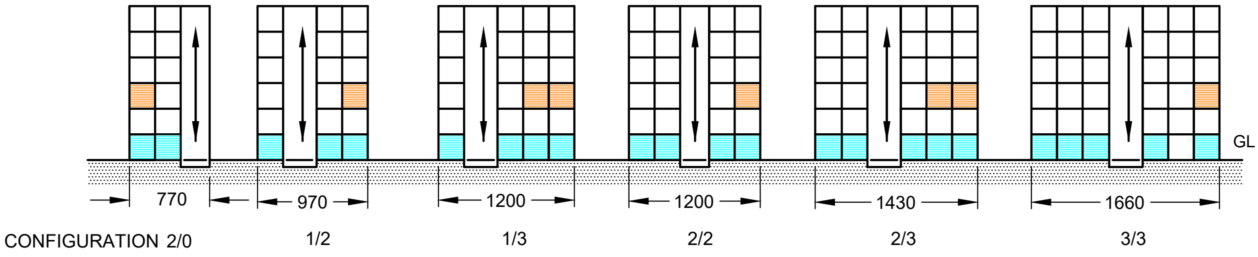
c) *Entrance room* — Its location shall be positioned for convenient access to vehicles entering the parking tower thereby allowing smooth entry and exit of vehicles, facilitating the parking process.

d) *Car handling and turning* — Turntables or turning devices to rotate vehicles to ensure proper alignment for exit direction.

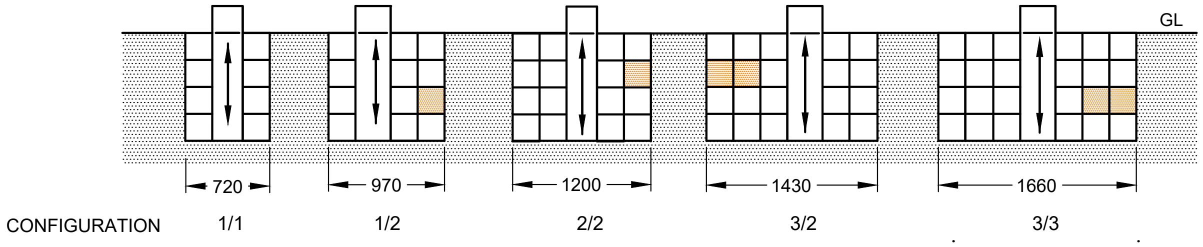
e) *Car hold area* — There shall be adequate space in front of the entrance room to accommodate vehicles during the parking and retrieval process.

f) *Car handling capacity* — The system should be able to handle approximately 25 cars to 30 cars per hour, with a full cycle of filling or evacuating the tower completed in about 3 h.

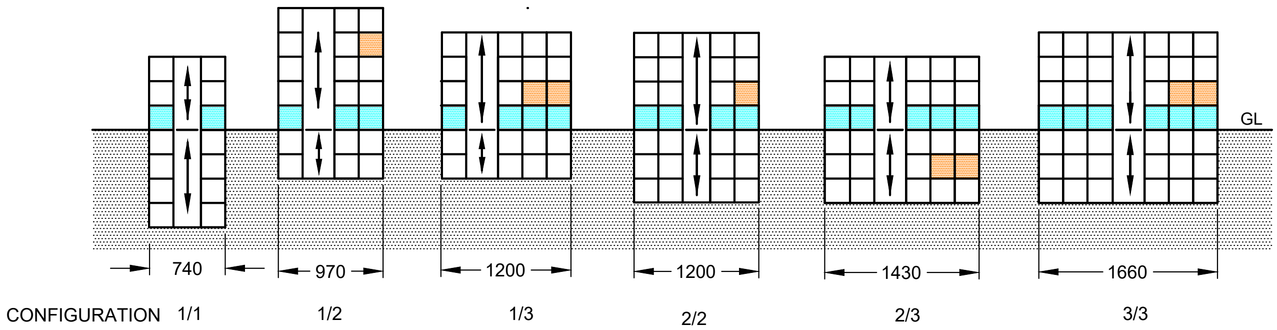
g) *Parking capacity* — The tower should have a capacity to accommodate up to 90 cars for optimum retrieval time.


GL
770
970
1200
1200
1430
1660
CONFIGURATION 2/0
1/2
1/3
2/2
2/3
3/3

9A TOWER TYPE (ABOVE GROUND)


GL
720
970
1200
1430
1660
CONFIGURATION
1/1
1/2
2/2
3/2
3/3

9B SHAFT TYPE (BELOW GROUND)


GL
740
970
1200
1200
1430
1660
CONFIGURATION 1/1
1/2
1/3
2/2
2/3
3/3

9C TOWER & SHAFT TYPE (STRUCTURE IS PARTLY ABOVE AND BELOW GROUND)

FIG. 9 VARIOUS ARRANGEMENTS DEPICTING THE SECTIONS/SLOTS FOR PARKING

h) *Lift locking mechanism* — It should be ensured that the lift platform is securely locked before any vehicle transfer or retrieval operation is performed.

j) *Platform guide rails* — Closed-type guide rails shall be employed to provide stability and ensure safe vehicle movement within the tower.

k) *Platform locking mechanism* — Each platform guide rails should have built-in feature which includes an integrated locking mechanism to secure vehicles in place.

m) *Tower structure stability* — Proper anchoring of the tower structure should be ensured for stability and safety during operation.

n) *Illumination inside shaft* — Light points shall be installed every 6.0 m, controlled by 3-phase 16A switches to ensure adequate visibility inside the shaft.

p) *Sound and vibration control* — The vertical structure should be connected to the RCC with sound isolation pads to mitigate noise and vibration transmission.

q) *Shaft size* — The shaft dimensions shall be designed to accommodate large-size cars comfortably.

r) *Finish of the structure* — The structure should be finished with hot-dip galvanization and is fire-resistant for up to 120 min to ensure durability and safety.

s) *Entrance door* — Safety doors shall be able to withstand a force of 300 N applied perpendicular to the surface without permanent deformation or impairment of functionality. The force should be distributed evenly over an area of 500 mm^2.

4.5 Longitudinal Parking System

This is a parking system having lift at centre with front and back arrangement when there is more space available in length than in width. This system is thus considered and designed to maximize parking efficiency in narrow spaces, particularly in narrow broad strips between buildings, such as the area between the set-back lines and the building.

4.5.1 *Key Features and Components*

The following shall be applicable:

a) *Vehicle accommodation*:

   1) *Car height and length* — The system shall be designed to accommodate various car heights and lengths, ensuring flexibility for different vehicle types; and

   2) *Capacity* — The slim parking system shall be capable of parking up to 30 cars, depending on the specific design and available space.

b) *Design efficiency:*

   1) *Floor plan* — The system shall be designed with a very small floor plan area and a slim construction, maximizing the use of narrow spaces; and

   2) *Ramps and driveways* — No space-intensive ramps or driveways shall be required for this system, allowing for a more compact and efficient design.

c) *Configurations and arrangements*:

   1) *Configurations* — The system shall offer configurations of 1/1 or 2/2, which are particularly suitable for the side margins of buildings;

   2) *Above or below ground* — The system should allow for both above-ground and below-ground arrangements, depending on the site's requirements (*see* Fig. 10 and Fig. 11);

   3) *Lengthwise transportation* — Vehicles shall be transported lengthwise with restricted levels to control the number of vehicles within the system; and

4) *Capacity* — The longitudinal parking system shall have a capacity of around 30 cars, accommodating the needs of various building types.

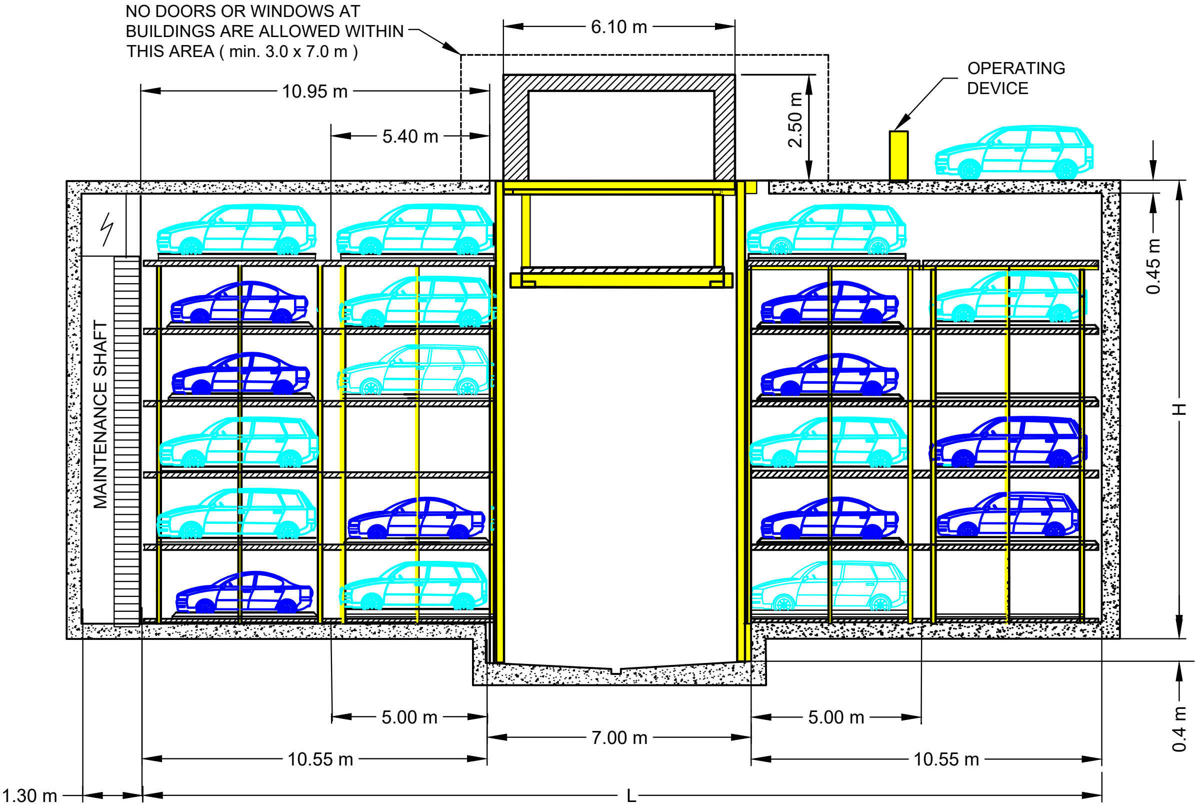

NO DOORS OR WINDOWS AT
BUILDINGS ARE ALLOWED WITHIN
THIS AREA (min. 3.0 x 7.0 m)
6.10 m
OPERATING
DEVICE
10.95 m
5.40 m
2.50 m
MAINTENANCE SHAFT
0.45 m
H
0.4 m
5.00 m
5.00 m
7.00 m
10.55 m
10.55 m
1.30 m
L

FIG. 10 ARRANGEMENT BELOW GROUND

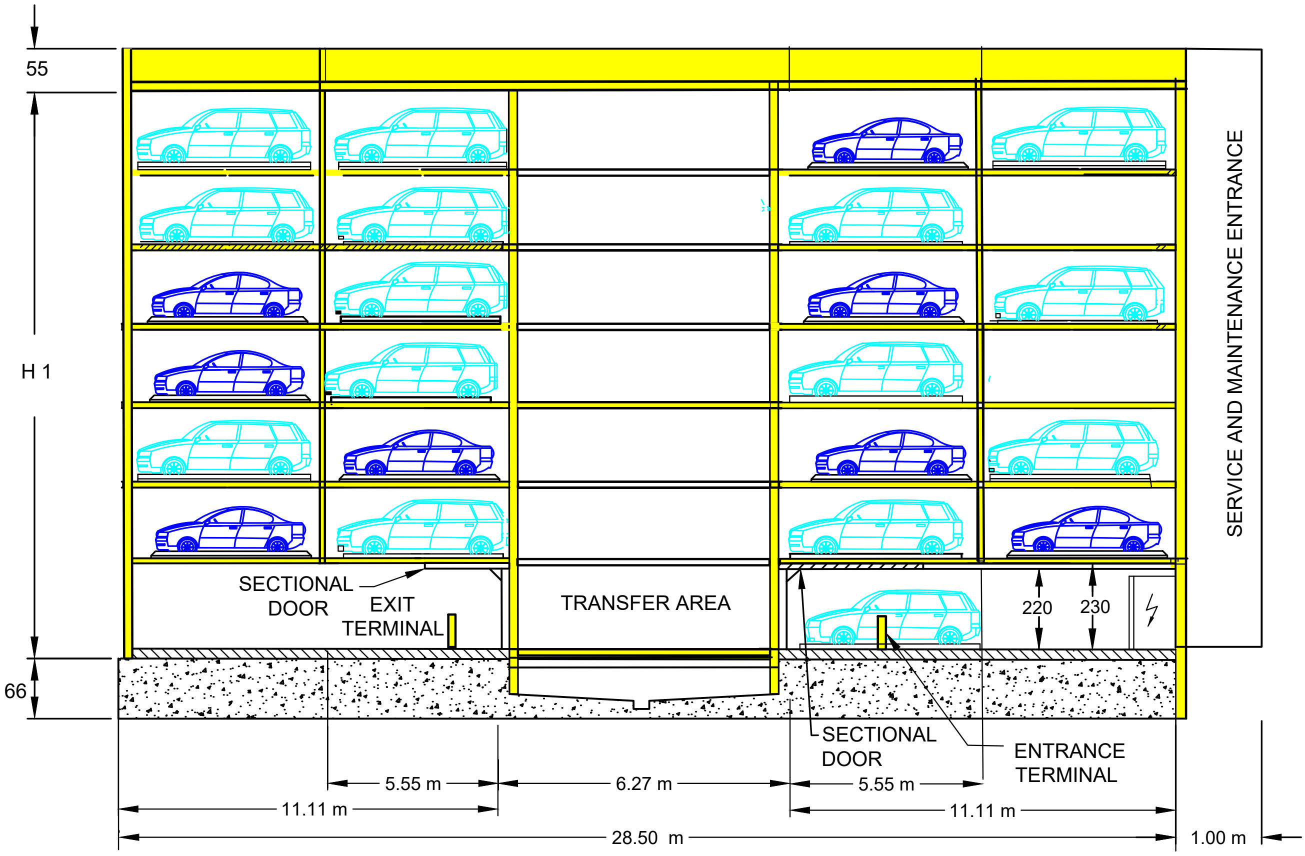

55
H 1
66
SECTIONAL
DOOR
EXIT
TERMINAL
TRANSFER AREA
220
230
SERVICE AND MAINTENANCE ENTRANCE
SECTIONAL
DOOR
ENTRANCE
TERMINAL
5.55 m
6.27 m
5.55 m
11.11 m
11.11 m
28.50 m
1.00 m

FIG. 11 ARRANGEMENT ABOVE GROUND

4.6 Chess Parking System

The chess parking system, also referred to as the level parker, shall be employed in scenarios where vertical space is optimized for vehicle storage. This system features a vertical lift serving multiple levels, with vehicles being horizontally circulated in a loop and transported to an entrance room or transfer area. *See* Fig. 12 and Fig. 13 for details of typical arrangement of the vehicles and the operation sequence.

4.6.1 *Key Features and Components*

a) *Vertical lift* — The system shall be equipped with a vertical lift that serves various levels, enabling the vertical movement of vehicles within the parking structure;

b) *Horizontal circulation* — Vehicles shall be circulated horizontally in a loop, allowing them to be transported efficiently to the designated entrance room or transfer area;

c) *Synchronized movement* — All platforms within the loop shall move simultaneously in synchronization, ensuring the coordinated transportation of vehicles;

d) *Performance considerations:*

   1) *Speed* — The chess parking system should be noted for its slower operational speed compared to other parking systems, as the synchronized movement of all platforms can reduce efficiency; and

   2) *Power requirements* — The system shall require more power due to the simultaneous movement of all platforms in the loop.

e) *Design efficiency* — The following parameters to be considered for efficiency:

   1) *Space utilization* — The system shall be designed to maximize vertical space utilization, making it suitable for locations with single entry and exit with efficient horizontal space utilization; and

   2) *Loop configuration* — The loop configuration should be designed to ensure smooth and continuous movement of vehicles within the system.

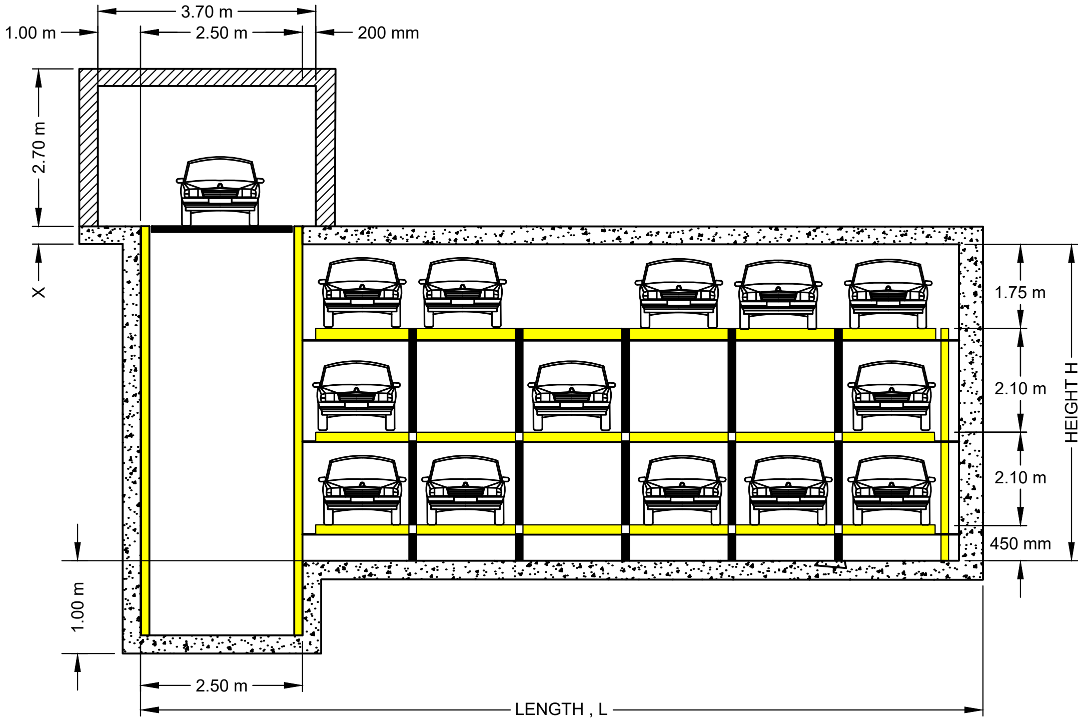


FIG. 12 CROSS SECTION SHOWING LIFT MOVEMENT AND PLATFORMS ARRANGEMENT

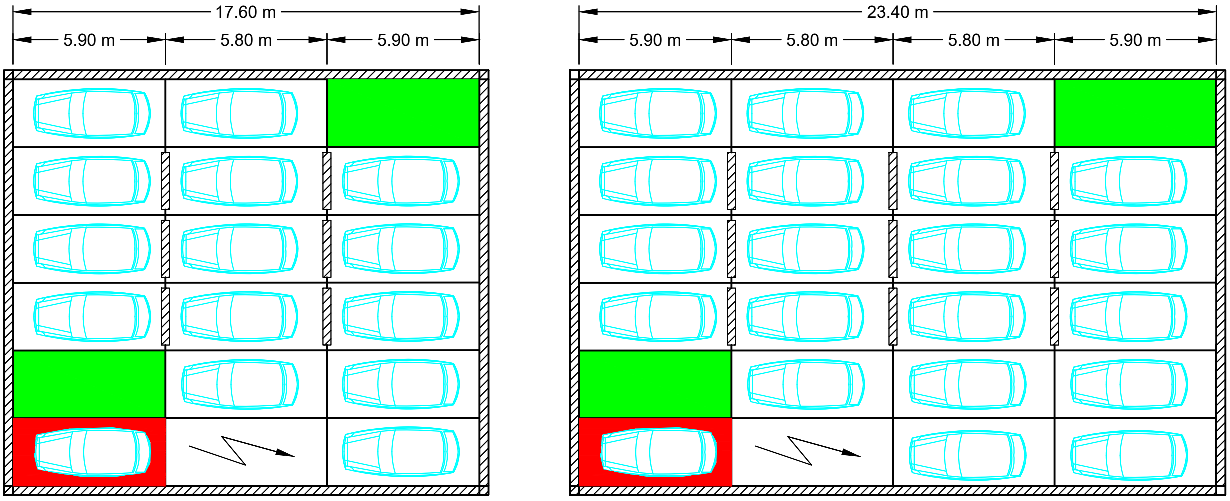


FIG. 13 ARRANGEMENT SHOWING MULTI-ROW ARRANGEMENT IN PLAN

4.7 Robotic Parking System

The robotic parking system is an advanced automated vehicle storage and retrieval system that shall utilize robotics technology to move vehicles efficiently within a parking facility. This system operates on the X, Y and Z axes, either with or without pallets, using steel or RCC structures. The system should ensure precise and swift car placement and retrieval, optimizing both space and time. Figure 14, Fig. 15 and Fig. 16 depict the typical arrangement in robotic parking system.

4.7.1 *With Pallets*

The following are the key features of this system:

a) *Parking arrangement* — Vehicles shall be parked on pallets, which shall remain engaged from the time of parking until retrieval. The system may be arranged above or below the ground, depending on the location of the entrance room;

b) *Structural requirements* — Steel structures used in this system shall be galvanized to ensure durability and protection against corrosion; and

c) *Installation flexibility* — This system shall be possible to install above ground, below ground, or with a combination of both, depending on site-specific requirements and design considerations.

4.7.2 *Without Pallets*

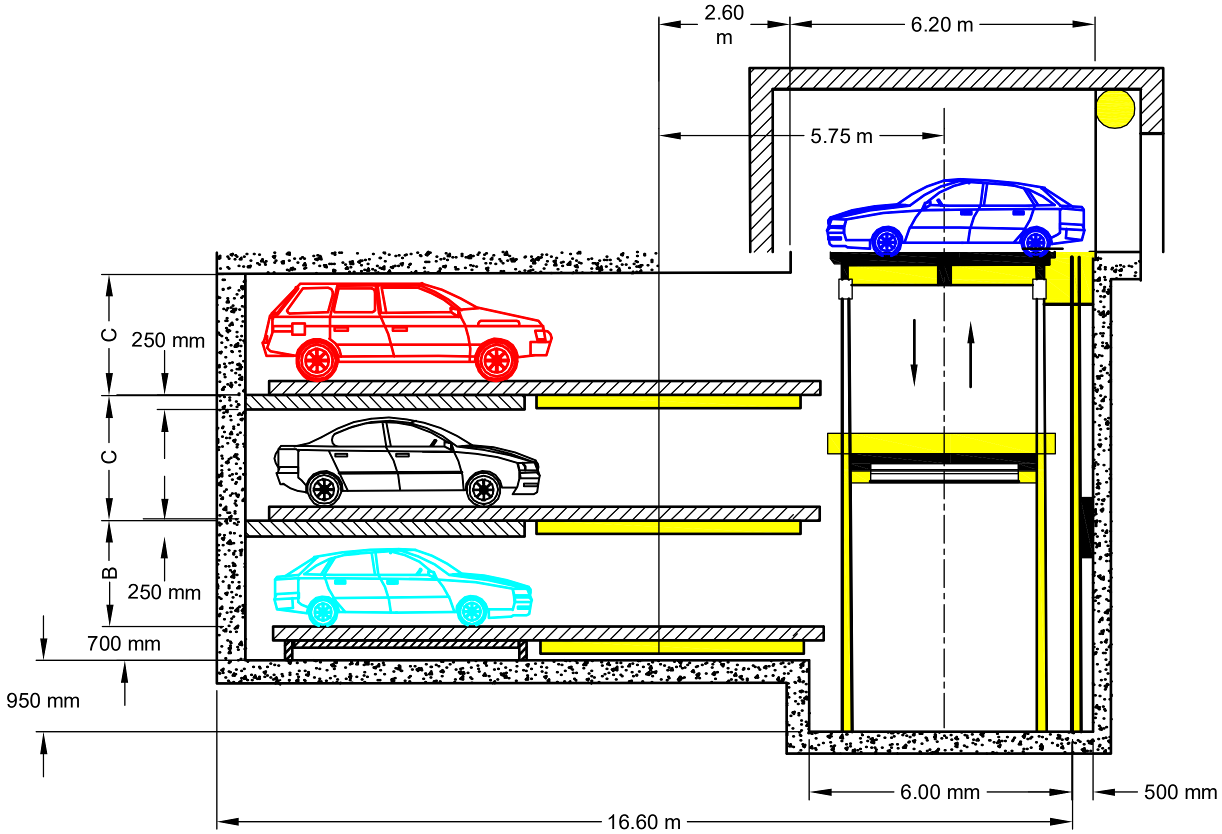
The following are the key features of this system:

a) *System movement* — The system shall operate on the X, Y and Z axes, with vehicles parked directly on RCC slabs or steel floor without the use of pallets. The system shall be faster in service as the car is transferred by a lift to the robot, utilizing a shuttle and dolly mechanism for movement;

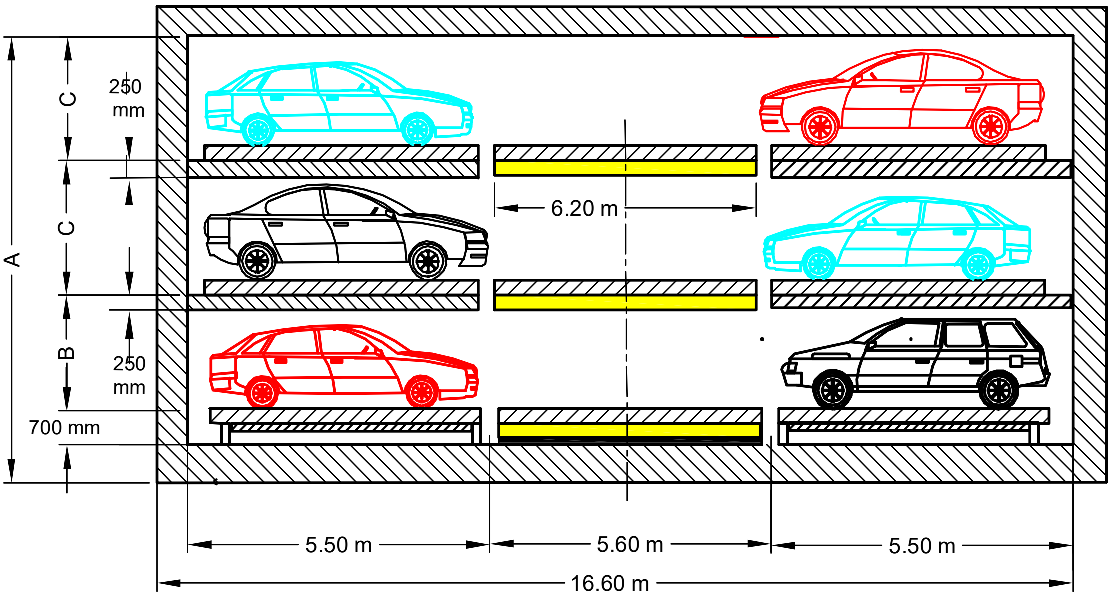
b) *Noise reduction* — Parking vehicles on RCC slabs should help reduce noise levels compared to pallet-based systems, providing a quieter operational environment;

c) *Fire safety* — The use of RCC slabs between levels shall aid in controlling the spread of fire from one level to another, enhancing the overall fire safety of the system; and

d) *Installation flexibility* — This system shall be possible to install above ground, below ground or with a combination of both, depending on site-specific requirements and design considerations.

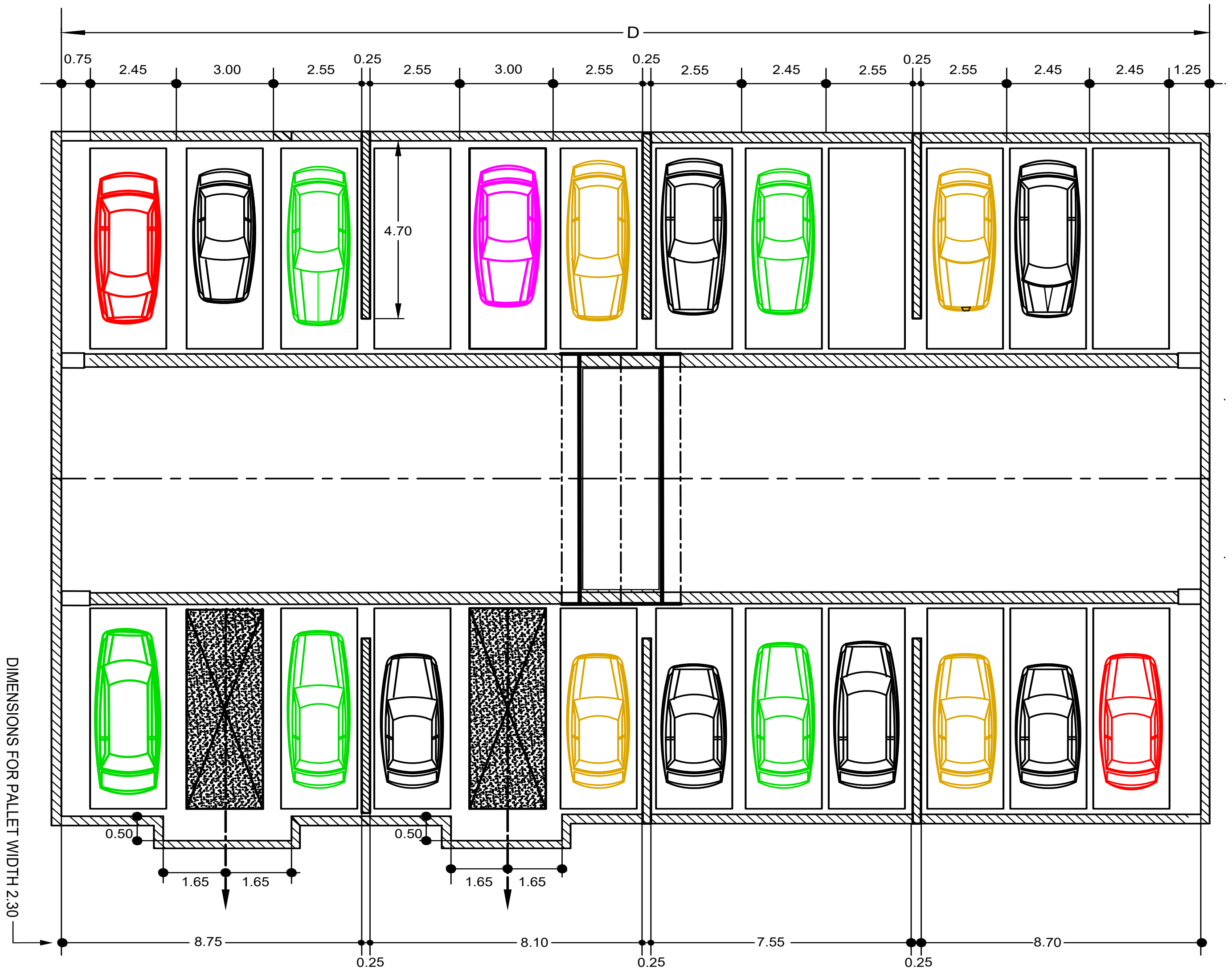

2.60 m
6.20 m
5.75 m
C
250 mm
C
B
250 mm
700 mm
950 mm
6.00 mm
500 mm
16.60 m

14 A WITH PALLETS


A
C
250 mm
C
B
250 mm
700 mm
6.20 m
5.50 m
5.60 m
5.50 m
16.60 m

14 B WITHOUT PALLETS

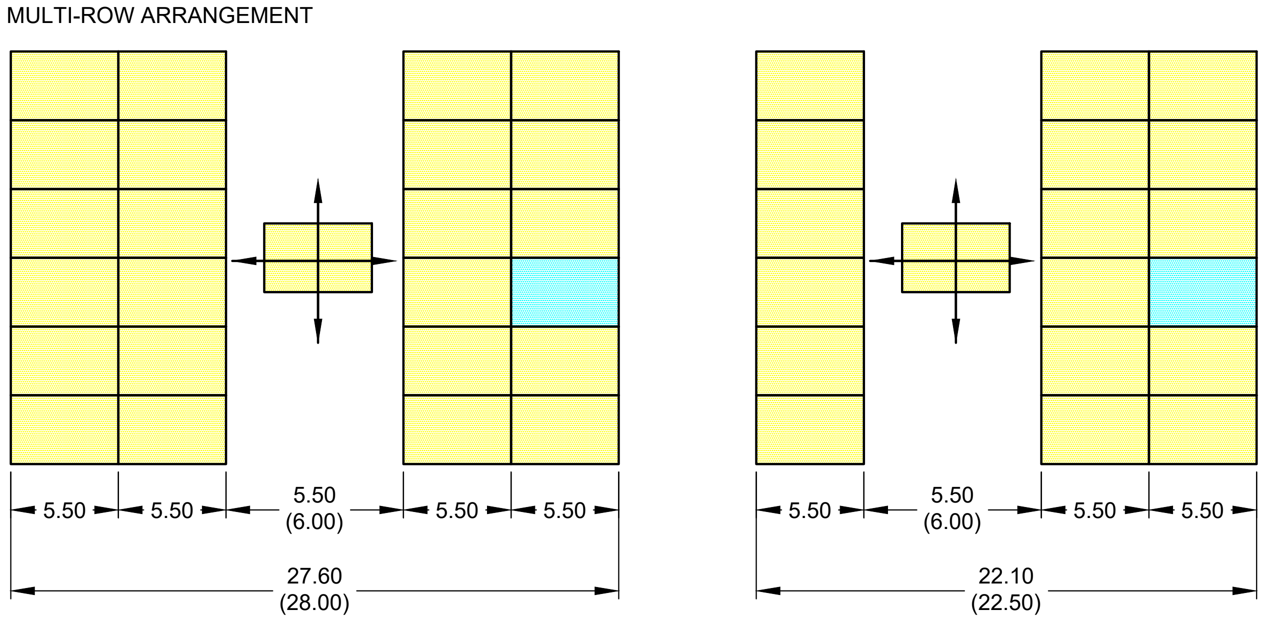
FIG.14 ROBOTIC PARKING SYSTEM CROSS-SECTIONAL VIEW


D
0.75
2.45
3.00
2.55
0.25
2.55
3.00
2.55
0.25
2.55
2.45
2.55
0.25
2.55
2.45
2.45
1.25
4.70
0.50
1.65
1.65
0.50
1.65
1.65
DIMENSIONS FOR PALLET WIDTH 2.30
8.75
8.10
7.55
8.70
0.25
0.25
0.25

All dimensions in metres.

NOTE — For the control unit, space (at least length 2.40 m × width 1.60 m × height 2.20 m) must be available near the transfer area.

FIG. 15 ROBOTIC PARKING SYSTEM PLAN



All dimensions in metres.

NOTE — The multi-row arrangement allows an optimum utilization of the available space and/or land area and saves construction costs, particularly with the shaft variant.

(Dimensions In Brackets Are for Storage and Retrieval Unit with Turning Device)

Fig. 16 Possibility of Multi-Row Arrangement

4.8 Rotary Parking

The rotary parking system is a space-efficient vehicle storage solution designed for locations where ground space is limited, but vertical space can be utilized. This system operates by rotating vehicles (anticlockwise or clockwise) in a vertical loop, allowing multiple cars to be parked in a compact footprint.

4.8.1 *Key Features*

The following are important features of rotary parking:

a) *Anchoring and structure* — The rotary parking system shall be a free-standing type, securely anchored to the ground. This ensures stability and safe operation, even in areas with limited space or challenging terrain;

b) *Entry and exit* — The system shall provide entry and exit at the ground level for easy access by drivers. To ensure safety, the entry and exit points shall be protected by an entrance door or gate that automatically opens and closes as vehicles enter or exit the system;

c) *Rotational movement* — The parking platforms within the system shall rotate in both clockwise and anti-clockwise directions, allowing for flexible vehicle placement and retrieval. This bi-directional movement enhances the system's efficiency, enabling quicker access to parked vehicles; and

d) *Vehicle capacity and variations*:

    1) *Capacity options* — The rotary parking system may be available in various configurations, typically accommodating up to 20 cars, among other possible variations. These options allow for customization based on the specific needs and space constraints of the installation site; and

    2) *Vertical loop design* — Vehicles are rotated vertically in a loop, with each vehicle occupying a designated platform. The system shall be designed to minimize the time required for vehicle retrieval, ensuring that any vehicle within the system can be accessed quickly and efficiently.

4.9 Sliding Platforms

These parking platforms are used to slide the car sideways or in longitudinal directions. Rails are placed directly on the flooring. Cars are parked on the platform and moved sideways.

5 PLANNING AND DESIGN GUIDELINES FOR PARKING SYSTEMS

5.1 Design Criteria for Power-Operated Parking Equipment

When designing or specifying power-operated parking systems, several critical design criteria shall be taken into consideration to ensure the safety, durability and efficiency of the equipment. These criteria are essential to accommodate various types of vehicles, ensuring smooth operation and long service life of the parking system.

5.2 Nominal Load Capacity

The nominal load capacity of the parking system should be designed to handle vehicles with a minimum weight of 2 000 kg and not more than 3 500 kg. This range is typical for most passenger vehicles and ensures that the system can safely accommodate both lighter and heavier cars within this spectrum.

5.3 Wheelset Load Distribution

The load on the wheelsets should be distributed evenly, with 50 percent of the nominal load allocated to the front and rear wheelsets. This balanced distribution is crucial for maintaining stability and preventing uneven stress on the parking platform.

5.4 Individual Wheel Loads

Each wheel should bear approximately 25 percent of the nominal load, ensuring that the weight is evenly distributed across all four wheels. This distribution minimizes the risk of overloading any single wheel, which could lead to mechanical failure or uneven wear on the system.

5.5 Wheelbase Specification

The design should account for a wheelbase of 2.90 m, measured from the centre of the front wheel to the centre of the rear wheel. This specification ensures compatibility with a wide range of vehicle sizes and provides adequate spacing for secure parking.

5.6 Track Gauge Requirements

The track gauge, or the distance between the wheels in width, should range from a minimum of 1.5 m to a maximum of 2.10 m. This range accommodates different vehicle widths while ensuring that the parking system can handle various car models without compromising stability.

5.7 Tyre Footprint Consideration

The tyre footprint, or the area of the tyre that comes into contact with the parking platform, should measure approximately 0.18 m by 0.18 m. This specification helps distribute the vehicle's weight evenly across the platform, reducing the risk of damage to the system.

5.8 Forces in Direction of Travel

The design should account for forces in the direction of travel equivalent to 1/7 of the nominal load in kilonewton (kN). This consideration is critical to ensure that the system can handle the dynamic forces exerted when vehicles move on or off the platform.

5.9 Transverse Forces

Forces transverse to the direction of travel should be considered as 1/20 of the nominal load in kilonewton (kN). While this does not exclude other design criteria, it ensures that the system can withstand lateral forces, such as those generated by turning or shifting vehicles.

5.10 Load Considerations for Parking Equipment

When designing or specifying parking equipment, it is essential to consider the worst-case loads that may occur. These include loads from the stationary position of the vehicle on the platform as well as dynamic loads during transportation or when the vehicle is driving onto the platform. These considerations help ensure that the system is robust enough to handle peak stresses without failure.

5.11 Equipment Life Expectancy

The parking system should be designed for a minimum operational life of 20 years. This long-term durability requirement ensures that the system remains functional and reliable over an extended period.

5.12 Operation Cycle Requirements

The system should be capable of performing at least one parking-in and one parking-out operation per day, amounting to two cycles per platform or space. This cycle rate should be sustainable every day of the year, ensuring the system can meet the daily demands of a busy parking facility.

6 ARRANGEMENT AND PLANNING DIMENSIONS

6.1 Grid and Rows

When planning and designing parking systems, it is essential to define the maximum number of rows and grids to ensure optimal space utilization and system efficiency. The arrangement of grids and rows in a parking module impacts the capacity and operational effectiveness of the parking system (*see* Fig. 17).

6.1.1 Maximum Number of Rows

The parking system shall not exceed a maximum of four rows to maintain manageable distances for vehicle retrieval and to ensure safety and accessibility within the parking structure.

6.1.2 *Maximum Number of Grids*

The maximum number of grids shall be as given below:

a) *One-row system* — A module with a maximum of 15 grids should be utilized. However, it is advisable to limit it to no more than 10 grids to maintain ease of access and operational efficiency;

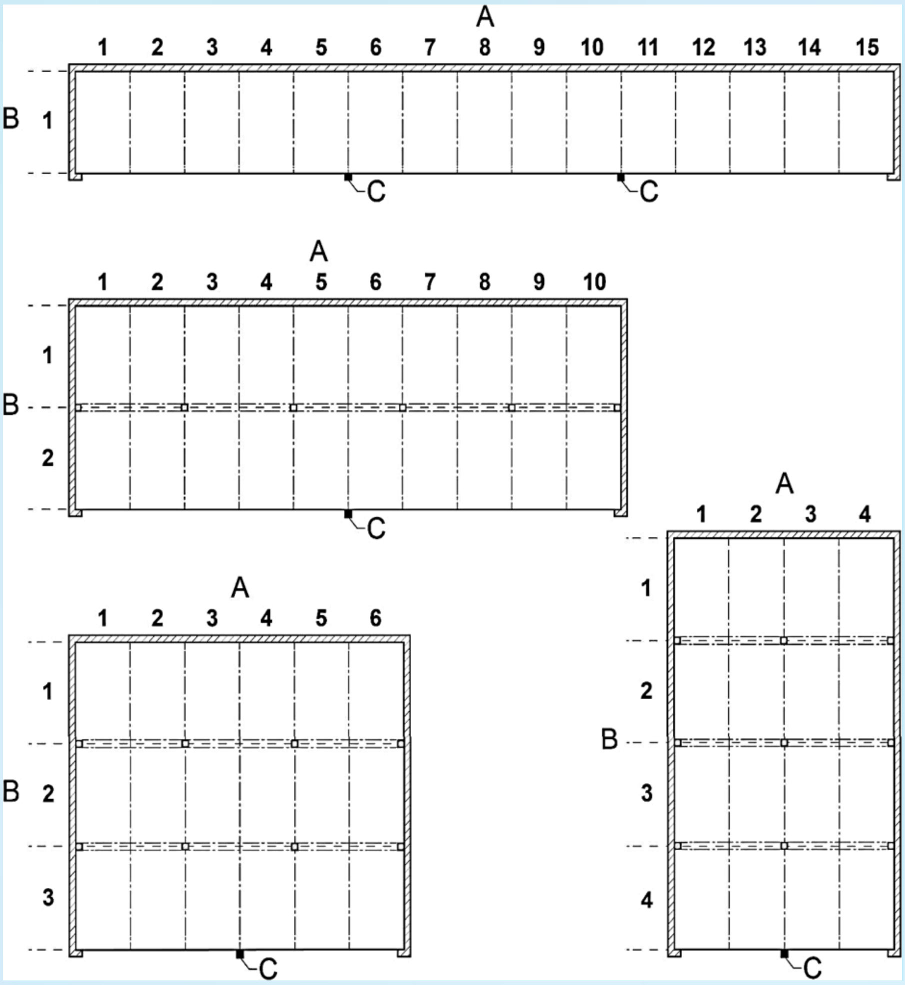
b) *Two-row system* — The module should contain no more than 10 grids to ensure that vehicles can be parked and retrieved with minimal obstruction;

c) *Three-row system* — The system should be designed with a maximum of 6 grids to allow for sufficient manoeuvring space within the parking structure; and

d) *Four-row system* — A limit of 4 grids per module should be adhered to for optimal operation and safety.

6.1.3 *Control Panel Requirements*

An additional control panel shall be installed after every maximum of 5 grids on either the left or right side of the parking system as shown in the Fig. 17. This requirement ensures that users can conveniently operate the system and enhances the safety and usability of the parking setup.



Key

Grid	Horizontal parking spaces
Rows	Back-to-back parking arrangement
C	Indicates control panel

FIG. 17 GRID AND ROWS IN PARKING SYSTEM

6.2 Arrangement and Planning

The suggested guidance on the arrangement and planning of the parking requirements are given above; *see also* Fig. 17.

6.2.1 *Open Parking Spaces*

Open-to-sky parking areas may be permitted in side margins or in the surrounding open spaces of a building.

6.2.2 *Closed Parking Spaces*

Parking areas within the building line, in basements or on lower ground or podium levels inside the building.

6.2.3 *Automatic Parking Spaces*

Unmanned areas where vehicles are transported from the entrance room by means of mechanical systems such as conveyors, lifts, etc and transported back to the exit room. The parking area may be clearly demarcated with a reflective paint and driveways shall be connected to all the parking areas.

6.2.4 *Car hold area*

The space between the entrance from the connecting road to the actual parking area shall be considered as the storage space or car hold area.

6.2.5 *Entrance and exit room*

This room should be properly ventilated and illuminated.

6.2.6 *Width of Parking Area*

The clear width of a parking space shall be not less than 2.7 m for small cars, such as sedans and hatchbacks. The clear width of a parking space shall be not less than 2.9 m for large cars, such as sport utility vehicles (SUVs). Typical layouts of parking spaces are illustrated in Fig. 20.

6.2.7 *Ramps and Driveways*

For curvatures and circular ramps or driveways, the inner radius shall be 5.0 m. Wider driveways with an inner radius of approximately 10.0 m should be considered for safety purposes (*see* Fig. 18).

6.2.8 *Pedestrian Walkway*

In large parking areas, a separate pedestrian walkway of 0.8 m next to driveways shall be considered, which should be raised above the main parking level or marked permanently and illuminated for visibility and safety.

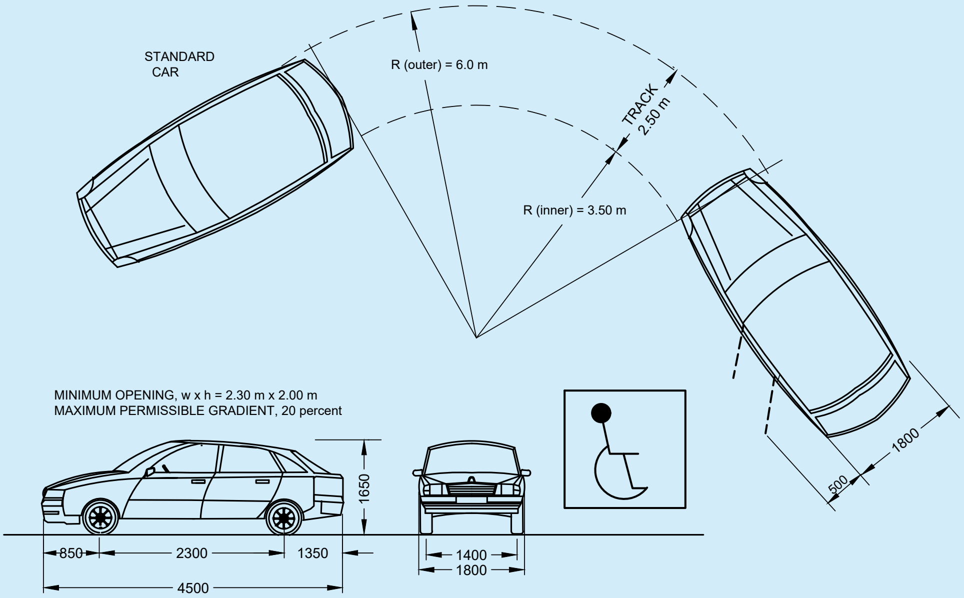


FIG. 18 PARKING SPACE DIMENSIONS

6.2.9 *Slope of the Ramps*

The inclination of ramps shall not exceed 15 percent or a 1 : 8 ratio. The recommended slope is 1 : 10. The width shall not be less than 2.75 m, and at least 3.5 m in circular or curved areas for single-lane traffic. The joint at the start and end of the ramp shall have a slope of 3 percent with proper curvature to ensure smooth travel and prevent vehicles from hitting the bottom or nose of the car. For public parking, a slope not exceeding 10 percent (1 : 10 ratio) should be considered. An extension of at least 3.0 m in front of the ramp shall be provided (*see* Fig. 19).

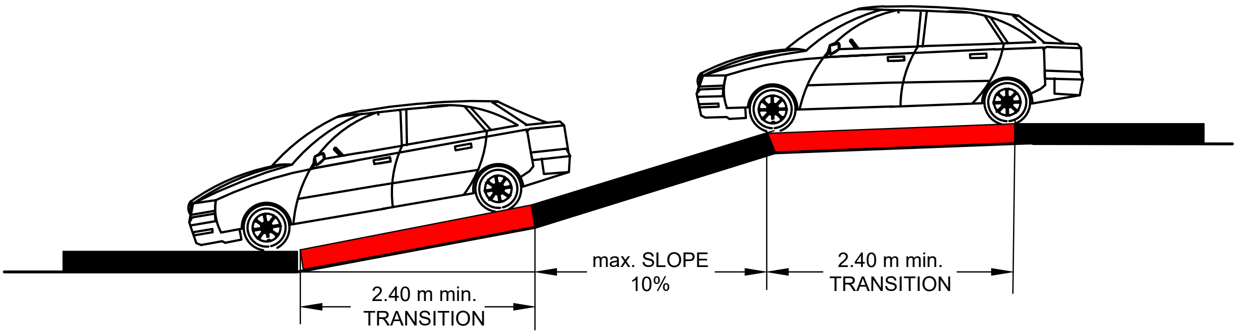


FIG. 19 TRANSITIONAL RAMP

6.2.10 *Size of Parking Space and Women Parking Space*

The length of car parks shall be 5.0 m, and parking arranged alongside driveways shall be at least 6.0 m wide. The entire parking space may be designed as a column-less structure for safety.

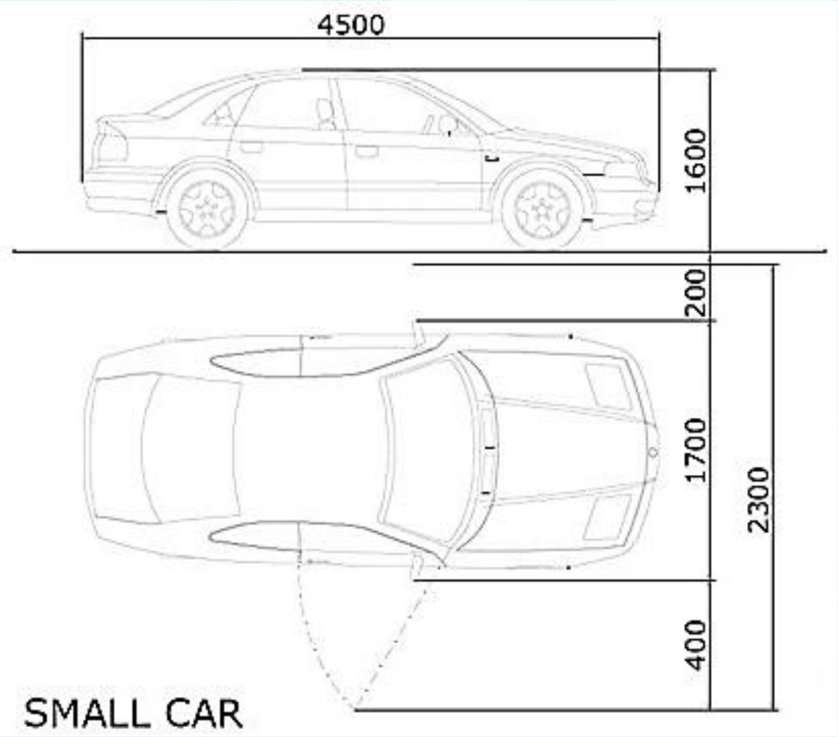
6.2.11 *Parking Space*

The minimum width for parking spaces shall be 2.3 m for small cars (*see* Fig. 20A) and 2.5 m for big cars (*see* Fig. 20B). For power-operated mechanized parking systems, at least 0.2 m of space on either side shall be added to the above basic widths. *See also* Fig. 20:

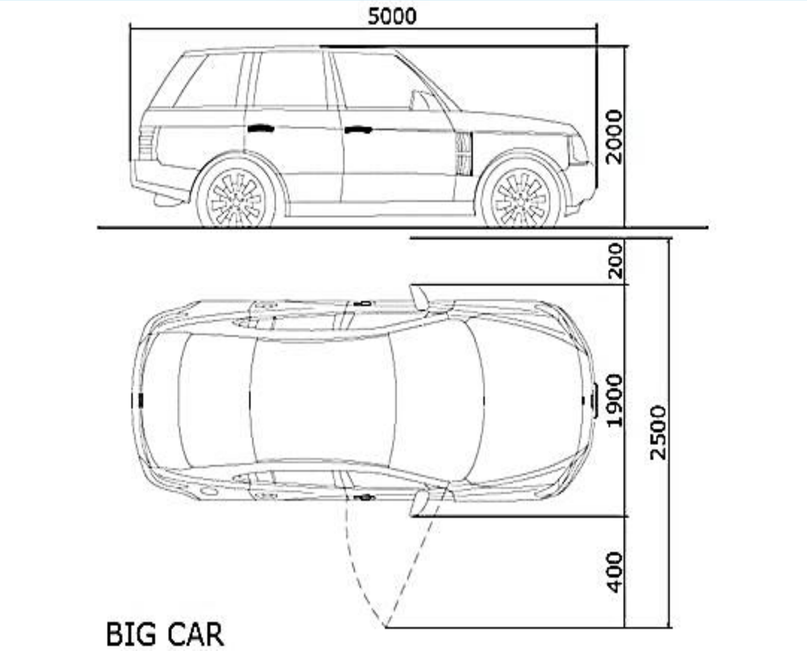
a) *Small cars* — 2 300 mm × 5 000 mm (clear space + additional space of 400 mm for mechanized clearance);

b) *Big cars* — 2 500 mm × 5 500 mm (clear space + additional space of 400 mm for mechanized clearance); and

c) *Clearance for door opening* — Minimum of 400 mm on the driver's side for normal parking and 1 000 mm for persons with disabilities.



20A FOR SMALL CAR



20B FOR BIG CAR

FIG. 20 PARKING SPACE DIMENSION

6.2.12 *Reserved Parking for Persons with Disabilities*

Parking spaces for the persons with disabilities shall be as per and shall be considered as conventional parking having size 3 900 mm in width with 5 400 mm in length. One to two percent of the parking spaces shall be reserved as per local norms and the type of project, located close to the barrier-free entrance and as close as possible to the ramp and passenger lifts. The area shall be highlighted with signages.

6.2.13 *Driveway Width for* 90 *Degree Entry*

The driveway width shall be at least 6.5 m in front of mechanized systems.

6.2.14 *Single Driveways/Passing Driveways*

Single driveways where parking is not connected shall be at least 2.75 m wide and for two-way traffic, the width shall be at least 5.0 m.

6.2.15 *Identification of Driveways*

Parking systems and driving aisles shall be clearly marked. The signage indicating entry/exit direction of driveways shall be permanently marked and illuminated. *See* Fig. 21 for guidance.

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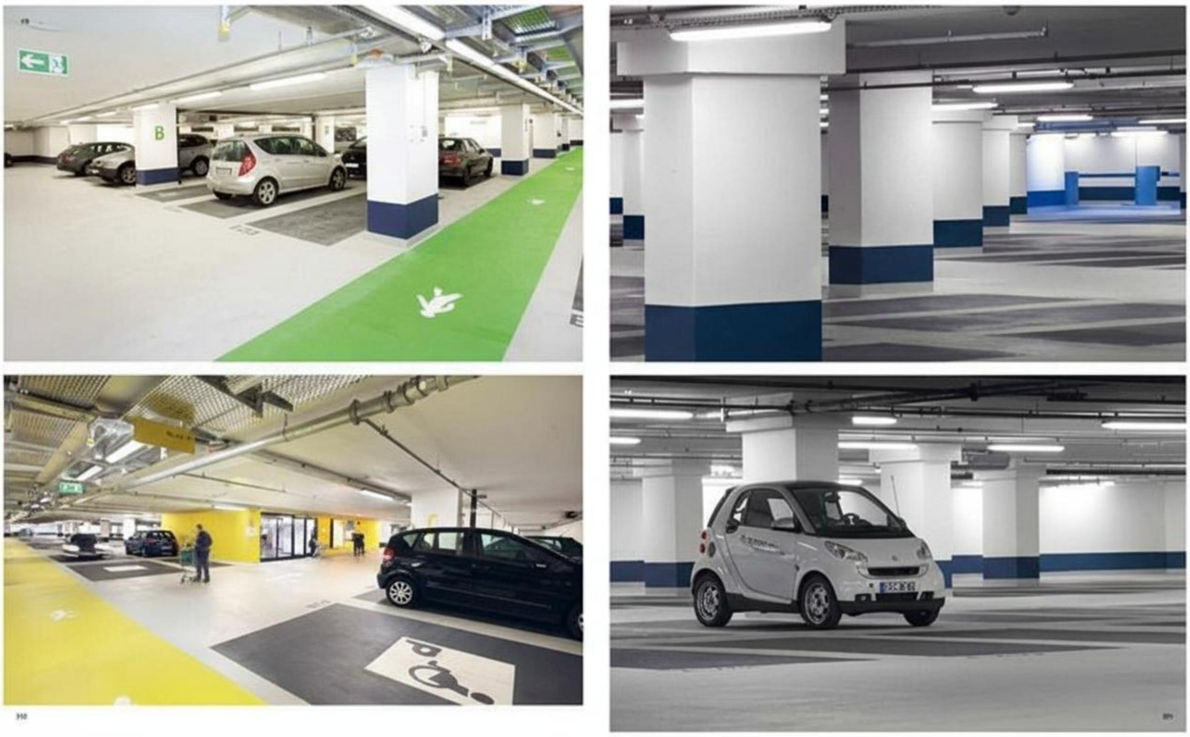

FIG. 21 MARKINGS IN DRIVEWAYS AND PARKING SPACES

6.2.16 *Demarcation of Parking Space*

Parking spaces shall be marked with numbers on the floor to facilitate easy identification of parking spots.

6.2.17 *Reserved Parking for Women*

Ten percent of the parking spaces in large parking area shall be reserved for women drivers and should be located near access ramps/roads, preferably in areas free of columns or other obstructions.

6.2.18 *Clear Height for Pedestrian Passage*

A clear passage height of 2.2 m in pedestrian areas shall be maintained and clearly marked with signages on the floor.

6.2.19 *Escape Route*

Every medium-sized and large-sized parking spaces shall have at least two independent escape routes on each floor. The second escape route may lead through ramp. In parking areas above ground, one escape route is sufficient. External staircases shall be arranged.

6.2.20 *Stairway*

At least two staircase or exit to the open air shall be provided from each floor. Permanent and easily recognizable signage/indications of exits shall be provided. General electric lighting shall be provided to ensure an illuminance of at least 20 lux in escape routes and driving aisles. Solar-powered illumination should be considered for environmental sustainability.

6.2.21 *Emergency Lighting in Parking Area*

Emergency lighting, with a backup power source independent of the mains supply, shall switch on automatically in the event of a power failure. The lighting shall be designed for at least 1 h of operation with an illuminance of at least 20 lux or shall be provided with fluorescent markings that offer adequate illumination for at least 1 h, leading to exits in an easily recognizable manner.

7 SAFETY REQUIREMENTS

7.1 Safety Doors

Parking systems employing pit type designs shall be protected by safety doors to ensure user safety and system integrity.

7.1.1 *Strength of Safety Doors*

The safety doors shall have mechanical strength in the closed position, capable of withstanding a force of 300 N applied at any point perpendicular to the door surface on either side, evenly distributed over an area of 500 mm^2. This force should not cause permanent deformation of the door or impair its normal function. The height of the safety doors shall be considered as 2.0 m unless restricted by a car height of less than 2.0 m. This requirement does not apply to emergency access doors for automatic systems. The size of the emergency access doors may be restricted to 0.65 m in width and 2.0 m in height. If the main door(s) is intended to be closed manually by the user, the control devices shall be located such that the door is visible from the operating position. Safety devices shall not be easily accessible to users. The safety device preventing the door from opening shall be designed as an interlock. The movement of the load-carrying means shall not be possible until the locking device(s) has/have engaged by at least 7 mm. The latch shall resist without permanent deformation or release of the latch when a force of 1 000 N is applied at the height of the latch in the direction of the door opening. The latch shall remain engaged and held permanently in position. Electromagnets, pneumatic and hydraulic devices shall not be used as retainers.

7.2 Operation of Parking Facilities

7.2.1 *General Operation*

The following lists the general operations in the semi-automatic parking facilities:

a) The user parks the motor vehicle in the transfer area;

b) The motor vehicle shall be automatically stored;

c) The motor vehicle shall be automatically made available for retrieval; and

d) The user retrieves the motor vehicle and drives out of the transfer area.

7.2.2 *Design of Transfer Area*

For permanent users, the design of the system shall allow the main door to be opened by signals from outside, such as remote control, magnetic card, induction loop, manually operated control devices, or mobile terminals. The particular door from which a ‘PARKING IN’ or ‘PARKING OUT’ call is registered shall open.

7.2.3 *Checking the Vehicle Dimensions*

The user shall ensure that the maximum vehicle dimensions and weights, as specified in the operating instructions, are not exceeded.

7.2.4 *Closing the Main Door*

The following illustrates the steps involved for:

a) *For manually operated doors* — The user shall exit the motor vehicle and leave the transfer area through the main door. The user shall check that no person remains in the transfer area before manually closing the main door; and

b) *For power-operated doors* — The user shall exit the motor vehicle and leave the transfer area through the main door. The user shall check that no person remains in the transfer area before closing the main door using the designated control device, such as a magnetic card or manually operated control device. Access during the closing process shall be monitored by a light barrier sensor.

7.3 Safe Practices

7.3.1 *Monitoring by System Operator*

The user should not remain in the car for an extended period and shall exit the car within 45 s. The operator shall ensure adherence to this practice for safety.

7.3.2 *Automatic Malfunction Detection Devices*

Semi-automatic parking facilities shall be equipped with one or more automatic malfunction detection devices designed and installed to minimize the risk of unsafe operation. When any fault or hazardous condition is detected, an appropriate audible and/or visible warning shall be provided to the user or operator. The equipment shall be immediately stopped using the emergency safety button located on the operation panel. Restarting the equipment shall only be possible by maintenance personnel and under the control of all safety devices.

7.3.3 *Operating Modes*

The changeover from automatic mode to any other operating mode shall only be carried out by authorized or instructed persons. The changeover to safety-related operating modes shall comply with all safety requirements.

7.3.4 *Safety Monitoring and Testing*

The following aspects shall be adhered to:

a) *Type test* — Verification of the machine type to determine whether the parking system meets the requirements;

b) *Individual testing* — Testing each parking system in order to ensure compliance with safety requirements before putting it in operation and handing over to end user;

c) *Design test* — Checking whether the design of the parking system or its components meets the functional requirements;

d) *Visual inspection* — Determining the presence of required safety features on the machine, system, or component, and ensuring that provided documents meet the functional requirements;

e) *Measurements* — Ensuring that specified measurable parameters, such as geometric dimensions and safety distances, are met; and

f) *Operational test* — Verifying that the parking system operates as intended and that all safety devices function correctly during a normal cycle or part of a cycle without load.

7.4 Safety Devices

Parking systems shall be equipped with the following safety devices to ensure the safe and efficient operation of the equipment:

a) *Limit switches* — These shall be installed to detect and control the movement of the parking platforms in the upward direction, preventing them from exceeding their designated range of motion;

b) *Non-return valve* — This shall be integrated into the hydraulic system to prevent the unintended lowering of the platform in the event of a hydraulic failure, ensuring that vehicles remain securely positioned;

c) *Wheel stoppers* — Wheel stoppers shall be provided at the end of each parking bay or platform to prevent vehicles from rolling off the platform. These shall be of sufficient strength and size to securely hold the vehicle in place;

d) *Locker* — These shall be fitted in the vertical guide rail element of the parking system to stop the downward movement in case of brake failure;

e) *Electromagnetic locks* — These shall be used to securely lock the platforms or gates in place when the parking system is not in operation, preventing unauthorized movement or access;

f) *Car height sensor* — A car height sensor may be installed to detect the height of the vehicle and ensure it is compatible with the parking system's designated height restrictions, preventing potential collisions with the platform or ceiling;

g) *Car in-out sensor* — These sensors shall detect the presence of a vehicle entering or exiting the parking bay, ensuring that the system operates when it is safe to do so; and

h) *Emergency stopper* — An emergency stop device should be provided at accessible locations within the parking area to immediately halt the operation of the system in the event of an emergency, preventing accidents or injuries.

7.5 Wiring Practices

Wiring practices for power-driven parking equipment, including the connections to the disconnection means from the power supply, shall adhere to the guidelines outlined in Part 1 of good practice [D-5C(1)] and [D-5C(2)]. The electrical equipment of the parking system shall comply with the good practice [D-5C(4)]. The earthing and bonding connections shall be as per the good practice [D-5C(3)] and lightning protection of the parking system shall comply with accepted standard [D-5C(5)].

7.5.1 Wiring methods both inside and outside of enclosures shall be clearly identified and marked to prevent incorrect connections that could result in hazardous conditions, such as unintended movement direction or disruption of safety devices.

7.5.2 Whenever possible, external wiring shall be positioned away from combustible materials and areas where it might be subject to mechanical damage. In situations where this cannot be avoided, the wiring shall be protected using appropriate means such as rigid conduits, flexible tubing, raceways or other suitable protective methods.

7.5.3 Electrical equipment shall be designed, marked, and arranged to minimize the risk of incorrect connections, which could lead to injury. Proper care shall be taken to ensure all connections are safe and correctly executed.

7.6 Essential Safety Guidelines for Operation of Parking Systems

Apart from the operational mechanisms, the following essential safety guidelines shall be observed for the successful and safe operation of various parking systems.

7.6.1 *Maintenance Doors*

Properly designed maintenance doors are critical to ensure safe access for inspection and repair without compromising system integrity. The following requirements shall apply:

a) In fully automatic systems, a separate maintenance door shall be provided in addition to the main door. This door shall be openable only from outside by authorized persons with a key and from inside without a key;

b) Maintenance doors shall not open inwards into the working area and shall be provided with appropriate electrical connection; and

c) When the maintenance door is opened, the parking equipment shall automatically stop by means of a safety switch or equivalent device. Restarting of the equipment shall only be possible when the service door is closed and shall be carried out by authorized personnel.

7.6.2 *Access and Inspection*

Safe and reliable access routes are essential for regular inspection, servicing and emergency interventions. Accordingly, the following provisions shall apply:

a) A separate staircase shall be externally installed, with access provided at every alternate level for inspection; and

b) Emergency doors for accessing the system shall be provided with electrical/electronic controls to switch off the system.

7.6.3 *Selector Switches*

Selector switches shall be located outside the working area with free access for changeover from mains supply to alternate power source.

7.6.4 *Safety Guards*

Fixed enclosure guards or interlocking guards shall be provided to protect persons from hazards such as crushing, shearing, entanglement or entrapment.

7.6.5 *Walkways, Control Stands and Platforms*

Safe access routes shall be ensured during installation. Permanent access to control panels and parking areas shall be provided in accordance with applicable building safety norms.

7.6.6 *Illumination of Working and Transfer Areas*

Adequate lighting is vital to maintain visibility, safety and ease of operation in both working areas and transfer areas. The following requirements shall apply:

a) Working areas where maintenance, inspection, cleaning, and lubrication are to be carried out shall be properly illuminated, with a minimum of 100 lux; and

b) The transfer area shall be adequately illuminated between 40 lux and 60 lux. Lighting in the transfer area may automatically switch off after closing of the main door.

7.6.7 *Safety Railings*

Safety railings of minimum 1 m height shall be provided in stack and puzzle parking systems to prevent accidental access to open spaces around the system.

7.6.8 *Operating Instructions*

Clear operating instructions shall be displayed at suitable locations.

7.6.9 *Restricted Entry*

Unauthorized persons shall be prevented from entering the transfer and working areas during system operation.

8 VENTILATION AND FIRE SAFETY REQUIREMENTS FOR PARKING SYSTEMS

8.1 Mechanical Exhaust Air Systems

8.1.1 Mechanical exhaust air systems shall be required in closed medium-sized and large parking areas. The supply air openings shall be distributed to ensure sufficient ventilation throughout all parts of the parking areas. If the supply air openings are inadequate, a mechanical supply air system shall be provided.

8.1.2 The mechanical exhaust air systems shall be dimensioned to ensure that the half-hourly mean value of carbon monoxide (CO) concentration in the air, measured at a height of 1.5 m above the floor, does not exceed 100 ppm. This requirement shall be deemed satisfied if the exhaust air systems in parking areas with low ingress and egress traffic discharge at least 6 m^3 of exhaust air per hour per m^2 of usable parking area. In other garages, the system shall discharge at least 12 m^3 of exhaust air per hour per m^2 of usable parking area.

8.1.3 Mechanical exhaust air systems shall be equipped with at least two equally sized fans in each ventilation system, which together shall provide the required total volume flow during simultaneous operation. Each fan of a mechanical supply or exhaust air system shall be supplied from a separate circuit, to which no other electrical systems shall be connected. If the ventilation system is temporarily operated with only one fan, the fans shall be switched in such a way that in the event of failure of one fan, the other fan automatically switches on.

8.2 CO Monitoring and Warning Systems

8.2.1 Large enclosed parking areas with substantial incoming and outgoing traffic shall have CO measuring and warning systems. The CO warning systems shall be designed to prompt users to switch off their engines through acoustic signals and flashing signals if the CO content in the air exceeds 250 ppm. These CO warning systems shall be connected to a backup power source.

8.3 Safety Notices

8.3.1 In enclosed medium-sized and large parking areas, the following notices shall be prominently and permanently displayed at the entrance and on each floor:

"EXHAUST FUMES ENDANGERS HEALTH.
AVOID PROLONGED STAY."

8.4 Fire Safety Provisions

8.4.1 Fire extinguishing systems, smoke and heat extraction systems, and fire alarm systems should be provided in accordance with the requirements specified in Part F 'Fire and Life Safety' of this NBCS.

8.4.2 Automatic parking areas with more than twenty parking spaces shall be equipped with sprinkler systems. For automatic parking areas with less than twenty parking spaces, power-operated lifting platforms that allow vehicles to be stacked, and parking spaces separated from tramlines by closures, non-automatic fire extinguishing systems shall be provided. The type of system shall be determined on a case-by-case basis in consultation with the fire protection authority, ensuring that all parking spaces within the parking areas can be reached with an extinguishing agent in every operating state.

8.4.3 Enclosed medium-sized and large parking areas shall be equipped with fire alarm systems if they are connected with structural installations or rooms for which fire alarm systems are required.

8.4.4 Fire extinguishing systems may also be required for enclosed medium-sized parking areas if necessary for deploying fire lines for flammable substances or electrical lines connected to the fire tank.

8.4.5 A sprinkler system shall be installed in all parking areas, regardless of size (small, medium or large) and shall be designed to cover all parked vehicles effectively. This requirement also applies to automatic parking areas with more than twenty parking spaces. The sprinkler system should preferably not be positioned at the immediate centre (S2 as depicted in Fig. 22) of the top area with respect to the parking system. Instead, it should have some eccentricity from the centre position (S1 and S3 as depicted in Fig. 22) to enhance effectiveness in the event of a fire, ensuring better coverage and rapid response.

8.5 Ventilation Requirements

8.5.1 Natural ventilation for parking system installed at ground or above natural ventilation shall be considered.

8.5.2 Natural ventilation for parking system installed below ground for low traffic, natural ventilation may also be sufficient.

8.5.3 *Ventilation Openings and Shafts* (*for Fully Automatic Systems*)

Permanent ventilation openings or ventilation shafts, with a total free cross-section of at least 0.15 m^2 per parking space, shall be provided up to a height of 2 m to ensure proper air circulation. These provisions shall comply with the requirements outlined in the local building code to maintain safety standards and mitigate fire risks.

8.6 Restrictions on Parking Locations

Motor vehicles shall not be parked in stairwells or generally accessible corridors, including ramps.

9 SPECIAL TECHNICAL REQUIREMENTS

This is considered for special applications of parking; for example, parking systems within the side margins of the existing buildings. These systems can be considered above or below the flooring within the side margins

9.1 Cantilever Systems

These systems are also installed within side margins, however due to its construction, the systems are not suitable for long life.

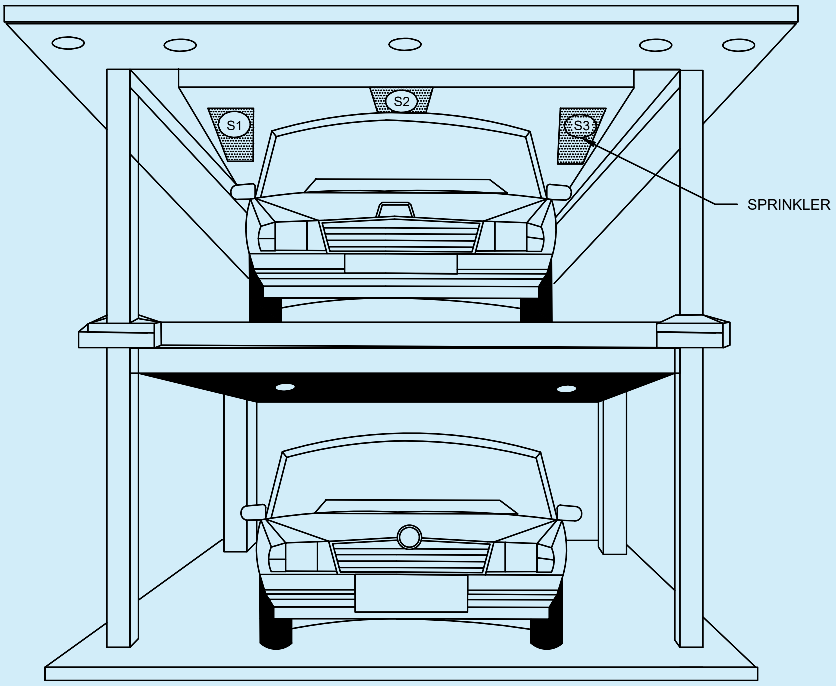

FIG. 22 PREFERRED SPRINKLER SYSTEM POSITIONING (AT S1 AND S3) IN THE UPPER LEVEL

9.2 Suspended Systems

These systems are hung from top connected through building beams and are not safe.

10 PERFORMANCE REQUIREMENTS FOR PARKING SYSTEMS

10.1 Design Considerations

When designing or specifying parking equipment, consideration shall be given to the worst-case loads that may arise from both the stationary position of a motor vehicle on the platform or load-carrying equipment, as well as during the vehicle's movement on the load-carrying equipment, where such movement may cause higher stresses.

10.2 Service Life Definition

The parking system shall be designed to meet the following minimum service life criteria:

a) Service life : 20 years
b) Cycle definition : 1 parking in and 1 parking out operation
c) Cycles per day : 2 cycles per platform or space
d) Operating days per year : 365 days

LIST OF STANDARDS

The following list records those standards which are acceptable as 'good practice' and 'accepted standards' in the fulfilment of the requirements of this NBCS. The latest version of a standard shall be adopted at the time of enforcement of this NBCS. The standards listed may be used for conformance with the requirements of the referred clauses in this NBCS.

In the following list, the number appearing in the first column within parenthesis indicates the number of the reference in this Part/Section.

	IS No.	*Title*
(1)	SP 30 : 2023	National Electrical Code of India 2023
(2)	IS 732 : 2019	Code of practice for electrical wiring installations (*fourth revision*)
(3)	IS 3043 : 2018	Code of practice for earthing (*second revision*)
(4)	IS 16504 (Part 1) : 2019/ IEC 60204-1 : 2016	Safety of machinery — Electrical equipment of machines: Part 1 General requirements (*first revision*)
(5)	IS/IEC 62305-1 : 2010	Protection against lightning: Part 1 General principles
	IS/IEC 62305-4 : 2010	Protection against lightning: Part 4 Electrical and electronic systems within structures

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART D BUILDING SERVICES

SECTION 6 INFORMATION AND COMMUNICATION ENABLED INSTALLATIONS

BUREAU OF INDIAN STANDARDS

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National Building Code Sectional Committee, CED 46

FOREWORD

This NBCS (Part D/Section 6) covers the essential requirements for information and communication enabled installations, technology systems and cabling installations in a building. It also covers the basic design and integration requirements for telecommunication spaces within building/buildings along with their cabling infrastructure, their pathway components and passive connectivity hardware. It also includes general requirements relating to installation of different wireless and wireline communication equipment, cable terminations, power connections and general guidelines required for planning and providing information and communication technology (ICT) services in the building at the planning and execution stages. The provisions given herein are basic requirements applicable to all residential and other buildings. These can be used at the time of upgradation of existing buildings for properly accommodating telecom systems/services. Buildings meant for data centres and those for housing telecom exchanges/facilities for offering public services may have various other considerations. For such buildings, provisions of this Section are indicative and may be a subject of actual requirements.

Telecommunication plays a vital role in modern society similar to electricity, water, gas, and transport systems. It is difficult to imagine a life without telecommunication technologies. In a building, a broad variety of telecommunication systems are expected to be installed. Buildings have provision for installation of various utilities. However, unlike traditional utilities, telecommunication systems are constantly evolving at a rapid pace.

Telecommunications connectivity can be delivered through cable, wire, optical fibre, fixed wireless and mobile wireless technologies. Each of these technologies when considered for use inside buildings, especially when the buildings are either commercial or multi-dwelling units or complexes, places its own requirement in terms of building space, power supply, internal extensions to various work areas/dwelling units. For example, for wire line services, broadband cable television, etc. The entry to the buildings/complexes will be through underground cables and the distribution of services further into the complexes will be from the bottom of the building to the upper stories. On the contrary, any wireless technologies, where antennas are to be installed at terrace along with a system which can distribute the signals through cables or in building solutions, the flow of cables will be from top storeys of the building to the bottom. Keeping in view that there are multiple telecom service providers (TSPs), there is growing need for provision of seamless wireless services to the users at public buildings such as airport, malls, hospitals, railway stations by sharing infrastructure without any discrimination.

The telecom facilities can be chosen by the user from the gamut of technologies and associated features as options are available based on the requirement, cost, service and maintenance convenience, future upgradation requirements, user preference, quality of service/experience etc. While providing telecom enabling infrastructure in the building, the provisions are to be made for making the infrastructure supportive for multiple technologies/ products and the requirements of telecom service providers. Use of building management system (BMS), access control, surveillance, and creation of 'Smart' building will require significant telecom infrastructure to be created within the buildings which may be supported by M2M communication technologies. Individual/tenant users of the building may also have their own M2M/IoT systems with wireline or wireless (cellular, satcom, wifi, loRa, zigbee, and other wireless protocols) gateways. The telecom support infrastructure in the buildings/campuses needs to be responsive and accommodative of these requirements.

In order to facilitate installation/upgradation of telecom systems, proper planning and understanding of enabling provisions for telecom technologies and physical infrastructure are necessary. Modern telecommunication technologies such as distributed antenna system, in-building solutions (using technologies for example wifi 6/6E or higher versions, cellular 4G/5G and beyond) are also to be considered during the building planning stage itself and providing shared access to multiple telecom service providers as per demand by end users. The enabling infrastructure may include cable riser systems, conduits, cable trays, fibre management systems, passive and active infrastructure, distributed antenna system (DAS), etc. Appropriate space need to be earmarked for installation of equipment at the entry point of service and running the cables, etc, through shafts and horizontal conduits inside the walls, centre of the corridors and centre of the work space, etc. Thus, cabling pathways infrastructure should be designed to be of general nature but flexible enough to accommodate a variety of current and future telecom systems and emerging technologies.

Choice of service to be provided inside the complexes/buildings will depend on the users. As already mentioned above, the delivery of service can be spread across technologies and across various service providers. Therefore, the arrangement for telecommunication infrastructure needs to be made in such a manner that the requirements and the challenges of at least near future (say 10 years) can be met without disturbing or retrofitting the building infrastructure. This Section has been formulated to cover these aspects.

In the formulation of this Section, due weightage has been given to international coordination among the standards and practices prevailing in different countries, in addition to relating it to the practices in this field in this country. This has been done by deriving assistance from the publications of ISO, IEC, ITU, TEC, TRAI Regulations and DOT Orders/Guidelines, etc.

Considering all the above, this Section was introduced in 2016 as a part of National Building Code of India to address the essential requirements for information and communication enabled installations and the related.

In this revision, this publication has been renamed as National Building Construction Standards (NBCS).

In line with technological advancements and evolving connectivity requirements, significant modifications have been made to the section on ICT installations in buildings, in this version of NBCS. These updates aim to address current demands for faster data transfer rates, advanced wireless standards, and improved maintenance protocols to ensure robust and reliable ICT infrastructure. The significant changes incorporated in this revision include:

a) The table on balanced twisted-pair cabling channel performance is updated to reflect maximum data transfer rates, aligning with present-day bandwidth demands and ensuring future readiness;

b) A new provision on meshed bonded networks, which provide enhanced immunity to electromagnetic interference (EMI) and are recommended for environments with high-density ICT equipment, in **4.1.1**;

c) A new clause **A-6** is included on overview of in-building solutions (IBS), including distributed antenna systems (DAS), leaky feeder cables, and small cells, to enhance indoor wireless connectivity in areas with weak signals. It also includes key considerations such as coverage requirements, interference management, capacity planning, and aesthetic integration to ensure seamless indoor mobile connectivity;

d) A new informative Annex B on street furniture that highlights the use of streetlights, utility poles, bus stops, traffic signals, etc to support ICT infrastructure; and

e) A new Annex C on building related information and digital connectivity requirements has been introduced.

As the regulation of land development and buildings is a State subject and is dealt by the States and local bodies such as urban local bodies within their jurisdiction through building regulatory documents like building regulations, building byelaws, and fire regulations, this document is voluntary in nature and is non-binding. The implementation depends on adoption by concerned parties or stipulations in a contract or by appropriate adoption by the concerned authorities.

For the purpose of deciding whether a particular requirement of this Section is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 'Rules for rounding off numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this Section.

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Important Explanatory Note for Users of this NBCS

In any Part/Section of this NBCS, where reference is made to **'good practice'** in relation to design, constructional procedures or other related information, and where reference is made to **'accepted standard'** in relation to material specification, testing, or other related information, the Indian Standards listed at the end of the Part/Section shall be used as a guide to the interpretation.

At the time of publication, the editions indicated in the standards were valid. All standards are subject to revision and parties to agreements based on any Part/Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

In the list of standards given at the end of a Part/Section, the number appearing within parentheses in the first column indicates the number of the reference of the standard in the Part/Section. For example:

a) Good practices [D-6(1)] refers to the Indian Standard(s) give at serial number (1) of the list of standards given at the end of this Part D/Section 6, that is, IS 9537 (Part 2) : 1981 'Specification for conduits for electrical installations: Part 2 Rigid steel conduits'

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART D BUILDING SERVICES

SECTION 6 INFORMATION AND COMMUNICATION ENABLED INSTALLATIONS

1 SCOPE

1.1 This NBCS (Part D/Section 6) covers the essential requirements for information and communication enabled installations, technology systems, cabling installations, and other passive and active equipment in a building. It also covers the basic design and integration requirements for telecommunication spaces within building/buildings along with their cabling infrastructure, their pathway components and passive connectivity hardware considering future requirements including flexibility requirement for installation of active infrastructure by the service providers.

1.2 It also includes general requirements relating to installation of different communication equipment, cable terminations, power connections and general guidelines required for planning and providing information and communication technology (ICT) services in the building at the planning and execution stages. The provisions given herein are basic requirements applicable to all residential and other buildings. These can also be used at the time of upgradation of existing buildings for properly accommodating telecom systems/services. Buildings meant for data centres and those for housing telecom exchanges/facilities for offering public services may have various other considerations. For such buildings, provisions of this Section are indicative and may be a subject of actual requirements. Introduction of street furniture as a crucial enabler of ICT infrastructure, leveraging existing structures like streetlights, utility poles, and bus stops to support small cells and air fibre for enhanced connectivity has been made.

NOTE — In this Section, 'Telecom' has been used interchangeably with 'ICT', as most of the time there may be only telecommunication hardware present. Apart from the provision of telecommunication systems, Information Technology (IT) system in the building may be either common for the building or separate for the individual users. In case the entire building is used by the same user, the IT system may be common and thus IT space for Building Management System (BMS), CCTV, etc, can be shared with telecom facilities. In case where individual IT systems owned by several users are provided, separate spaces may be earmarked inside telecom spaces for individual IT infrastructure. Sometimes, individual users may also use the common IT facilities. However, the cabling, wiring, etc, for IT systems should use the same pathways, which are used for telecommunication hardware.

2 TERMINOLOGY

For the purpose of this Section, the following definitions shall apply.

2.1 Access Point — A hardware device or a computer's software that acts as a communication hub or as an interconnection port for users of wireless devices to connect them to a wired or wireless local area network (LAN).

2.2 Antenna — An electrical device designed to transmit or receive radio waves or more generally, electromagnetic waves for the purpose of radio frequency communication such as Wi-Fi, radio, television, satellite communication, radar communication and mobile communication. This is also called an aerial.

2.3 Attenuation — A general term that refers to any reduction in the strength of an electrical/electromagnetic signal.

2.4 Backbone — A high-capacity facility (for example, pathway, cable or conductors) which acts as a major pathway within a network from which further smaller capacity facilities get distributed.

2.5 Backbone Cabling Media Distribution and Building Pathway — A part of a building premises telecom cable distribution system that provides connection between telecommunications spaces. It typically provides building connections between floors in multi-storeyed buildings as well as campus connections in multi-building environments.

2.6 Building Management System — It is a low voltage automation or remote control system installed for managing different building sub-systems like, heating, ventilation, lighting, air conditioning, fire protection, access control, etc.

2.7 Bus Bar — It refers to thick strips of copper or aluminium, in electrical power distribution that conduct electricity within a switchboard, distribution board, substation, or other electrical apparatus.

2.8 Coaxial Cable — A type of wire that consists of a centre wire surrounded by insulation and then a grounded shield of braided wire. The shield minimizes electrical and radio frequency interference.

2.9 Consolidation Point (CP) — A location for interconnection between horizontal cables extending from building pathways and horizontal cables extending into furniture pathways.

2.10 Cross-Connect — A facility enabling the termination of cable elements and their interconnection or cross-connection.

2.11 Distributed Antenna System (DAS) — It is a system that uses network of physically or spatially separated antennas to extend radio coverage of any technology inside a building.

2.12 Direct to Home (DTH) — The direct reception of satellite programs using small dish antennae (personal dish) placed on a roof or window of a house.

2.13 Frequency — The measurement of the number of times that a repeated event occurs per unit of time.

2.14 Horizontal Cabling — It includes:

a) the cabling between and including the telecommunications outlet/connector and the horizontal cross-connect; and

b) the cabling between and including the building management system outlet or the first mechanical termination of the horizontal connection point and the horizontal cross-connect.

2.15 Horizontal Cabling Media Distribution and Building Pathway — It consists of the horizontal cabling in the building, the horizontal pathways supporting the horizontal cabling, and the telecommunications spaces that support the horizontal pathways. The use of the term horizontal in the name of the element does not require that the elements be placed or installed parallel to the ground or floor.

2.16 Horizontal Cross-Connect (HC) — A cross-connect of horizontal cabling to other cabling, for example, horizontal, backbone, and equipment.

2.17 In-Building Solution (IBS) — It is a telecom infrastructure solution designed to enhance indoor network coverage for mobile or fixed wireless or Wi-Fi network for seamless indoor connectivity. DAS can be a part of IBS.

2.18 Inside Plant (ISP) — Telecommunications infrastructure designed for installation, interior to the buildings.

2.19 Intermediate Cross-Connect (IC) — A cross-connect between first level and second level backbone cabling. First level backbone is a cable between a main cross-connect (MC) and intermediate cross-connect (IC) or horizontal cross-connect (HC). Second level backbone exists between an intermediate cross-connect (IC) and horizontal cross-connect (HC).

2.20 Internet of Things (IoT) — A network of all physical objects connected to internet primarily using M2M communication technologies.

2.21 Local Multipoint Distribution System (LMDS) — A broadband radio service designed to provide two-way transmission of voice, high-speed data and video (wireless cable TV) digitally through microwave.

2.22 Local Area Network (LAN) — A computer network covering a local area, like a home, office or small group of buildings.

2.23 Machine to Machine (M2M) Communication — It is a set of wired/wireless communication technologies which enable machine/device (for example sensor, meter, etc) to capture an event (for example temperature, motion, meter reading, etc) and relay through communication network to an application that translates the data from device to a meaningful information.

2.24 Main Cross-Connect (MC) — A cross-connect for first level backbone cables, entrance cables, and equipment cables.

2.25 Main Distribution Frame (MDF) — A structure where all the copper wires, fibre or coaxial cables for a network terminates for patching/cross-connection on separate or composite frames.

2.26 Metropolitan Area Network (MAN) — A network designed to carry data over an area larger than a campus, such as an entire city and its outlying area.

2.27 Multichannel Multipoint Distribution System (MMDS) — A method of delivering multiple voice/data/television signals digitally by microwave transmission to subscriber households.

2.28 Multi-user Telecommunications Outlet Assembly (MUTOA) — A grouping in one location of several telecommunications outlet/connectors.

2.29 Optical Fibre — It refers to the medium and the technology associated with the transmission of signals/information as light pulses along a glass fibre.

2.30 Optical Distribution Frame (ODF) — Optical fibre distribution frame where ends of optical fibre terminates for further patching/cross-connection.

2.31 Outside Plant (OSP) — Telecommunications infrastructure designed for installation, exterior to the buildings.

2.32 Propagation Delay — In a communications system, it refers to the time lag between the departure of a signal from the source and the arrival of the signal at the destination.

2.33 Public Mobile Network — A network that is established and operated by a telecom service provider for the specific purpose of providing mobile telecommunications services to the public using technologies such as GSM, CDMA and LTE.

2.34 Radio Frequency — A frequency range from 20 kHz and above, used for transmitting/receiving text, data, audio, or video signals.

2.35 Server — Any computer on a network that contains data or applications shared by users of the network on their client terminals.

2.36 Splicing — The process of permanent joining of bare fibre end to another fibre by means of splicing tools.

2.37 Smart City/Building/Home — An innovative city/building/home that uses information and communication technologies, and other means to improve quality of life, efficiency of operation and services and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social and environmental aspects.

2.38 Telecommunication Spaces — The rooms and areas where telecommunications cabling systems are terminated, cross-connected and interconnected to installed telecommunications equipment. Various examples of these based on the function and areas, are equipment room (ER), telecommunications room (TR), entrance facilities (EF) and telecommunication enclosures (TE).

NOTE — The definitions of telecommunication spaces and workspace (*see* **2.46**) are used for calculation of infrastructure requirements, facilities, etc. This does not inhibit the utilization of space for any other purpose. Depending upon the requirements, number of telecommunication spaces in a given building may vary for the same area.

2.39 Telecom Service Provider (TSP) — A service provider who is duly authorized by Government of India or its designated entity to operate telecom services.

For example, access service providers, telecom infrastructure providers (IP1s), internet service providers (ISP), virtual network operators (VNOs), satellite communication service providers, public data offices (PDO) and public data office aggregators (PDOA), or any other wireline, wireless, direct to home (DTH), cable service providers, IPTV service providers and any other service provider authorized by the government from time to time.

2.40 Telecom Tower/Mast/Pole — A vertical structure for installation of antenna(e) that provide radio frequency air interface for telecommunications services. It can also be in the form of mast or multiple poles of varying height. Poles may be located at different points typically on the roof.

2.41 Telecommunication Media and Connecting Hardware — It consists of cables, equipment cords, patch cords, and connecting hardware components. All balanced twisted-pair, optical fibre, coaxial cabling and wireless systems are made up of such components. These cabling components and resulting cabling systems are used in outside plant (OSP) and premises cabling [also known as inside plant (ISP)] environments of the building telecommunication infrastructure.

2.42 Underground Cable Vault (UCV) — An underground cable vault (part of an underground duct system) used to facilitate placing, connecting, and maintaining telecommunications cables and associated equipment. It collectively refers to manholes, hand holes, and pull holes.

2.43 Very Small Aperture Terminal (VSAT) — It usually refers to satellite terminal used to transmit and receive signal from satellites with an antenna installed in user premises.

2.44 Wide Area Network (WAN) — It is a network that is capable of spanning a geographical area larger than a city.

2.45 Workstation — An electronic device that performs some information processing or display function and connects to the communications network. Typically, this may be a desktop computer with keyboard and display or laptop computer, but might also be a telephone, a printer, an access control terminal, or some data-gathering device.

2.46 Workspace — Any location and the space around where a workstation may be located. Typically, there can be several workspaces in a room.

3 GENERAL REQUIREMENTS FOR TELECOMMUNICATION SPACES AND CONNECTING HARDWARE

3.1 Telecommunication Spaces

3.1.1 *General Considerations*

The following shall be the considerations for telecommunication spaces:

a) *Accessibility* — Telecom spaces that are intended to serve multiple users should be located in common spaces that should be accessible through a common corridor or outside door. The space for each telecom service providers may be separated to the extent feasible by partitions for security reason and controlled access to their equipment. The telecommunication spaces should be accessible, but the access should be controlled against the unauthorized access (for example, with a lock and key arrangement or by an electronic access system).

b) *Acoustic noise levels* — Acoustic noise levels in telecom spaces should be kept to a minimum by not collocating noise-generating equipment (for example, photocopy equipment, high-speed printers, and mechanical equipment).

c) *Administration* — All pertinent documentation of deployment of telecom equipment and cables should be maintained by owner or agent when the installation is completed. All telecom spaces shall have appropriate signs to identify the space and should be included within the security plan of the building. There must be sufficient space between the equipment of different service providers for maintenance and better workmanship.

d) *Cable separation* — Telecom cables should be separated from possible sources of electromagnetic interference (EMI) and from possible radio frequency interference (RFI). For safety purposes, power cables should be separated from telecom cables.

e) *Ceilings* — The general requirements for ceilings in telecom spaces should include the following:

   1) Generally, the minimum ceiling height shall be 2.4 m above finished floor. However, consideration may be given for having a 3 m ceiling height.

   2) If suspended ceilings are provided, necessary rodent protection may be provided.

3) The ceiling finish should minimize dust and be light coloured to enhance the room lighting.

f) *Conduits, trays, slots, sleeves and ducts* — Slot/sleeve systems should be located in places where pulling and termination of cables is easy to achieve. Bend radius requirements and service loop guidelines shall be considered. Sleeves and slots should not be left open after cable installation. All sleeves and slots shall be fire-stopped. (*See also* Part F 'Fire and Life Safety' of this NBCS for guidance purpose).

The size and number of conduits or sleeves used for backbone pathways depends on the usable floor space served by the backbone distribution system. However, sleeves in multiple of 100 mm are recommended to serve a TR, ER or EF. Multiple telecom spaces on the same floor shall be interconnected with a minimum of one 75 mm conduit or a pathway that provides equivalent capacity.

g) *Dust and static electricity* — Dust and static electricity should be avoided by:

1) Placing active printers outside of telecom spaces.

2) Treating floors, walls, and ceiling to minimize dust.

h) *Electrical power* — When active equipment of TSPs or the building equipment (for example, PABX) are installed in TR/ER, etc, the telecom spaces shall be equipped to provide adequate electrical power with redundancy and sub-meters to each of the service providers at TRs and ERs. The recommendations are as under:

1) A power generator set should be considered if longer power interruptions are expected for which the battery backup is not adequate. Further, as telecom services are required on 24 × 7 basis, uninterrupted electrical power for telecom services shall be provided from local or central uninterrupted power supply (UPS) with adequate battery backup. Further, UPS arrangement may be extended to equipment in TE/corridors also.

2) Separate socket outlets for equipment, tools, test instruments, etc.

3) Separate electrical distribution panels that serve telecom equipment/spaces from those that serve other purposes are recommended. These should be clearly identified with proper sign writing.

j) *Prevention from flooding* — Telecom spaces should be located above any threat of flooding. When locating telecom spaces where a threat of flooding is unavoidable, rack elevations may be designed so that active equipment and telecom components are placed above the threat level. Sometimes locating the ER/TR on a floor above ground floor may be safer. The locations that are below or adjacent to areas of potential water hazard (for example, restrooms, kitchens) should be avoided. Liquid carrying pipes (for example, water, waste, steam) should not be routed through, above, or in the walls encompassing the ICTs space. If due to unavoidable circumstances, liquid carrying pipes are passing through telecom spaces then these spaces may be preferably monitored for water seepage by deploying suitable water seepage detection system. Otherwise, regular watch may be kept to detect seepage.

When air conditioning ducts are installed in telecom spaces, water dripping/leaking from AC vent should be controlled and, if required, monitored by water leaking system. Instructions for prevention from liquid cleaning agents, air purifying liquids, pest repellents and sprays usage should be indicated by proper sign writing.

k) *Lighting* — Following are the important considerations for lighting of telecom spaces:

1) Locating light switches near the entrance(s) to the telecom space.

2) Coordinating the lighting layout with the planned equipment layout (especially overhead cable trays) to ensure that lighting is not obstructed.

3) Providing electrical power for the lighting and ICT equipment from different circuits.

4) Placing at least one light or set of lights on normal power and one light or set of lights on emergency/UPS power.

5) Using a light coloured finish on walls, floors, and cabinets to enhance room lighting.

6) Providing task lighting illumination at the point of cable termination.

7) Providing adequate lighting of spaces, which may be controlled by automated controllers such as building management system (BMS), if required, or ensured otherwise. Use of dimmers and

occupancy sensors is not recommended.

m) *Location* — All telecom spaces shall be located in areas that are best suited (preferably centrally located to reduce the cable length) to serve the occupants of a floor or building. The following shall be observed when locating the spaces:

   1) Telecom spaces in multi-floor buildings should be aligned vertically.

   2) Telecom spaces should be located in areas that are dedicated to telecom use. Equipment that is not related to the support of telecom spaces (for example, piping, duct work, distribution of building power) shall not be located in or pass through a telecom space.

n) *Environmental control* — When active devices which are heat producing equipment are present, original equipment manufacturer (OEM) recommended temperature and humidity range should be maintained by adequate arrangement for heat dissipation. If environmental parameters are exceeded, an alarm should be activated. A positive pressure is required to be maintained with a minimum of one air change per hour in the telecom space. More stringent requirements may apply based on the equipment needs in the telecom space. It is recommended to have sufficient arrangements of air conditioners for cooling of telecommunication equipment housed or to be housed in telecom room and equipment room.

p) *Fire protection* — The telecom spaces shall be equipped with adequate fire detection, alarm and suppression systems. (*See also* Part F 'Fire and Life Safety' of this NBCS for guidance purpose). Fire retardant cables are recommended to be used inside the building to reduce incidences of fire.

q) *Bonding and grounding* — All equipment and cable shields shall be properly bonded to the telecom bonding and grounding infrastructure of the space (*see* **4.1** for details).

3.1.2 *Equipment Room* (*ER*)

3.1.2.1 An equipment room is an environmentally controlled centralized space for telecom equipment that usually house equipment of higher complexity than telecommunication rooms and also usually houses a main or intermediate cross-connect. Any or all of the functions of a telecommunications room may be provided in an equipment room. ERs differ from TRs in the way, that, ERs are generally considered to serve a building, campus, tenant, or SP, whereas TRs serve a floor area of a building. In some cases, an ER may also contain the EF or it may serve as TR. ERs may be connected to backbone pathways that run both within and between buildings. Although an ER usually serves an entire building, many building designs may use more than one ER in order to provide separate facilities for different types of equipment and services or redundant facilities and disaster recovery strategies.

The initial assessment for design and specifications for an ER shall be based on detailed information about the site, including:

a) User requirements;

b) Telecom pathway locations;

c) Service providers' requirements;

d) Environment/facility conditions; and

e) Building requirements.

The functional earth terminals of ICT equipment shall be connected either directly to the Primary Bonding Busber (PBB) or through an Secondary Bonding Busber (SBB) as per **4.1**. Where mesh bonding network is used, multiple connections (minimum four) from ICT to mesh-BN are recommended.

3.1.2.2 *Space allocation and layout*

The space allocation and layout may be determined by following methods:

a) *Determining size based on area served* — When the telecom designer does not know what specific equipment will be used in an ER, the designer can use the amount of floor space that the room will serve, to determine the minimum size of the ER. If the usable floor space is also unknown, the usable floor space may be estimated by deducting 20 percent from the total floor area.

   Generally, an area of 9.3 m^2 may be considered for calculating the work areas. If work areas are smaller leading to possible increase in number of work areas in building, the size of the ER should be increased accordingly. The minimum reco mmended size for ER is 14 m^2. The general practice is to provide 0.07 m^2 of ER space for every 10 m^2 of usable floor space. For special use buildings, such as, hospitals and hotels, ER size requirements may vary.

b) *Telecom service provider space requirements* — If equipment or cable terminations that are owned or maintained by a TSP are to be located in the ER, then location and amount of space required shall be determined as per the space requirement of TSP.

c) *Telecom equipment locations* — As equipment for communication systems are located in the various equipment rooms throughout the building, these rooms shall be physically secure, aesthetically provisioned and conveniently located. The communication equipment may be located with due consideration of the modular provision of building design and criteria for expansion joints matching to electrical distribution and maximum fire safety distance requirements. The other considerations for telecom equipment location include the following aspects.

   1) Types of cables, their uses, bending radius, turning radius, conduit radius, etc;

   2) *Provision for future expansion* — In view of the evolving nature of the communication technologies, provision for future expansion should be ensured by way of stand-by arrangements. The distribution infrastructure should also be as flexible as possible. Small conduits will quickly fill up and may not accommodate some technologies, for example, low loss broadband or high capacity fibre optic cables. The most flexible distribution design involves cable trays for horizontal (floor level) distribution with large conduit sleeves for wall penetration, where necessary. Vertical trunk distribution should also be achieved with conduit sleeves; and

   3) *Maintainability* — As it is difficult to remove or shift just a few cables from a crowded or convoluted conduit system for operational or maintenance requirements, steps should be taken to ensure easy access and maintainability of cable system right in the initial architectural design stage.

3.1.3 *Telecommunications Room* (*TR*)

3.1.3.1 A telecommunications room is the area within a building that houses the telecommunications cabling system and associated equipment. This includes the mechanical terminators and/or cross-connects for floor-serving distribution facility for horizontal cabling and backbone cabling system. There should be at least one TR or TE per floor. TR or TE can also house active equipment, like LAN switches, routers, OLT, DAS, cable TV or DTH systems etc, or passive equipment, like optical splitters, FDMS. Most of these equipment are available in wall mount units. The switches/routers can also be shared between telecom equipment and other low voltage in-building systems. This reduces the demand on floor space requirements for TR/TE. Sometimes, a TSP with the consent of the building owner may require to provide additional equipment, such as for mobile signal booster, at a later stage, in TR/TE. Therefore, it is recommended to have additional space in advance, especially in tall buildings of five storeys or higher, preferably on top floor.

The functional earth terminals of ICT equipment shall be connected either directly to the PBB or through an SBB as per 4.1. Where mesh bonding network is used, multiple connections (minimum two) from ICT to mesh-BN are recommended.

3.1.3.2 Multiple rooms TEs are required if the cable length between the horizontal cabling (floor distribution) [HC (FD)] and the work area outlet location, including slack, exceeds 90 m (or more in case of optical fibre depending upon its type and application as indicated in 3.2.4.2). If the usable floor space to be served exceeds 930 m^2, additional TRs should be considered. Following are the guidelines for TR size:

Sl No. (1)	*Area Served* (2)	*Dimension of TR* (3)
i)	465 m^2 or less	3 m × 2.4 m
ii)	More than 465 m^2 and less than equal to 930 m^2	3 m × 3.4 m

NOTE — The size of 3 m × 2.4 m has been specified to allow a centre rack, cabinet, or enclosure configuration.

In smaller buildings, less space is required to serve the telecom distribution needs of the occupants. The size guidelines for smaller buildings should be as below:

Sl No.	*Building Smaller Than*	*Served as*
(1)	(2)	(3)
i)	465 m^2	Shallow/Walk-in rooms (Walk-in rooms shall be at least 1.3 m × 1.3 m. Shallow rooms shall be at least 0.6 m deep by 2.6 m wide.)
ii)	93 m^2	Wall cabinets, self-contained cabinets, enclosed cabinets

NOTE — Installation of active equipment in shallow or walk-in rooms is not recommended because many types of equipment require environmental controls and a depth of at least 1 m.

3.1.4 *Entrance Facilities* (*EF*)

Building entrance facilities (EF) provide the point at which outdoor cabling of the telecom service provider interfaces with the intra-building/intra-campus backbone cabling. In cases, where the functions of the EF are combined with the functions of the ER in the same space, the room may house equipment that is owned and maintained by service providers. In these cases, requirements specified by the service providers shall be considered when designing the ER.

If a separate space is required for service providers, it should be in or adjacent to the EF and may require a mesh partition or locked cabinet. A space of at least 1.2 m × 1.83 m shall be considered for each service provider. An entrance facility necessarily be an enclosed space. However, having an enclosed area or access protected area is suggested at all occasions, considering safety requirements.

The duct from the cable vault (CV) of the telecom service provider generally consists of 100 mm conduits encased in reinforced concrete. The exact number of conduits will depend upon the size and use of the building. These conduits may be used for all communication systems serving the building including additional capacity and access cables and pathways capacity. To maintain the safety of the TSP cable, it may preferably enter the building above the ground and then feed the equipment room.

A separate 230 V, 16/6 A circuit with double outlets should be provided (for plugging in temporary test equipment or to power the tools) every 2.4 m along the EF and ER combined wall. All wall outlets are to be located approximately 300 mm above the finished floor levels with the breaker and clearly labelled. In addition, two dedicated 230 V, 16/6 A sockets should be provided for each (permanently installed) communication service rack. If the sockets of racks are fed from UPS power, appropriate levelling may be provided to distinguish between main power sockets and UPS power sockets.

3.1.5 *Telecommunication Enclosures* (*TE*)

A TE is simply a case or housing for telecom equipment, cable terminations, and cross-connect cabling for distribution of telecom services on a floor. The TE may also contain access points for wireless services. Although, TEs serve much in the same way as that of a TR, a minimum of one TE should be located on each floor, if no TR is considered on the floor. The TE door(s) may be hinged or removable. If the enclosure consists of metallic components, it shall be earthed to either PBB or SBB.

3.2 Telecom Media and Connecting Hardware

3.2.1 A cabling system consists of cables, equipment cords, patch cords, and connecting hardware components like cable patch panel, MDF and FDMS. All balanced twisted-pair, optical fibre, and coaxial cabling systems are made up of such components. There can be different topologies for cabling used in a building like star, tree, bus bar, ring, etc, or a combination of these to suit different technological requirements. Within a building, most of the wiring is between the work spaces and the equipment room. Wireless systems can also be part of the telecom media. However, connectivity to the network, which delivers telecom service, is generally provided using cables at the back end.

The selection of appropriate style of cabling is important and accordingly, some of the user requirements to be considered before selecting the specifications and style of cabling and connectors for a telecom enabled building may include the following:

a) Number of user work areas and telecom spaces used to serve the building occupants;

b) Types of services and technology used for delivery of services;

c) Number of telecom outlets/connectors desired at each user work area;

d) Number and styles of user equipment (for example, telephony, LAN, building automation);

e) Cabling system transmission performance expectations;

f) Backbone distances and horizontal cable lengths involved in the building or campus;

g) Future growth expectations (for example, 15 percent to 20 percent recommended minimum growth factor);

h) Environmental conditions including electromagnetic interference; and

j) Other types of low voltage systems and their network requirements.

3.2.2 The cables should have ferrule marking at the terminations as well as along the length of the cable at suitable interval. Similarly, copper pair/fibre pair should be identifiable at terminating end for easy identification and convenience during maintenance. For the purpose, a suitable chart should be available at locations, like inside cross-connect box. Further, all the documentation of pathways and cables should be properly maintained.

3.2.3 While designing the cabling system for large multi-tenant building, it should be kept in mind that the tenants may prefer subscribing to the services of multiple service providers. Thus, enough space should be available in ducts, pathways, etc, for laying additional conduits/trays, keeping in view the present and future demands. Capacity for pathways (that is, conduit, raceways, trays, baskets) may be planned so that initial installation achieves a fill of 40 percent and at final installation, fill of 60 percent, taking into account the expected future requirements.

3.2.4 Various cabling systems are described under **3.2.4.1** to **3.2.4.3**. For the purpose of reference, details about connecting hardware components and classification of cables by fire safety properties are given in Annex A.

3.2.4.1 *Copper twisted-pair*

The transmission performance of balanced twisted-pair cabling and telecom associated components are based on a number of factors within the cabling or component design. These performance levels use the terms category and class. Standards developed internationally utilize both class and category, depending on the specific cabling element, as described in Table 1.

Table 1 Balanced Twisted-Pair Cabling Channel Performance

(*Clause* 3.2.4.1)

Sl No. (1)	ISO Category/Class (2)	TIA Category (3)	Frequency MHz (4)	Maximum Data Transfer Rate (5)
i)	Category 3/Class C	Category 3	16	10 Mbps
ii)	Category 5/Class D	Category 5e	100	1 Gbps
iii)	Category 6/Class E	Category 6	250	1 Gbps
iv)	Category 6A/Class EA	Category 6A	500	10 Gbps
v)	Category 7/Class F	NA	600	10 Gbps
vi)	Category 7A/Class FA	NA	1 000	10 Gbps
vii)	Category 8/Class G	Category 8	1 500 to 2 000	25/40Gbps

NOTE — For Category 8/Class G balanced twisted-pair cabling, the maximum permissible distance is restricted to 30 m.

A large number of cable designs are used in the ICT industry, resulting in various names and acronyms for their identification. Specialist publication (*see* NOTE) may be referred which gives balanced twisted-pair cable designations using *x*/*y* designation, where *x* is the overall screen type and *y* is the individual pair screen type, which may be used. Details of various nomenclature based on this, using various categories of cables, are given in Annex A.

NOTE — The specialist publication referred here is ISO/IEC 11801 : 2002 'Information technology — Generic cabling for customer premises'.

3.2.4.2 *Optical fibre*

Optical fibre cables are used in backbone and horizontal cabling applications, when the service is delivered on fibre to the user or inter/intra building communication is to be carried on fibre. For example, of former is gigabit passive optical network (GPON), which require fibre to the home (FTTH) and the example of latter is LAN implementation using optical network. Transmission of information through optical fibre cables is not degraded by crosstalk, ambient noise, lightning, and most electromagnetic interference (EMI). It has better loss characteristics compared to copper pair. Thus, it permits high data rate communication to be carried out to a much larger distances than copper pair.

Optical fibres are classified as either single-mode or multi-mode. Single-mode optical fibres have a relatively small diameter featuring a core of 8 µm to 11 µm and a cladding diameter of approximately 125 µm. Multi-mode optical fibre has a larger core diameter (for example 50 µm or 62.5 µm) with the cladding of approximately 125 µm. Multi-mode fibre has higher loss compared to single-mode fibre. However, it is generally recommended for in building/intra campus use as it cost less than the single fibre. The latter has low loss characteristics and can carry higher speed to longer distances due to which it is mainly used in long haul applications. However, depending upon the size of the building/campus or availability of various types of cables, combination of both types of cables or only single-mode cable may need to be used. Use of single-mode fibre has the advantage that future upgradation requirements are taken care of right in the beginning.

Optical fibre cables are available in various capacities in terms of number of fibres like 6 fibre, 12 fibre, 24 fibre, 48 fibre, 96 fibre, etc. Each fibre has a different colour which helps in easier identification during installation and operations. The colour scheme is repeated for every group of 12 fibres for higher fibre count cables.

Selection of optical fibre cable size for different segments of cabling depends upon various factors.

The colour code chart for fibre optic cable is as under:

Sl No. (1)	*Fibre/Tube No.* (2)	*Color* (3)
i)	1	Blue
ii)	2	Orange
iii)	3	Green
iv)	4	Brown
v)	5	Grey
vi)	6	White
vii)	7	Red
viii)	8	Black
ix)	9	Yellow
x)	10	Purple
xi)	11	Rose
xii)	12	Aqua

NOTE — The specifications of the certain types of optical fibre cables are available in Department of Telecommunications, Telecom Engineering Centre (TEC), Govt. of India, the details of which can be seen from TEC website, www.tec.gov.in

When it is decided to use optical fibre cable, choice is to be made from among variety of standard cables. There are two broad categories of cables namely multi-mode optical fibre (OM) and single-mode optical fibre (OS). The former is suitable for much shorter distances compared to the later as, data rate supported by cable is a function of cable length used. OM cables are preferred cables for campus applications as they are economical for short distances. OM cables are further sub-categorized into OM1, OM2, OM3 and OM4, which are differentiated based on data speed and distance combinations. Once the data speed and distance to be covered is decided, choice of cable category becomes simpler. When used inside the buildings, attenuation of signals is caused due to cable fibres facing sharp bends. Multi-mode cables show larger attenuation than single-mode cables on bends inside the building. Thus, bend insensitive and fire retardant optical fibre cable as per relevant TEC specification are recommended for use in the buildings.

Considering that backbone cable carries the combined traffic of all work areas and the growth of data use with time, provision for future expansion should be provided. It is recommended that planning should be done for 10 Gbps to 1 Tbps or above speeds depending upon anticipated requirements of the users. Therefore, when using multi-mode cable, choice may need to be made typically from among OM3 and OM4 cables.

A chart showing typical length and data rate support characteristics of various cables is given below:

Sl No. (1)	*Subsystem Backbone* (2)	*Lengths Up to* (3)	*Data Rates Up to* (4)
i)	Campus backbones (OM1 fibre)	2 000 m	155 Mb/s
ii)	Campus backbones (OM2 fibre)	550 m	1 Gb/s
iii)	Building backbones (OM2 fibre)	300 m	1 Gb/s
iv)	Building backbones (OM3 fibre)	300 m	10 Gb/s
		100 m	100 Gb/s
v)	Campus/building backbones (OM4 fibre)	550 m	10 Gb/s
		150 m	100 Gb/s
vi)	Campus/building backbones (OS fibre)	10 000 m	100 Gb/s

Enhanced versions of OM3/OM4 cables can also be examined for use. Once the cable category is selected, care should be taken that active equipment which feeds the fibre is equipped with the corresponding interface, to take care of, for example requirement of different optical power source and optical wavelengths for different types of cables. Further, from each TR drop fibre or cable of 2 to 4 fibres are also recommended.

3.2.4.3 *Coaxial cable*

The predominant coaxial cables are Series-6, Series-11, and radio grade (RG) 59. These coaxial cables have a characteristic impedance of 75 Ω. While the termination procedures may be similar, special attention shall be paid to the manufacturer’s specific instructions for termination and connectors. The cables/passive components used for DAS/IBS system should cover frequency range from 400 MHz to 4 000 MHz. Coaxial RF telecom cables of various sizes (for example, 12.70 mm, 22.23 mm, 31.75 mm) or as required for efficient RF signal transmission be deployed to ensure comprehensive mobile signal coverage within the building.

Coaxial cable is used for computer networks, CATV and video systems. Historically, coaxial cable was designated as RG cable. Coaxial cables used in broadband applications are available in the market with following constructional variations:

a) Centre conductor diameter;

b) Centre conductor being solid or stranded;

c) Dielectric composition;

d) Outer braid’s percent of coverage; and

e) Impedance.

3.2.5 *Wireless Systems*

Wireless connectivity is also provided inside the building for enabling access to public mobile network or for enabling internet/intranet connectivity with flexibility of user terminal movement. Various wireless systems are described below:

a) *Wireless LAN* (*WLAN*) *access point* (*AP*) — A wireless LAN (WLAN) access point (AP) is a network device located in areas of a building or campus and placed in relatively close proximity to where users interact with their wireless enabled network devices. APs allow wireless enabled devices (for example, computer, printer, mobile, tablets, laptop, IoT devices or any other device) to connect through Wi-Fi or related standards. Wireless networks here can even include the networks of low voltage automation system in the building as well as M2M/IoT smart buildings/smart homes/smart offices. There are various wireless standards for M2M/IoT device connectivity. AP network devices are typically mounted on walls or ceilings with structured cabling that provides a physical connection to a HC (FD), which provides further connectivity to private/public network through the facility installed in TR/TE.

b) *Wi-Fi access points* (*WAP*) *with centralized controller* — Access point shall support at least IEEE 802.11 ax/be or any higher versions/ more modern standards. There may be numbers of WAPs to cover area/building and in such situation user may prefer centralized controller. Centralized controller can be hardware or software based and depending upon number of WAPs may be provided at each ER/TR/TE. These access points can also be used for connecting the low voltage automation systems (building management system and other in-building system). The access points are connected to the network as described in (a).

NOTE — The secure access to Wi-Fi network and authorization of users is critical and the same will need to be ensured by owner.

c) *Distributed antenna systems* (*DAS*)/*In-building solutions* (*IBS*) — DAS/IBS are signal distribution systems for strengthening the public mobile wireless signal inside the buildings or installations. They require cable and passive antenna to be installed in corridors/rooms, normally along the centre line. The active equipment, wherever required can be installed in ER/TR/TE, on which cables to/from DAS/IBS are connected.

d) *Wireless repeater* — It takes an existing signal from a wireless router or wireless access point and rebroadcast it with amplified signal. It is also called wireless range extender. This is used to mitigate low signal issues.

While planning and installing wireless devices, it is required to maintain enough spacing between them to avoid frequency overlap and interference by their own signal. The wireless coverage area radius is impacted by a number of factors including the following, and these factors like penetration losses, signal to noise ratio etc, are to be taken into account by using for which the site survey approach and planning. An appropriate planning tool should be considered for this purpose:

1) Building materials (concrete, sheetrock, wood, steel, etc);

2) Building configuration (closed, semi-closed or open space); and

3) Building furnishings (cabinets, partitions, furniture, etc).

Periodic monitoring is desirable for maintaining wireless coverage.

3.2.6 *Connecting Hardware*

The ends of cable terminating in work areas or on intermediate equipment like LAN switches, splitters, etc, need to be provided with connectors. There can be variety of equipment which may be connected to the cable ends. Hence, a careful planning should be done to identify types of connectors with flexibility to connect variety of equipment keeping in view also the fact that the cable ends are permanently wired on to connector panels in the work areas. Details of the typical connecting hardware are given in Annex A.

3.3 Backbone Cabling Media Distribution and Building Pathways

The backbone distribution system provides interconnection between telecom spaces, that is, telecommunication rooms, equipment rooms and entrance facilities. It consists of the backbone cables, intermediate and main cross-connects, mechanical terminations and patch cords or jumpers used for backbone-to-backbone cross- connection. This includes:

a) Vertical cable connections between floors (risers);

b) Cables between an equipment room and building cable entrance facilities; and

c) Cables between buildings (inter building).

The elements of the telecommunications cabling system structure are:

1) Horizontal cabling;

2) Backbone cabling;

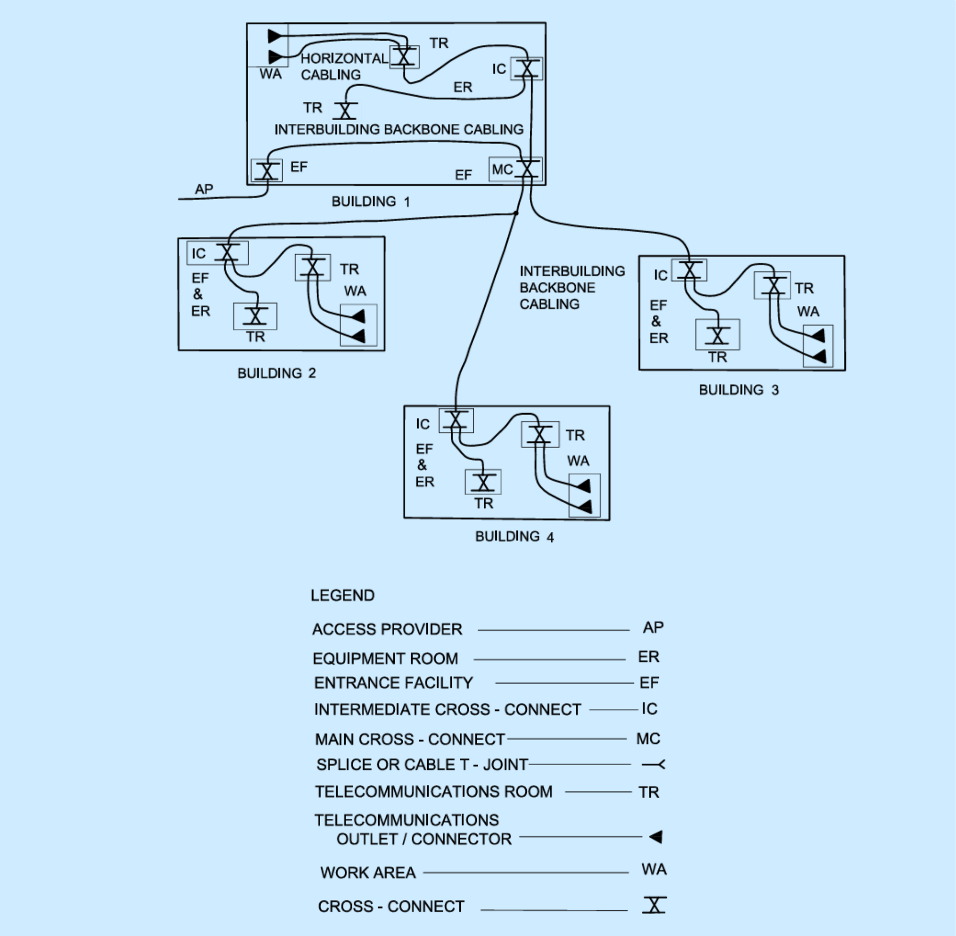
3) Work area;

4) Telecommunications rooms;

5) Equipment rooms; and

6) Entrance facilities.

Figure 1 illustrates a representative model for the various functional elements that comprise a building campus/complex telecommunications cabling system. It depicts the relationship between the elements and how they are configured to create a total system.


TR
HORIZONTAL
CABLING
WA
IC
ER
TR
INTERBUILDING BACKBONE CABLING
EF
EF
MC
AP
BUILDING 1
IC
EF
&
ER
TR
WA
TR
BUILDING 2
INTERBUILDING
BACKBONE
CABLING
IC
EF
&
ER
TR
WA
TR
BUILDING 3
IC
EF
&
ER
TR
WA
TR
BUILDING 4
LEGEND
ACCESS PROVIDER AP
EQUIPMENT ROOM ER
ENTRANCE FACILITY EF
INTERMEDIATE CROSS - CONNECT IC
MAIN CROSS - CONNECT MC
SPLICE OR CABLE T - JOINT
TELECOMMUNICATIONS ROOM TR
TELECOMMUNICATIONS OUTLET / CONNECTOR
WORK AREA WA
CROSS - CONNECT

NOTES

1 This figure is not meant to be an all-inclusive representation of the telecommunications cabling system and is provided only as a typical example.

2 All cross-connects located in the telecommunications rooms (TRs) in this figure are horizontal cross-connects (HCs).

3 This illustration can be used for extending connectivity in big complexes or townships which may also require multiple EF depending upon the design of complex/township.

FIG. 1 TYPICAL TELECOMMUNICATIONS CABLING SYSTEM

3.3.1 *Backbone Cabling and Topologies*

Cabling between the building cross-connect (main or intermediate) and the horizontal cabling (floor distribution) [HC (FD)] is designated as backbone cabling. In a multi-building complex, inter-building cabling, though terminating in the EF, is designated as inter-building backbone cabling. The cable(s) can be of any type, for example, copper pair, optical fibre or coaxial.

3.3.1.1 The two primary options for connectivity are:

a) Star topology, where the HC (FD) is connected directly to the main cross-connect (campus distributor) [MC (CD)] which is further connected to inter building backbone, where applicable; and

b) Hierarchical star topology, where some or all of the HCs (FDs) are connected to an intermediate cross-connect (building distributor) [IC (BD)], which in turn, is connected to the MC (CD).

3.3.1.2 The best design is the star design between the building MC and the HCs. However, in some extremely large buildings (for example, high-rises), a hierarchical star may be an option for consideration. The trade-offs between different cable sizes and labour cost is to be considered to determine a suitable cost effective solution. The direct connections between HCs are generally avoided. Although this kind of connectivity might be of value in providing a redundant path, a user should design a link from HC to HC only in specific applications. The best design is the star design between the building MC and the HCs.

3.3.1.3 A typical star configuration in a building with MC (CD) or HC (FD) is given Fig. 2.

3.3.1.4 An example of backbone hierarchical star topology with addition of IC (BD) is shown in Fig. 3.

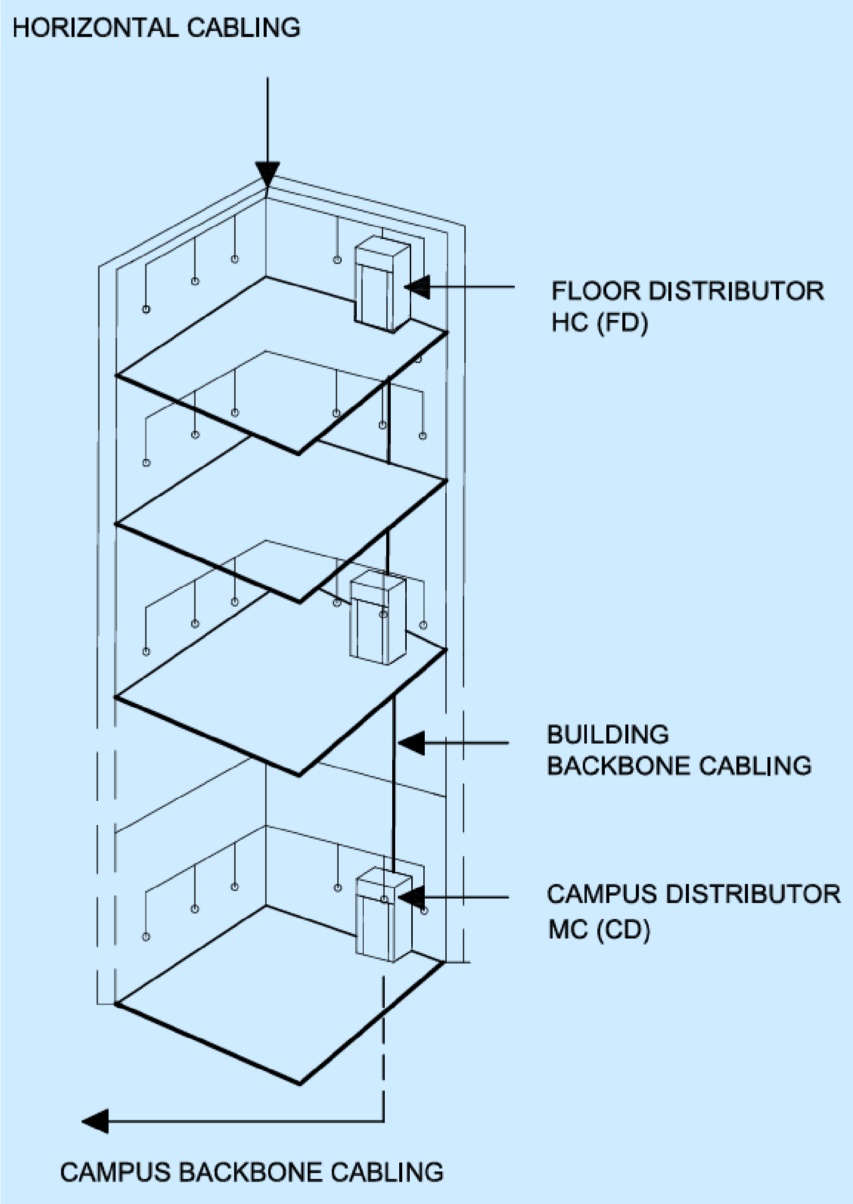
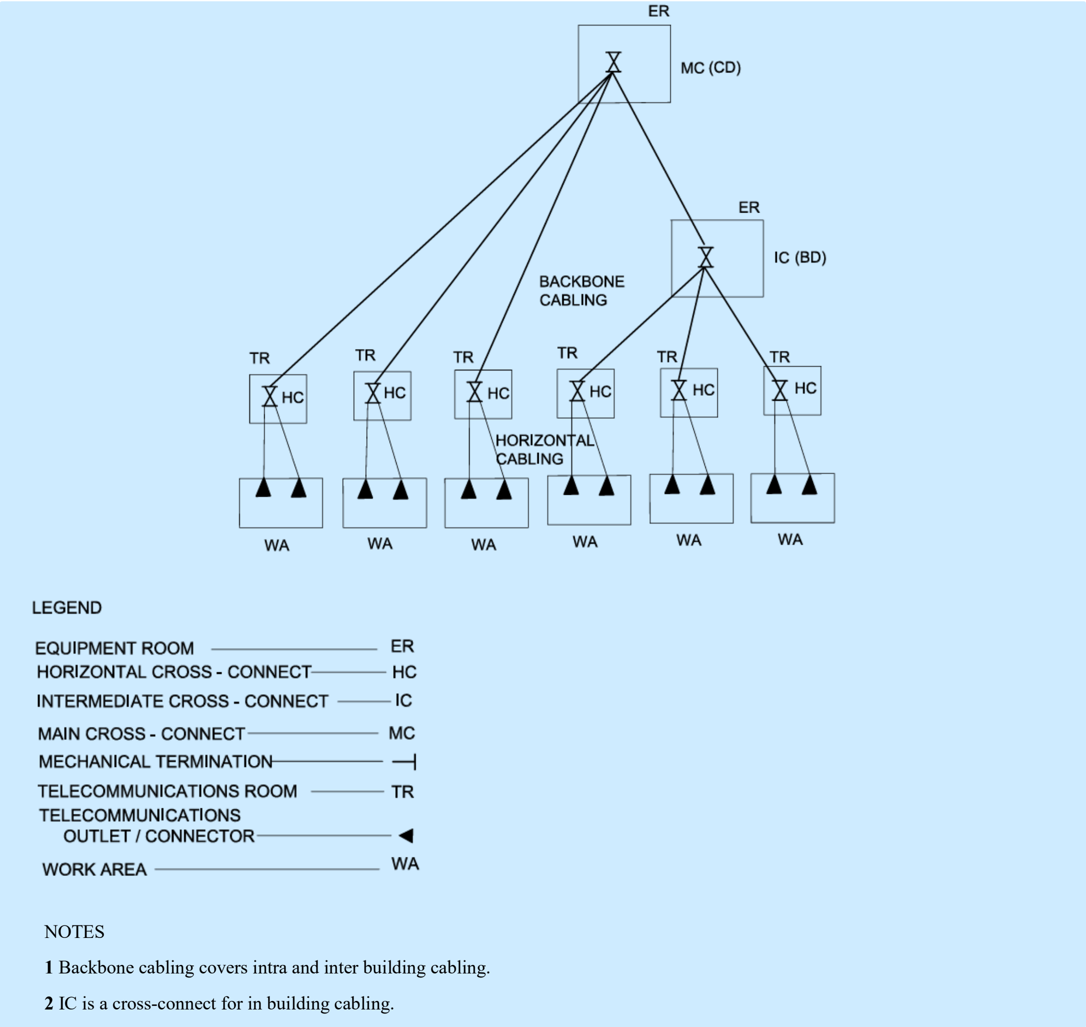

HORIZONTAL CABLING
FLOOR DISTRIBUTOR
HC (FD)
BUILDING
BACKBONE CABLING
CAMPUS DISTRIBUTOR
MC (CD)
CAMPUS BACKBONE CABLING

FIG. 2 TYPICAL CABLING STAR CONFIGURATION IN A BUILDING


ER
MC (CD)
ER
IC (BD)
BACKBONE
CABLING
TR
HC
HORIZONTAL
CABLING
WA
LEGEND
EQUIPMENT ROOM — ER
HORIZONTAL CROSS - CONNECT — HC
INTERMEDIATE CROSS - CONNECT — IC
MAIN CROSS - CONNECT — MC
MECHANICAL TERMINATION — ⊣
TELECOMMUNICATIONS ROOM — TR
TELECOMMUNICATIONS OUTLET / CONNECTOR — ◀
WORK AREA — WA

NOTES

1 Backbone cabling covers intra and inter building cabling.

2 IC is a cross-connect for in building cabling.

FIG. 3 EXAMPLE OF BACKBONE HIERARCHICAL STAR TOPOLOGY

3.3.2 *Inter-Building Pathways*

In a campus environment, inter-building pathways are required to connect separate buildings. For this, underground, buried, aerial and tunnel are the main pathway types used. As the complexes have varying conditions of land features and locations, size and use of building, choice if any or combination of the pathways need to be made based on local requirements. The cable running over the pathways generally terminates at the entrance facility of the building at both ends.

3.3.2.1 *Underground inter-building backbone pathways*

The pathway shall be fully covered and the cabling shall be installed within protective conduit or ducting for the entire external section of the cable route in all inter-building pathways. Provision should be made for existing as well as future demand. Underground pathways consist of conduit, ducts and troughs; possibly including manholes. The manhole can be planned normally, if:

a) The cable requires joint;

b) The distribution of copper/fibre pair is required midway; or

c) Numbers of bends in the path are more than two.

Each manhole should be dimensioned to accommodate spare cable of 2 m to 4 m length in each direction, which is generally kept in spare loop to take care of maintenance needs. All conduit and duct shall have a diameter of at least 100 mm. Bends are not recommended; however, if required, there should be not more than two 90° bends.

In a multi-building and multi-operator campus, an underground cable vault (UCV) may be considered close to entrance facility. Manholes/pull holes may also be provided for O&M activity in the outside plant pathway system for the pulling, placing, and splicing of cables. Size of UCV, manholes and pull holes should be decided based on the pathway capacity, number and types of cables, etc. All such points should be covered with properly marked iron covers of appropriate thickness and structural support below them keeping in view the load they are expected to bear due to pedestrian or vehicle movement.

In the planning for underground cabling, the following shall be considered:

a) Limitations dictated by the topology (this includes land development);

b) Grading of the underground pathway to permit proper drainage;

c) Need to vent gaseous vapours; and

d) Amount of vehicle traffic to determine the amount of cover over the pathway and whether or not concrete encasement is required.

3.3.2.2 *Direct buried inter-building backbone pathways*

In this case, the telecommunications cables are completely covered in earth. Direct burial of telecommunications cables is achieved by trenching, augering or boring (pipe-pushing). When selecting a route for the pathway, it is important to consider the landscaping, fencing, trees, paved areas and other possible services. Direct burial has the challenges of cable repair in case of faults and also in future upgradation.

3.3.2.3 *Aerial inter-building backbone pathways*

An aerial pathway consists of poles, cable-support strand and support system. Some considerations to make when using aerial backbone include the following:

a) Appearance of the building and surrounding areas;

b) Separation and clearances for electrical installations and roads;

c) Span length, building attachments, storm loading and mechanical protection; and

d) Initial number of cables and future growth potential.

3.3.2.4 *Tunnel inter-building backbone pathways*

Tunnels provide pathways for conduit, trays, wire-ways or support strand. Normally tunnels support other building services too. Hence, the location of telecom pathways within a tunnel should be planned to allow for accessibility as well as for separation from other services. In general, tunnelling inside the premises for telecom services alone may not be cost effective.

3.3.3 *Backbone Building Pathways*

Backbone building pathways can be built in various ways depending upon the building layout, locations of TR/TE, etc. While designing and implementing such pathways, certain requirements need to be met and precaution taken. Typical topologies and requirements/ precautions relating to these are described below:

a) *Vertically pathway topology* — Vertically aligned TRs with connecting sleeves or slots are the most common type of backbone pathway though it is not a necessary condition. Vertical alignment is desirable because the building planner can stack them with other mechanical spaces, and it makes distribution of telecom cables more efficient because of shorter conduits and cabling runs. If the TRs/TEs are not aligned vertically above one another, the conduits interconnecting them will have horizontal offsets. There shall be not more than two 90° bends in any such conduit run. Any bend shall have an inside radius 10 times the diameter of the conduit (typically 1 m). If these conditions cannot be met, then intermediate pull boxes shall be used wherever a non-standard transition is required. This pull box shall be at least 600 mm × 600 mm in the plane of the attached conduits, and 150 mm deep. All conduits other than simple sleeves between floors shall be fitted with a continuous 1.5 mm nylon pull rope, or a 0.6 mm steel fish wire or a 0.5 mm fibre composite fish wire.

b) *Conduits, trays, slots, sleeves, and ducts* — All rigid metallic conduit pipes shall be of steel and shall be conforming to accepted standard [D-6(1)]. The wall thickness of the pipe shall be not less than 1.6 mm (16 SWG) for conduits up to 32 mm diameter and not less than 2 mm (14 SWG) for conduits above 32 mm diameter. These shall be solid drawn or reamed by welding and finished with galvanized or stove enamelled surface.

   All non-metallic conduit pipes and accessories shall be of suitable material complying with the accepted standards [D-6(2)] for rigid conduits, and accepted standards [D-6(3)] for flexible conduits. Such pipes shall not be exposed.

   The vertical backbone pathway consists of telecommunications rooms located on each floor, tied together by sleeves or slots. In this context, the term 'sleeve' refers to a circular opening in a wall, ceiling or floor to permit the passage of cables between adjacent spaces. A 'slot' is the same as a 'sleeve', except that the shape of the opening is usually rectangular. The cable sleeves or slots are positioned adjacent to a wall on which the backbone cables can be supported. The recommendation in respect of slots and sleeves are as under:

   1) Slots with a minimum 25 mm high curb; and

   2) Sleeves to extend a minimum of 25 mm above the floor level and a maximum of 77 mm above the floor level. Sleeves should be located at a minimum of 25 mm from the wall or between adjacent sleeves to provide room for bushings, but not so far from the wall that it becomes a tripping hazard or create too large a cable span from the sleeve to the backboard/tray.

c) *Riser systems* — For connectivity to TR/TE on upper floors from the building EF, conduit or raceway should preferably be provided vertically. Vertically mounted ladder rack shall be mounted on the wall between incoming and outgoing sleeves within the TR/TE. The ladder rack should be used to provide strain-relief for cables transiting TR/TE within the riser system. If the building plan is large enough to require a second communications TR/TE on one or more floors, then the riser pathway should preferably be duplicated from the EF up to second set of TR/TE.

d) *Vertical pathway size* — A minimum of three 100 mm diameter conduits, or equivalent raceway cross section, should be provided between the TR/TE on adjacent floors and between the EF and the first floor TR/TE.

e) *Access to the roof* — For installations like antenna, powering the roof top/tower top equipment, access shall be provided through suitable number of conduits. This connectivity from the roof should be seepage and rodent proof. A minimum of two 75 mm and one 20 mm conduit shall extend from the topmost TR/TE to the roof terminated in a weatherproof metal enclosure. Sometimes, it may not be feasible or desirable to have direct vertical access, thus requiring horizontal extension from the rooms before vertical extension, the user may keep this in view for taking action with respect to architectural considerations.

f) *Pathway finish details* — Conduit shall be free of burrs or sharp edges. Sheet metal sleeves, if used, shall have rolled edges. Conduits or sleeves shall protrude at least 25 mm from the surface they penetrate but not more than 75 mm. Conduits shall be fitted with a smooth bushing.

g) *Fire protection of shafts* — All penetrations shall be filled with fire resistant material. Fire compartment plan and integrity of compartment should be maintained by either blocking permanently or by recognized systems automatically responding to temperature increase.

h) *Open cable shafts* — Open cable shafts should be used when available and where large quantities of cables are required on a floor that is distant from the main ER. Backbone cable pathways shall not be located in elevator shafts.

j) *Enclosed metallic raceways or conduits* — Enclosed metallic raceways or conduits are also used as vertical and horizontal cable pathways. It should be bonded to form a common bonding network.

k) *Cable trays* — A cable tray can be used as a vertical cable pathway within shafts or as part of the pathway between vertically aligned TRs. A cable tray can be open or covered and provides a means for attaching vertical cable runs to the cable tray members. The cable tray can also accommodate ethernet LAN cables running from building management system and other low voltage automation system in the building.

3.3.4 *Ethernet in the First Mile* (*EFM*)

Ethernet in the first mile (EFM), also known as ethernet to the last mile, describes the access network from the access point to the subscriber's premise. The first mile is the critical connection from business and residential users to the public and the public network.

Ethernet is the dominant mode of digital connectivity to user computers and other devices. Local area network (LAN) connectivity is extended to the end user computers through ethernet cable and connector. Ethernet cables generally used are Cat 5e and Cat 6. However, higher categories of cables are available (Cat 7 and Cat 8), which supports data rates of 10 Gbps and 40 Gbps. In many implementations, backbone and horizontal cabling may be on optical fibre. Such implementations address the Cat 5e/Cat 6 cable length limitations as only the last drop from TR/TE to the work area will use Cat 5e/ Cat 6 cable.

However, in many large buildings, optical to ethernet converters/switches may be required to be installed beyond TR/TE also, which may be installed in safe places in corridors false ceiling, work area, etc, where provision for supply of power should also be made. This holds true for Cat 5e/Cat 6 backbone and/or horizontal cabling also. Cabling to work area may be through conduits inside the wall or conduits on open surfaces. In cases where multiple tenants want to set up their own LAN, they may set up their system and horizontal cabling. However, they should preferably use backbone cabling of the building to reach EF for further connectivity to a telecom service provider for internet/leased bandwidth, etc.

3.4 Horizontal Cabling Media Distribution and Building Pathways

A horizontal distribution system consists of the horizontal cabling, the horizontal pathways supporting the horizontal cabling, and the telecom spaces that support the horizontal pathways. As horizontal distribution systems, cabling, and pathways often change direction, elevation, or physical orientation to accommodate obstructions, barriers, and other building systems, the use of the term horizontal in the name of the element does not require that the elements be placed or installed parallel to the ground or floor.

3.4.1 *Horizontal Cabling Systems*

The horizontal cabling is the portion of the telecommunications cabling system that extends from the work area telecommunications outlet/connector to the horizontal cross-connect in the telecommunications room (TR). The horizontal cabling includes horizontal cables, telecommunications outlet/connectors in the work area, mechanical terminations, and patch cords or jumpers located in the telecommunications room, and may include multi-user telecommunications outlet assemblies and consolidation points.

3.4.1.1 The following media types can be considered as options for horizontal cabling:

a) Four-pair 100 Ω unshielded twisted-pair (UTP) or screened twisted-pair (ScTP) cables with a distance limit of 90 m taking care of 10 m patch cord/jumper cable required for work area.

b) In case of optical fibre, OM cable normally of grade lower than or equal to the backbone cable may be selected. Such limitation is not faced if OS or appropriate ITU-T standard single-mode cables as mentioned in 3.2.4.2 are used. Distance limits with respect to data rate to be supported on horizontal cabling system may be seen from table under 3.2.4.2. Care should be taken that the equipment for corresponding fibre interface is selected.

While laying cables, maximum recommended length of cable by including provision for jumper cables/patch cords in TR and extension in work area should be kept in view.

3.4.2 The requirements for horizontal pathways, measures for avoiding electromagnetic interference in the design of cabling pathways are described in 3.4.2.1 and 3.4.2.2.

3.4.2.1 *Horizontal pathways*

Horizontal pathways are used for distributing, supporting, and providing access to horizontal cabling and telecom associated connecting hardware between the telecom outlets/connectors and the HC, typically located in the ER, TR or TE. Horizontal cabling is contained within horizontal pathways. Generally, the horizontal pathways are one of two types:

a) Continuous pathways (for example, conduit, cable tray, cable matting) used for containment of telecom cabling.

b) Non-continuous pathways (for example, the space between cable supports such as J-hooks) through which cables are placed between physical supports or containment components.

A pathway component should be designed to accommodate all standards compliant cabling and address the potential need for change and expansion during the life cycle of the cabling system and building. The emphasis should be first on the design of pathway systems and then on the cabling systems design. This approach helps to ensure a robust pathway system that supports the cabling installation over the facility's life cycle. As frequently accessing or changing the horizontal cabling leads to disruption to occupants, the choice and layout of horizontal cabling types are important to the design of the building structured cabling system. The following should be considered for the horizontal distribution system's design:

1) Allow for the accommodation of change over the facility's life cycle with the goal of reducing long-term maintenance and operational costs;
2) Utilize standardized cabling, components and systems; and
3) Include appropriate pathway and cabling components to accommodate ease of access and a variety of user specified technology applications.

The horizontal cabling system should be designed in order to support various telecom applications, including:

i) Voice services;
ii) Data services;
iii) Audio and video services; and
iv) Building signalling systems [for example, smart building ICT systems, building automation systems (BAS), and fire safety and security systems].

It is preferable to have provision for conduits, junction box, etc, during planning and construction stage for providing radio/wireless data equipment at the centre line of rooms and corridors to avoid unplanned provisions later on.

3.4.2.2 *Avoiding electromagnetic interference* (*EMI*)

Avoiding electromagnetic interference (EMI) is an important consideration in the design of cabling pathways. Providing physical separation from sources of EMI for these elements of the telecom infrastructure inherently provides separation of their contents (for example, cable and connecting hardware).

The telecom pathways should be located away from sources of EMI to the extent feasible, including:

a) Electrical power cabling and transformers;
b) RF sources;
c) Large motors and generators;
d) Induction heaters;
e) Arc welders;
f) X-ray equipment; and
g) Photocopy equipment.

3.4.2.3 *Topology*

Horizontal cabling should be installed in a physical star topology. Each telecom outlet/connector should be cabled directly to an HC (FD) in the appropriate telecom space. Exceptions to this practice are possible, when:

a) A consolidation point (CP) or multi-user telecommunications outlet assembly (MUTOA) is used to connect the open office cabling;
b) A transition point (TP) is required the connect to under-carpet cabling; or
c) Centralized optical fibre cabling is implemented from main cross-connect (campus distributor) [MC (CD)] to the work area(s).

Some applications may utilize a bus, ring, or tree topology, which can be implemented within a physical star topology. However, in case of large number of work areas, ring or tree topology may require intermediate distribution points like MUTOA, etc. Typical horizontal and work area cabling using a star topology is shown in Fig. 4.

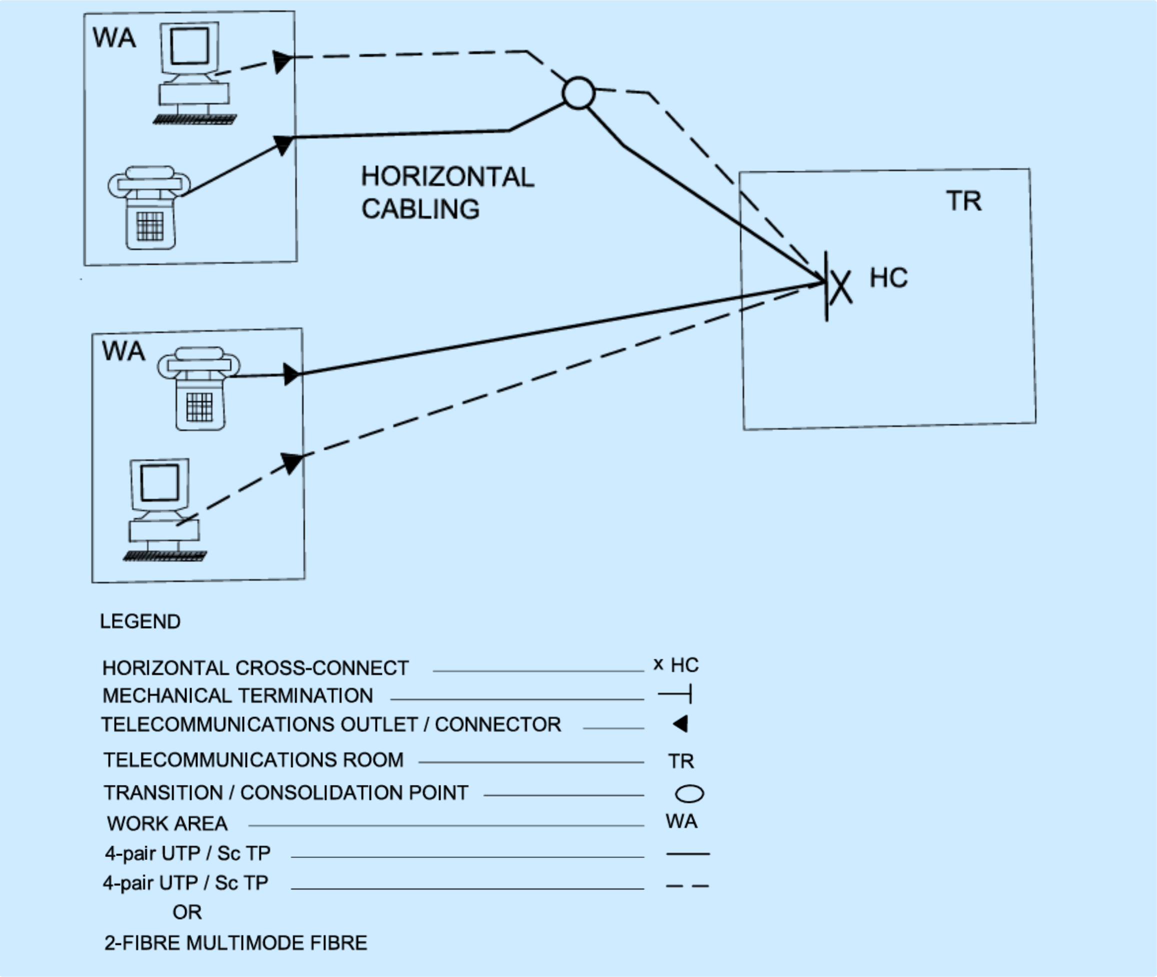

WA
HORIZONTAL CABLING
TR
HC
WA
LEGEND
HORIZONTAL CROSS-CONNECT — x HC
MECHANICAL TERMINATION — ⊣
TELECOMMUNICATIONS OUTLET / CONNECTOR — ◀
TELECOMMUNICATIONS ROOM — TR
TRANSITION / CONSOLIDATION POINT — ○
WORK AREA — WA
4-pair UTP / Sc TP — ——
4-pair UTP / Sc TP — – –
OR
2-FIBRE MULTIMODE FIBRE

FIG. 4 TYPICAL HORIZONTAL AND WORK AREA CABLING USING A STAR TOPOLOGY

3.4.2.4 *Work areas and open office cabling*

3.4.2.4.1 The work area includes those spaces in a building where occupants normally work and interact with their ICT equipment. While work areas have traditionally been fixed, discrete locations, open office cabling design practices have introduced flexible layouts to support collaborative work by small teams. Such spaces are often rearranged to meet changing requirements of group work. Many other open office work situations also require frequent reconfiguration. An interconnection in the horizontal cabling allows open office spaces to be reconfigured frequently without disturbing horizontal system cabling runs. Work area equipment that may require access to the horizontal cabling includes:

a) Telephones;

b) Networking equipment;

c) Fax machines;

d) Computers;

e) Network peripherals; and

f) Any device plugged into a telecom outlet/connector that is located within the work area.

3.4.2.4.2 The key elements of open office cabling are the MUTOA and CP. To accommodate equipment in the work area, following components are typically used as needed:

a) Telecom outlet/connector;

b) Work area equipment cords;

c) MUTOAs and CPs; and

d) WAPs.

Some of these components and requirements or recommendations relating to them are described below:

a) *Multi-user telecom outlet assembly* (*MUTOA*) — The MUTOA serves as a method of connecting more than one user (work area) to the horizontal cabling system. MUTOAs may be advantageous in open office spaces that are moved or reconfigured frequently. A MUTOA facilitates the termination of horizontal cabling system cables in a common location within a furniture cluster or similar open area. The use of MUTOAs allows the horizontal cabling to remain unchanged when the open office plan is changed. Work area equipment cords originating from the MUTOA should be routed through work area pathways (for example, furniture pathways). Each furniture cluster should have one MUTOA which may typically serve 12 work spaces. The work area equipment cords shall be connected directly to work area equipment without any additional connections. For copper cables, any combination of horizontal, work area cables and equipment cords may not exceed 100 m. The work area cables shall be connected directly to work station equipment without the use of any additional intermediate connections (*see* Fig. 5); and

b) *Consolidation Point* (*CP*) — The consolidation point (CP) is an interconnection point within the horizontal cabling system. Like the MUTOA, a CP may be used for balanced twisted-pair cabling or optical fibre cabling. The functional difference between the CP and the MUTOA in the open office environment is that the CP introduces an additional connection for each horizontal cabling run. A CP may be useful when reconfiguration is not so frequent as to require the flexibility of the MUTOA. The CP may be located in the suspended ceilings, access floors, modular office furniture or work area. Further CPs may serve a zone consisting of number of work areas even in different rooms.

   Some additional considerations and guidelines that apply specifically to the CP are as under:

   i) Cross-connections should not be used at a CP. Not more than one CP should be used within the same horizontal system cable run so as to avoid additional points of failure. Depending upon the size and number of the cables, there can be a single CP for all cables or separate CPs for different sets of cables;

   ii) For balanced twisted-pair cabling, the CP should be located at least 15 m from the HC (FD) in order to reduce the effect of near end cross talk (NEXT) and return loss from multiple connections in close proximity;

   iii) CPs shall be located in fully accessible and permanent locations. CPs shall not be located in an obstructed area; and

   iv) The CP should be sized and cabled so that it meets the telecom requirements of the zone it serves. If the floor space requirements change for an existing CP, then the CP should be reconfigured to accommodate the new requirements (*see* Fig. 6).

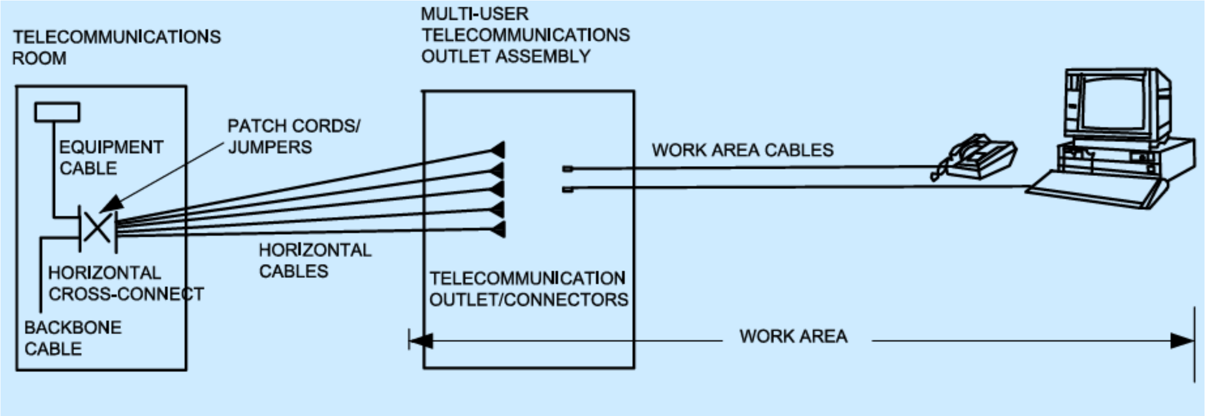

TELECOMMUNICATIONS ROOM
MULTI-USER TELECOMMUNICATIONS OUTLET ASSEMBLY
EQUIPMENT CABLE
PATCH CORDS/ JUMPERS
WORK AREA CABLES
HORIZONTAL CROSS-CONNECT
HORIZONTAL CABLES
TELECOMMUNICATION OUTLET/CONNECTORS
BACKBONE CABLE
WORK AREA

FIG. 5 APPLICATION OF MULTI-USER TELECOMMUNICATIONS OUTLET ASSEMBLY

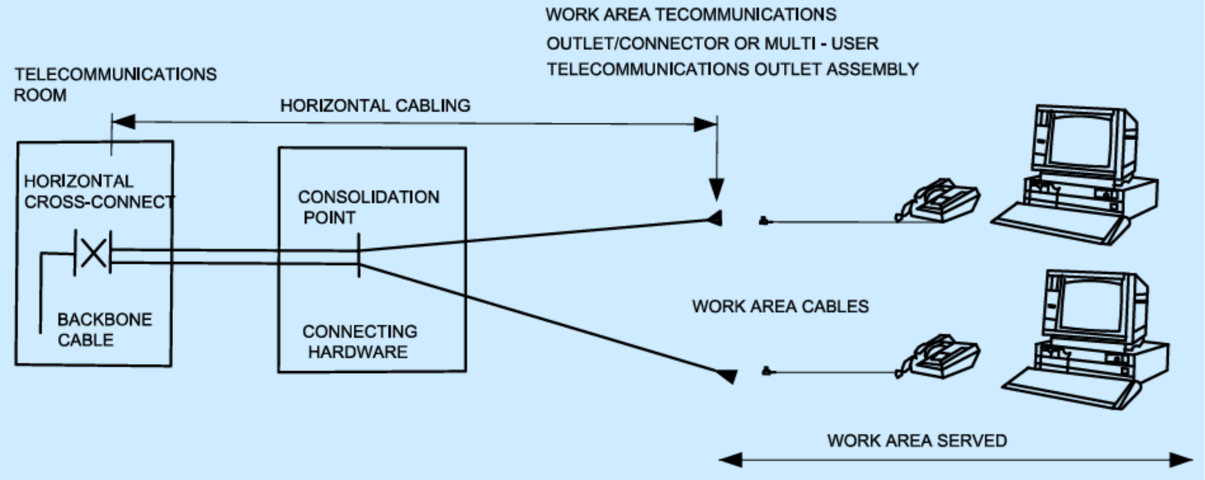

WORK AREA TECOMMUNICATIONS OUTLET/CONNECTOR OR MULTI - USER TELECOMMUNICATIONS OUTLET ASSEMBLY
TELECOMMUNICATIONS ROOM
HORIZONTAL CABLING
HORIZONTAL CROSS-CONNECT
CONSOLIDATION POINT
BACKBONE CABLE
CONNECTING HARDWARE
WORK AREA CABLES
WORK AREA SERVED

FIG. 6 APPLICATION OF CONSOLIDATION POINT

3.4.2.5 *Centralized optical fibre cabling* (*fibre to the desk*)

The HCs (FD), deployed throughout a building and located on each floor of a building, offers maximum flexibility to the user, especially in the deployment of distributed electronics or in multi-tenant buildings. In spite of the advantages of distributed cross-connections, some users may prefer data networks with centralized electronics which requires centralized cabling to provide connections from the work areas to the centralized cross-connect. Any of the following methods can be used for cabling:

a) Pull-through cabling from the centralized cross-connection;

b) Interconnection cabling in a floor-serving telecom space; and

c) Spliced cabling in a floor-serving telecom space.

However, flexibility for rearrangement of work areas and need for additional work areas in future by the user should be kept in view while adopting any of the above methods.

3.5 Building Information for Telecommunication Infrastructure Planning

For facilitation of proper design or upgradation of telecommunication infrastructure, it is important to have some basic information about the building and its users. For this purpose, a template containing a typical set of data points is provided in Annex C. Additional details may also be included as deemed necessary, so as to meet the objective of ensuring appropriate planning, design, and implementation of telecommunication infrastructure and services.

4 SPECIFIC REQUIREMENTS FOR TELECOM INFRASTRUCTURE CABLING

4.1 Telecommunications Bonding and Grounding

The bonding and earthing infrastructure of a telecom installation is an essential part of an information technology systems (ICT) design. Earthing systems are an integral part of the signal or telecommunications cabling system that they support. In addition to helping protect personnel and equipment from hazardous voltages, a proper earthing system may reduce electromagnetic interference (EMI) to and from the telecommunications cabling system. Improper earthing can produce induced voltages and those voltages can disrupt other telecommunications circuits. Earthing and bonding shall meet the appropriate requirements and practices of applicable standards.

The overall purpose for the ICTs bonding infrastructure is to equalize potentials between metallic surfaces (exposed and extraneous conductive parts) predominantly in the event of lightning, a.c. electrical system faults, electromagnetic induction, or electrostatic discharge.

The primary bonding busbar (PBB) serves as the dedicated extension of the building's protective earthing system for the ICTs infrastructure from the main earthing terminal (MET). It serves as the central attachment point for the telecom bonding backbone (TBB). Secondary bonding busbar (SBB) is the earthing connection point for ICTs infrastructure systems (for example, cabling, pathways) and ICTs equipment in the area served by an ER or TR. The PBB and-SBB should be a pre-drilled copper bus bar with holes for use with standard-sized lugs. A TBB is a ICTs bonding conductor to connect equipment/TRs/TEs on multiple floors of a building with an ultimate connection to the PBB. Typical telecommunication earthing and bonding arrangement is shown in Fig. 7.

PBB is recommended for minimum dimensions of 6.35 mm thick, 101.6 mm wide and variable in length and the recommended minimum dimension for SBB is 6.35 mm thick and 50 mm wide. The TBB conductor sizing are as under:

Sl No. (1)	*Maximum PBB-SBB length (l)* m (2)	*TBB cross-sectional area* mm^2 (3)
i)	$l \leq 4$	16
ii)	$4 < l \leq 6$	25
iii)	$6 < l \leq 8$	35
iv)	$8 < l \leq 10$	35
v)	$10 < l \leq 13$	50
vi)	$13 < l \leq 16$	60
vii)	$16 < l \leq 20$	70
viii)	$20 < l \leq 26$	95
ix)	$26 < l \leq 32$	120
x)	$32 < l \leq 38$	150
xi)	$38 < l \leq 46$	150
xii)	$46 < l \leq 53$	185
xiii)	$53 < l \leq 76$	150
xiv)	$76 < l \leq 91$	300

NOTE — For lengths in excess of those shown above, the conductor cross-sectional area should be calculated as 3.3 mm^2 per meter. The figures given in parentheses are in AWG.

4.1.1 *Meshed Bonded Networks*

The mesh bonded networks provide enhanced immunity to EMI compared to that provided by the other bonding networks. This may be preferred for application, where high density of ICT equipment are installed, for example data centres, hospitals, airports. A merged MESH-BN and protective earthing network in buildings shall include the interconnections to the integrated lightning protection system, bonding measures of antenna installations (including satellite receiving equipment under private property) and cable networks, bonding measures of information technology cabling. The typical indicative diagram for meshed bonded network is given in Fig 8.

NOTE — For further information refer special publication, ISO/IEC 30129 : 2015 'Information technology — Telecommunications bonding networks for buildings and other structures'.

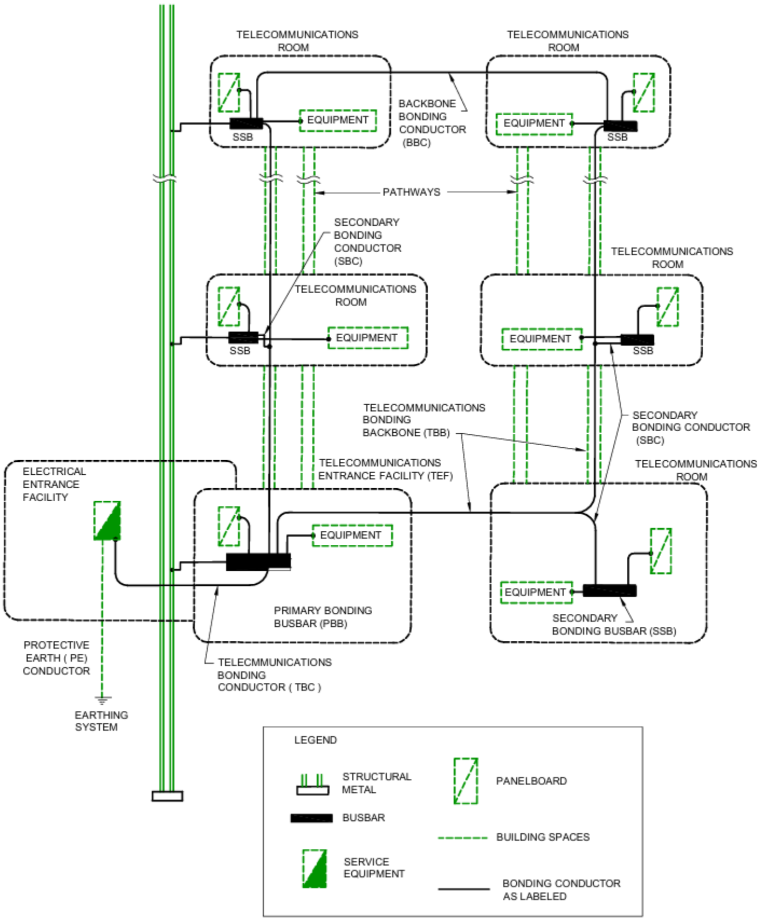

TELECOMMUNICATIONS ROOM
TELECOMMUNICATIONS ROOM
EQUIPMENT
SSB
BACKBONE BONDING CONDUCTOR (BBC)
EQUIPMENT
SSB
PATHWAYS
SECONDARY BONDING CONDUCTOR (SBC)
TELECOMMUNICATIONS ROOM
TELECOMMUNICATIONS ROOM
SSB
EQUIPMENT
EQUIPMENT
SSB
TELECOMMUNICATIONS BONDING BACKBONE (TBB)
SECONDARY BONDING CONDUCTOR (SBC)
TELECOMMUNICATIONS ENTRANCE FACILITY (TEF)
TELECOMMUNICATIONS ROOM
ELECTRICAL ENTRANCE FACILITY
EQUIPMENT
EQUIPMENT
PRIMARY BONDING BUSBAR (PBB)
SECONDARY BONDING BUSBAR (SSB)
PROTECTIVE EARTH (PE) CONDUCTOR
TELECMMUNICATIONS BONDING CONDUCTOR (TBC)
EARTHING SYSTEM
LEGEND
STRUCTURAL METAL
PANELBOARD
BUSBAR
BUILDING SPACES
SERVICE EQUIPMENT
BONDING CONDUCTOR AS LABELED

FIG. 7 TYPICAL TELECOMMUNICATION EARTHING AND BONDING ARRANGEMENT

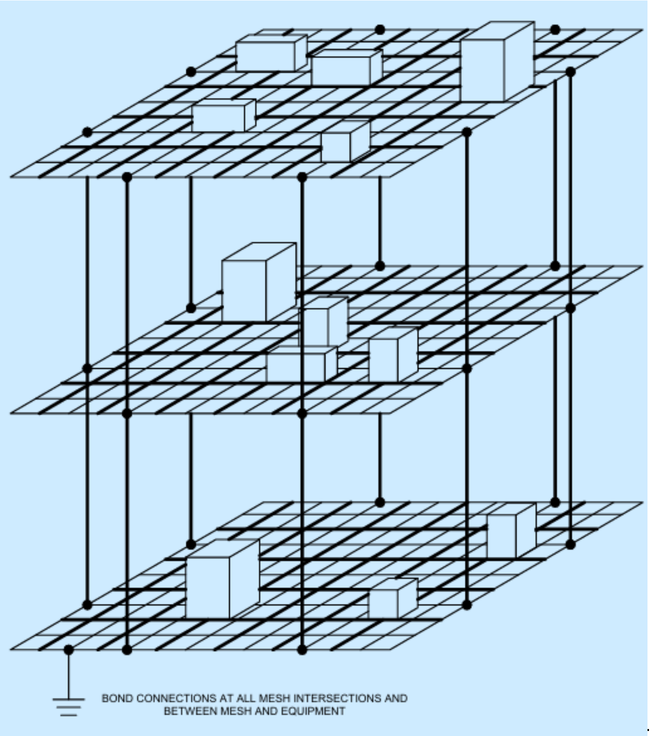

BOND CONNECTIONS AT ALL MESH INTERSECTIONS AND BETWEEN MESH AND EQUIPMENT

FIG. 8 MESH-BN WITH EQUIPMENT CABINETS, FRAMES, RACKS, CBN AND GLOBAL EARTHING BONDED TOGETHER

4.2 Installation and Workplace Safety

4.2.1 *Cabling Installation Guidelines*

The installation of system components has a tremendous effect on the final performance level of the network; therefore, it is essential to ensure that the performance of the entire network is not diminished through improper installation. The cables can be easily damaged if they are improperly handled or installed. It is imperative that certain procedures be followed in the handling of these cables to avoid damage and/or limiting their usefulness.

Care shall be taken not to stretch or abrade cables during installation, that is, the pulling tension for cables shall not be exceeded. Cables that pass through the infrastructure of the building shall be suitably protected against damage. Through walls and floors, this shall involve an appropriate type of sleeve; through any form of metalwork or stiff plastic then a rubber grommet shall be used.

To ensure cable management and also strain relief, cables shall be properly dressed using velcro cable ties. However, cable's ties should never be over tightened. On vertical runs, the cables shall be dressed and tied from the bottom up, thus putting minimum strain on the cables. In order that the system may be easily re-routed, or damaged sections quickly replaced, free access to the cable should be ensured and where possible, it is important to leave draw cords in ducting, piping, etc, for future use.

4.2.1.1 *Improvement areas*

a) *Do not exceed the maximum tensile load* — On runs from 40 m to 100 m, use proper lubricants and make sure they are compatible with the cable jacket. On runs over 100 m, use proper lubricants and pull from the middle out to both ends. If possible, use an automated puller with tension control or at least a breakaway-pulling eye;

b) *Maintaining minimum bending radius* — Sharp bends in the cable may damage the insulating material, thus causing unacceptable losses in the transmission medium. Therefore, the internal radius of every bend in a cable shall be such as not to cause damage to the cable, nor impair the characteristics of the cable;

c) *Proper cable slack at outlet points and patch panels* — Install the system such that sufficient slack remains to enable re-termination of the outlets, a minimum of twice, and a limited scope for movement of the cabinets;

d) *Patch panels and cable management* — Where possible, patch panels shall be installed within the communications units from the top, continuing downwards;

e) *Electromagnetic compatibility* (*EMC*) — As a passive medium, structured cabling need not comply with the EMC regulations. However, telecom designers should be aware that cabling, when connected to transmission equipment, could radiate, receive and conduct electromagnetic disturbances and act accordingly. When crossing mains cables, this shall be done at right angles;

f) *Maintaining proper cable routes* — Cable shall not be routed over pipes, conduits, other cabling, ceiling tiles, etc, but shall rest directly on the supporting surface so as to minimize the potential for sharp bends, kinks, etc. Every cable used shall be supported in such a way that it is not exposed to undue mechanical strain so that there is no appreciable mechanical strain on the terminations; and

g) *Labelling* — The cable shall be clearly labelled at both ends, as outlined in the documentation and/or drawing. Each 8P8C connector (information outlet) shall be individually labelled. The label shall contain a unique identification, as outlined in the documentation and/or drawing, and shall be indelible and placed behind a transparent cover. At the patch panels, each socket shall be labelled according to its corresponding outlet identification.

4.2.2 *Workplace Safety*

Following measures shall be ensured for workplace safety:

a) To maintain workplace safety, personal protective equipment (PPE) like protective clothing, helmets and goggles should be used to protect the personnel from injury or infection from hazards such as physical, electrical, heat, chemical and biohazards;

b) Lighting in telecom spaces shall be provided in an adequate amount such that continuing work operations, routine observations, and the passage of employees can be carried out in a safe and healthful manner. Certain specific tasks in centres, such as splicing cable and the maintenance and repair of equipment frame line-ups, may require a higher level of illumination and adequate provisioning should be provided for the purpose; and

c) While working with optical fibre installation, the real issue of eye safety is getting fibre scraps into the eye. The broken ends of fibres and scraps of fibre created during the termination and splicing may also be dangerous. Therefore, protective eyewear such as safety glasses should be worn by personnel while carrying out splicing and termination operations. Further, fibre optic splicing and termination use various chemical cleaners and adhesives as part of the processes. Therefore, careful handling of fibre, cleaner and adhesive shall be ensured by the use of safety gloves and respiratory masks.

5 OTHER APPLICATIONS IN TELECOM INFRASTRUCTURE CABLING

5.1 Electronic Access Control (EAC)

EAC is important for overall personal safety and the protection of physical and intellectual property. EAC devices can include locks, integrated electronic devices controlling a single door or room, or a complex system of interconnected electronic devices controlling a zone, building, or campus. Access to private or secured spaces can be controlled in a great variety of methods. In addition, the user often has multiple levels of access required within a space. Personnel may have access to any given number of these. This access level may be required to change during the course of the day, week, or month. In contrast to a lock-and-key system, a modern computer-supported control system can meet these and many other user goals. This system employs programmable EAC. Time-of-day and day-of-the-week access levels can be applied to all personnel who have authorized entry. Additional precautions should be taken against weaknesses in the EAC system (for example, piggybacking, tailgating, unauthorized entry). A great number of possibilities exist from the passive card to biometrics and any combination in between. A user may issue smart cards.

A typical EAC cable consists of four individually shielded pairs that are used for the door strike, card reader, door contact, and request for exit. The four individual wire pairs may be supplied individually or in a group. Coloured foil shields or jacket colours may be used to designate the intended purpose of each of the wire pairs within the cables.

In a shared communication environment, the EAC data travels along with other building systems and data networks packets on the same physical network. This is often accomplished through an ethernet connection. It may also use building automation networks. Another media for shared communication relies on a private branch exchange and local analog telephone line (*See* Annex A for details).

5.2 Video Surveillance

Video surveillance is the extension of human vision to areas requiring surveillance. Some primary applications of this technology include investigation, prosecution, deterrence, observation and intrusion detection. In addition to traditional capture devices that operate within the visible band of the electromagnetic spectrum, other technologies provide unique viewing capabilities using IR, thermal and film cameras. (*See* Annex A for details.)

ANNEX A

(*Clauses* 3.2.4, 3.2.4.1, 3.2.6, 5.1 *and* 5.2)

ADDITIONAL GUIDELINES FOR INFORMATION AND COMMUNICATION ENABLED INSTALLATIONS

A-1 GENERAL

This Annex contains information which supplements the text of this Section. The information can be used to make decisions while exercising options from among various types of hardware, cables, etc, and also for guidance.

A-2 CONNECTORS AND CONNECTING HARDWARE

Various types of connecting hardware may be as described below.

A-2.1 Balanced Copper Twisted-Pair Connectors:

a) *Insulation displacement contact* (*IDC*) *connectors* — The insulation displacement contact (IDC) is a gas-tight physical contact between two electrical conductors. The gas-tight contact is established by a cold weld with the elimination of the air gap between the conductor and the IDC and therefore the possibility of contact interface corrosion. Such contact creates a reliable, long-lasting connection with stable electrical properties. IDC connectors also eliminate conductor preparation (for example, insulation removal), reducing the termination time and the number of tools;

b) *Modular plug* — Modular plugs have IDC contacts designed for either stranded or solid conductors as well as connectors having universal contacts that accept both stranded and solid conductors. Materials used to build modular plugs are typically flame retardant polycarbonate (body) and phosphor bronze with gold plating over nickel in contact area (contacts); and

c) *Modular jack* — Modular jacks are available in various sizes and shapes (keyed and unkeyed). The number of positions indicates the connector's width, while the number of contacts installed into the available positions indicates the maximum number of conductors the connector can terminate.

A-2.2 Optical Fibre Connectors

The most common optical fibre interfaces include:

a) *LC connector* — It is a simplex connector that can be converted to a duplex using a clip. It is keyed, low-loss, pull-proof and wiggle-proof. It can be terminated in many different ways, including using anaerobic (quick cure) adhesive, cleave and crimp, and hot melt. This is often referred to as a small form factor (SFF) connector. The LC connector provides a pull-proof design and small size perfect for high-density applications. It is available in simplex or duplex versions. The LC connector is provided with a 1.25 mm ferrule. It also incorporates a unique latching mechanism providing stability in system rack mounts.

b) *Subscriber connector (SC)* — It is a simplex connector that can be converted to a duplex using a clip. It is keyed, low-loss, pull-proof, and wiggle-proof. It can be terminated in many different ways, including using anaerobic (quick cure) adhesive, cleave and crimp, and hot melt. The SC connector is a snap-in connector that latches with a simple push-pull motion, with a 2.5 mm ferrule and is widely used for its excellent performance. It is also available in a duplex configuration.

c) *Straight tip (ST) compatible* — It is a simplex connector. It is a keyed, low loss connector. It can be terminated many different ways, including using anaerobic (quick cure) adhesive, cleave and crimp and hot melt.

d) *Splices (Optical fibre connectors)* —These are used for adding optical fibre cable lengths. There are two primary splicing methods for optical fibres, fusion and mechanical. Both methods are field proven and have excellent long-term reliability when completed according to the manufacturer's instructions. Splices and stripped optical fibre cables are protected and secured by a splice enclosure. When a splice enclosure is used for splicing inside a building, it is generally secured to a rack or wall. In both cases, the splice enclosure contains the optical fibre splices in splice trays or organizers, typically in groups of 6, 12, 24, or more optical fibres per splice tray or organizer.

A-2.3 Coaxial Connectors

Connectors are installed on the end of a coaxial cable to provide electrical and mechanical connection to a system component. Either male or female connectors can be attached to coaxial cable, but most installations use male connectors on cable ends.

There are many styles of coaxial cable connectors. Three popular styles are:

a) BNC-style connector;
b) F-style connector; and
c) N-style connector.

A-2.4 Connecting Hardware

Cables are terminated in outlets in work areas or intermediate equipment through connecting hardware. Basic connecting hardware styles are:

a) Telecom outlets/connectors, including multiuser outlets;
b) Patch panels;
c) Connecting (wiring) blocks;
d) Cable assemblies;
e) Optical distribution frames; and
f) Splices.

To facilitate their installation, servicing, administration and maintenance, connecting hardware of different styles of connectors may be considered to be grouped in one unit. However, depending upon the given situation, one or more type of connecting hardware (copper pair, coaxial or optical) may be installed on separate panels/frames.

A-3 CLASSIFICATION OF CABLES BY FIRE SAFETY PROPERTIES

A-3.1 Twisted Pair Cables

Different communication cable types and their markings on cable sheath are as given below:

Sl No. (1)	*Marking* (2)	*Cable Type* (3)
i)	CMP	Communications plenum cable
ii)	CMR	Communications riser cable
iii)	CMG/CM	Communications general-purpose cable
iv)	CMX	Communications cable, limited use
v)	CMUC	Under carpet communications wire and cable

A-3.1.1 *Type CMP* (*Communications Plenum Cable*)

Type CMP communications plenum cables are suitable for use in ducts and plenums and they have adequate fire-resistant and low smoke-producing characteristics.

A-3.1.2 *Type CMR* (*Communications Riser Cable*)

Type CMR communications riser cables are suitable for use in a vertical run in a shaft when penetrating one or more floors as they have fire-resistant characteristics and thus be capable of preventing the carrying of fire from floor to floor.

A-3.1.3 *Type CMG/CM* (*Communications General-Purpose Cable*)

Type CMG general-purpose communications cables are suitable for general-purpose communications use, with the exception of risers and plenums, and these cables are resistant to the spread of fire.

A-3.1.4 *Type CMX* (*Communications Cable, Limited Use*)

Type CMX limited-use communications cables are suitable for use in dwellings and raceways as being resistant to flame spread.

A-3.1.5 *Type CMUC* (*Under Carpet Communications Wire and Cable*)

Type CMUC under carpet communications wires and cables are suitable for under carpet use and they are resistant to flame spread.

A-3.2 Optical Fibre Cables

Different optical fibre cable types and their markings on cable are as given below:

Sl No. (1)	*Marking* (2)	*Cable Type/Suitability* (3)
i)	*OFNP*	Non-conductive optical fibre plenum cable
ii)	*OFCP*	Conductive optical fibre plenum cable
iii)	*OFNR*	Non-conductive optical fibre riser cable
iv)	*OFCR*	Conductive optical fibre riser cable
v)	*OFNG*	Non-conductive optical fibre general-purpose cable
vi)	*OFCG*	Conductive optical fibre general-purpose cable
vii)	*OFN*	Non-conductive optical fibre general-purpose cable
viii)	*OFC*	Conductive optical fibre general-purpose cable

A-3.2.1 *Types OFNP and OFCP*

Types OFNP and OFCP non-conductive and conductive optical fibre plenum cables are suitable for use in ducts and plenums and they have adequate fire-resistant and low smoke-producing characteristics.

A-3.2.2 *Types OFNR and OFCR*

Types OFNR and OFCR non-conductive and conductive optical fibre riser cables are suitable for use in a vertical run in a shaft when penetrating one or more floors and have the fire-resistant characteristics capable of preventing the carrying of fire from floor to floor.

A-3.2.3 *Types OFNG and OFCG*

Types OFNG and OFCG non-conductive and conductive general-purpose optical fibre cables are suitable for general-purpose use, with the exception of risers and plenums, and these cables are resistant to the spread of fire.

A-3.2.4 *Types OFN and OFC*

Types OFN and OFC non-conductive and conductive optical fibre cables are suitable for general-purpose use, with the exception of risers and plenums and have resistance to the spread of fire.

A-4 BALANCED TWISTED-PAIR CABLE NOMENCLATURE

Details of nomenclatures of twisted pair cables using various combinations of overall screen type and individual pair screen type, as follows, are given in Table 2:

Sl No. (1)	*Overall Screen Type* (*x*) (2)	*Individual Pair Screen Type* (*y*) (3)
i)	Overall screen absent (*U*)	Individual screens absent (*U*)
ii)	Overall foil screen (*F*)	Individual foil screens (*F*)
iii)	Overall braid screen (*S*)	
iv)	Dual overall screen (foil + braid) (*SF*)	

Table 2 Balanced Cable Nomenclature

(*Clause* A-4)

Sl No. (1)	**Global Abbreviations** (*x*/*y*) (2)	**North American Abbreviation** (3)	**Overall Braid Screen** (4)	**Overall Foil Screen** (5)	**Individual Foil Screen** (6)
i)	*U*/*U* TP	*U* TP	No	No	No
ii)	*U*/*F* TP	*S* TP	No	No	Yes
iii)	*F*/*U* TP	*F* TP, *S*cTP, PiMF	No	Yes	No
iv)	*F*/*F* TP	*S* TP, *SS* TP	No	Yes	Yes
v)	*S*/*U* TP	*S* TP	Yes	No	No
vi)	*S*/*F* TP	*S* TP, *SS* TP	Yes	No	Yes
vii)	*SF*/*U* TP	*S* TP, *SS* TP	Yes	Yes	No
viii)	*SF*/*F* TP	*S* TP, *SS* TP	Yes	Yes	Yes

NOTE — The abbreviations represent as follows:

1 F/F TP — Foil-screened foil-screened twisted-pair (Individually foil-screened twisted-pair in overall foil screen).

2 F/U TP — Foil-screened unscreened twisted-pair (Unscreened twisted-pair in overall foil screen).

3 S/F TP — Braid-screened foil-screened twisted-pair (Individually foil-screened twisted-pair in overall braid screen).

4 S/U TP — Braid-screened unscreened twisted-pair (Unscreened twisted-pair in overall braid screen).

5 Sc TP — Screened twisted-pair.

6 SF/F TP — Braid-screened-foil-screened foil-screened twisted-pair (Individually foil-screened twisted-pair in overall foil and braid screen).

7 SF/U TP — Braid-screened-foil-screened unscreened twisted-pair (Unscreened twisted-pair in overall foil and braid screen).

8 U/F TP — Unscreened foil-screened twisted-pair (Individually foil-screened twisted-pair).

9 U/U TP — Overall unshielded twisted-pair with unshielded twisted-pair.

A-5 ELECTRONIC ACCESS CONTROL (EAC) AND VIDEO SURVEILLANCE

A-5.1 Electronic Access Control (EAC)

An EAC system allows several levels of security. Once the number and type of people are determined, a user or access level for each person is established. Access levels are incorporated into the system integration and the areas of access are determined. Factors affecting the user level include security clearances, job title, rank, short-term employee and employee type. The access level is determined by the physical layout of building and is directly related to the doors and other portals it controls.

The basic components of an EAC system include:

a) A computer;

b) One or more control panels; and

c) One or more peripheral devices connected to the control panels (for example, card reader, siren and sensor).

The host computer runs the EAC software, manages the system parameters, maintains the system database, and controls all communication with the control panels. The host computer receives all event and alarm transactions from the control panels. It then saves them into separate history files that may be used to run reports by specific criteria.

The control panels manage the activation of peripheral devices by turning the devices on or off and controlling access to certain areas through card readers and door-locking hardware.

Media for communications may include the following:

a) *Balanced twisted-pair* — Shielded twisted-pair, unshielded twisted-pair, and screened twisted-pair;

b) *Optical fibre* — Multi-mode and single-mode;

c) *Wireless* — Microwave, radio frequency (RF), and infrared (IR); and

d) Cellular networks connection.

A-5.2 Video Surveillance

A-5.2.1 In addition to traditional capture devices that operate within the visible band of the electromagnetic spectrum, other technologies that provide unique viewing capabilities are, as follows:

a) *IR cameras* — These refer to specially designed imagers capable of seeing into the low IR bandwidth. They are sometimes referred to as starlight cameras because of their night time viewing capabilities;

b) *Thermal cameras* — They capture heat or temperature values of a scene rather than light values, regardless of how bright or dark the scene appears to the human eye. Although the identification of colours and details are impossible with thermal cameras (because they only view temperature), these cameras are quite useful in viewing dark scenes for activities that have heat signatures; and

c) *Film cameras* — They have been on the market for many years. These self-sustaining units are equipped with traditional camera film, which permanently stores the scenes. The film requires replacement when exhausted.

A-5.2.2 Camera placement is based on security objectives identified through a need-assessment. Video surveillance applications include two typical types of camera mounts, as follows:

a) *Fixed* — It refers to a camera dedicated to single view that does not change unless the camera is physically moved; and

b) *Pan and tilt* — It refers to a camera with a pan and tilt that allows for a 180º or 360º view, which is controlled electronically from a remote viewing station.

From a practical standpoint, the trade-off between the two types is that a pan and tilt provides a more flexible area of coverage at a higher cost than a fixed camera. Pan and tilt technology allows for auto-panning where the camera moves in a predefined cycle. Camera mounting locations are typically dictated by the available physical infrastructure and are balanced against the required field of views. Connectivity of cameras to the main system in a building environment is generally through coaxial cables.

A-6 OVERVIEW OF IN-BUILDING SOLUTIONS (IBS)

A-6.1 General

The information in this annexure can be used to plan IBS to provide seamless mobile data and voice experience for indoor users including in areas like lifts, staircase and basements. IBS is a telecommunications infrastructure designed to enhance wireless network coverage. It is particularly useful in establishments such as offices, malls, hospitals, airports, sport arenas, multistorey residential complexes and other areas, where outdoor mobile signals may be weak due to distance and structural obstructions.

A-6.2 Types of In-Building Solutions

The various types of IBS technologies, to enhance indoor connectivity, are as under:

A-6.2.1 *Distributed Antenna Systems* (*DAS*) — It consist of multiple antennas distributed throughout a building or a venue. These antennas connect to a radio frequency source(s) and distribute signals effectively overcoming signal degradation in indoor environments. Typical layout of a DAS is shown in the Fig. 9. Following are the main components of DAS:

a) *Distributed antennas* — Acts as radiating source for RF signals. These are distributed throughout the building based on radio network planning;

b) *Splitter* — A passive component that divides the RF signal power equally among multiple output ports;

c) *Coupler* — A passive device that extracts a small portion of the signal from the main feed while allowing most of it to continue;

d) *Radio unit* — The radio frequency or mobile signal source that connects the in-building system to the mobile network; and

e) *RF or fibre cable for signal distribution* — The RF is used in passive DAS to carry the radio signals up to the antennas while fibre cable is used to connect master and slave unit in case of active DAS.

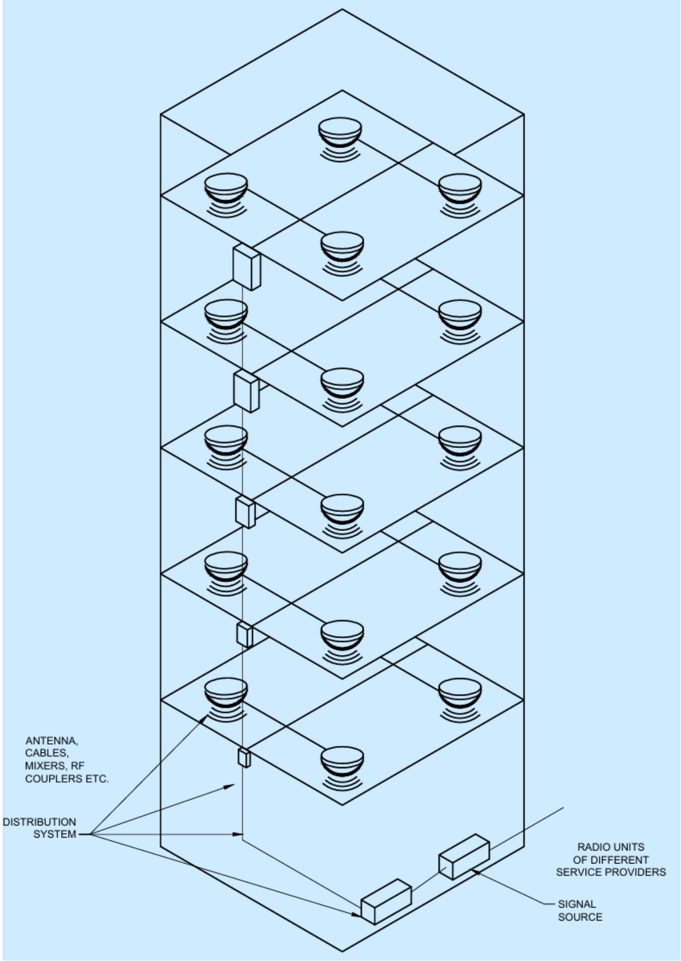

ANTENNA, CABLES, MIXERS, RF COUPLERS ETC.
DISTRIBUTION SYSTEM
RADIO UNITS OF DIFFERENT SERVICE PROVIDERS
SIGNAL SOURCE

FIG. 9 TYPICAL COMPONENTS OF A DISTRIBUTED ANTENNA SYSTEM (DAS)

A DAS can support multi frequency bands to carry radio frequency signals of multiple service providers for different technologies (2G/3G/4G/5G, etc) using common DAS. This common DAS infrastructure provide considerable cost savings with improved building aesthetics while providing seamless mobile coverage including in basements, lifts and lobbies.

There are different types of distributed antenna systems suitable for different use cases. Overview of some important DASs are covered below:

1) *Passive distributed antenna system* (*DAS*) — In passive DAS, only passive components are used to distribute the RF signals. The size of the cable depends upon the frequency in use, coverage and capacity requirement. The distribution of combined mobile signal is done using passive components in the network like RF cable, couplers and splitters. The RF signal is coupled with the antennas installed across the floor(s) for radiating in different sections of the building as indicated in the Fig 10; and

2) *Active distributed antenna system* — This type of system is used where the coverage is required in a huge building and airport etc. where conventional passive cable system does not give adequate coverage due to high losses in the coaxial cables as shown in Fig 11.

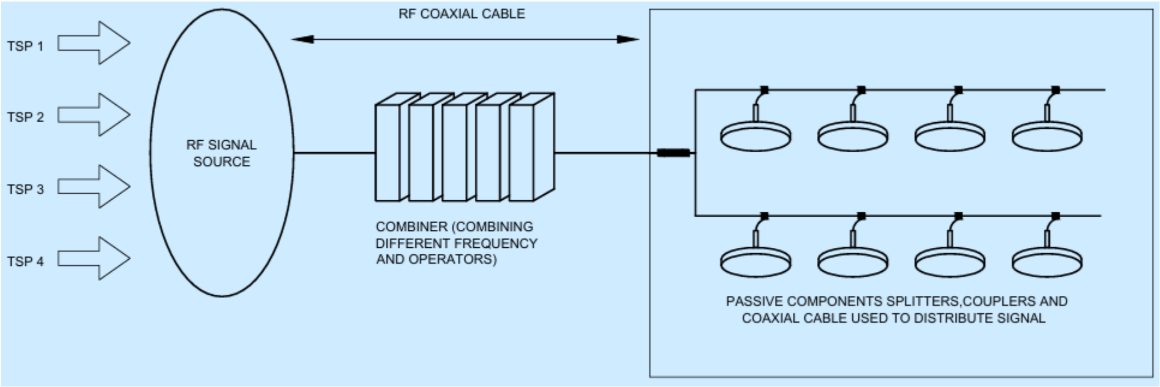

TSP 1
TSP 2
TSP 3
TSP 4
RF SIGNAL SOURCE
RF COAXIAL CABLE
COMBINER (COMBINING DIFFERENT FREQUENCY AND OPERATORS)
PASSIVE COMPONENTS SPLITTERS,COUPLERS AND COAXIAL CABLE USED TO DISTRIBUTE SIGNAL

FIG. 10 KEY COMPONENTS OF TYPICAL PASSIVE DAS

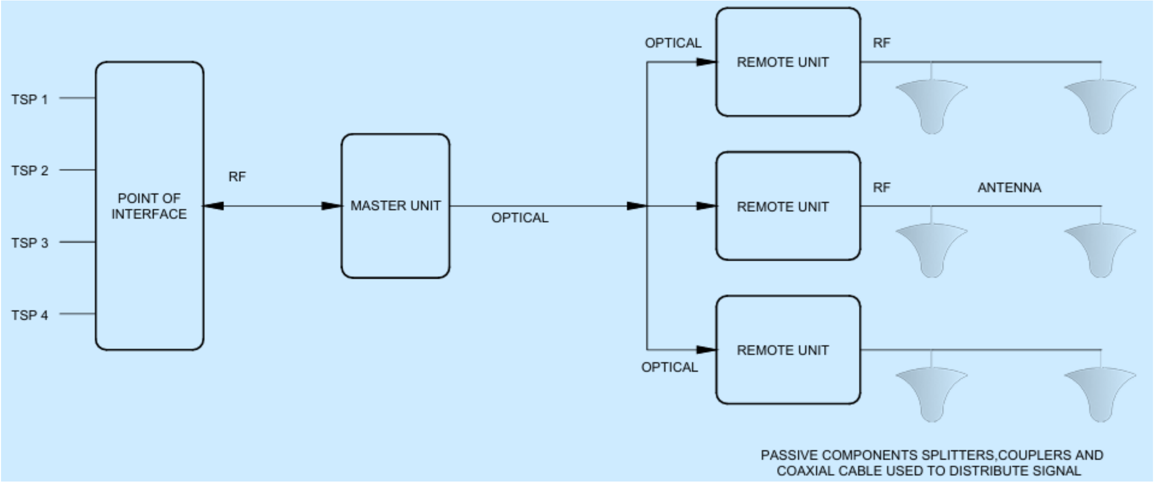

TSP 1
TSP 2
TSP 3
TSP 4
POINT OF INTERFACE
RF
MASTER UNIT
OPTICAL
OPTICAL
REMOTE UNIT
RF
REMOTE UNIT
RF
ANTENNA
OPTICAL
REMOTE UNIT
PASSIVE COMPONENTS SPLITTERS,COUPLERS AND COAXIAL CABLE USED TO DISTRIBUTE SIGNAL

FIG. 11 KEY COMPONENTS OF TYPICAL ACTIVE DAS

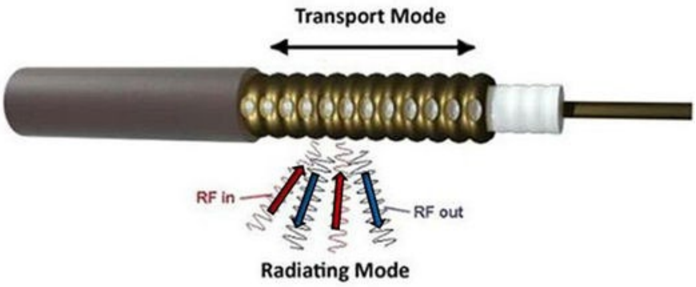

Transport Mode
RF in
RF out
Radiating Mode

FIG. 12 TYPICAL LEAKY CABLE INSTALLATION IN A TUNNEL

A-6.2.2 *Leaky Feeder Cable System* — In this system this is a special type of cable known as leaky feeder cable in which the slots are cut as window in the cable itself and when the RF signal is pumped in it which get radiated through these windows which acts as an antenna as indicated in Fig. 12. Such cables are generally used in the tunnels where installation of active components may be difficult.

A-6.2.3 *Small Cells, Including Femtocell and Pico Cells* — They are low-powered radio access nodes designed to cover small geographic areas, such as a single room or a specific area in a larger venue. They complement main cellular networks by providing targeted coverage and traffic capacity.

A-6.3 Key Considerations for Planning an In-Building Solution

a) *Coverage requirements* — Determining the appropriate coverage levels for an in-building solution depends on user density and the types of applications being used. High-density areas require a robust network capable of handling simultaneous connections from multiple users. The design should account for variations in density across different floors and zones to ensure uniform coverage. Additionally, the nature of services being provided whether voice, video, or data — Plays a crucial role in coverage planning;

b) *Interference management* — Effective interference management is essential to maintain signal quality within an indoor environment. Identifying potential interference sources, such as nearby wireless networks, electronic devices, and structural obstacles, helps in mitigating performance issues. To minimize interference, strategies such as frequency planning, power control, and spatial diversity should be implemented;

c) *Capacity planning* — Proper capacity planning ensures that an in-building solution can handle both current and future network demands. By analyzing user behaviours and application requirements, network designers can forecast growth in user numbers and data consumption patterns; and

d) *Aesthetics and integration* — Careful placement of antennas, cables, and other infrastructure components helps maintain the visual appeal of the space. Where possible, discreet installations such as ceiling-mounted antennas or concealed cabling are preferred. Engaging stakeholders including building owners, architects, and end-users during the IBS design phase ensures that the network aligns with both functional and aesthetic requirements.

NOTE — The relevant standards, prescribed by Telecom Engineering Centre (TEC), Department of Telecom, Ministry of Communications, may be referred at [https://www.tec.gov.in] for the implementation of in-building solutions.

ANNEX B

(*Foreword*)

STREET FURNITURE FOR ICT INSTALLATIONS

B-1 Street furniture, such as streetlights, utility poles, bus stops, and traffic signals, is expected to play a significant role in enabling ICT infrastructure, especially as India deploys next-generation technologies targeting the mobile devices used by public. As ICT installations expand, these existing structures provide an efficient and cost-effective foundation for small cell and air fibre, supporting enhanced connectivity, quicker deployments, and seamless integration into urban landscapes. The Telecom Regulatory Authority of India (TRAI) and the PM Gati Shakti National Master Plan recognize the potential of street furniture in, integrating digital connectivity into public infrastructure. Additionally, the *Telecommunications* (*Right of Way*) *Rules*, 2024, defines small cells as having a coverage range of up to 2 km, reinforcing their role in improving network reach

Further, under the PM Gati Shakti National Master Plan, 26.5 million units of street furniture have been mapped digitally to simplify planning, accelerate approvals, and reduce site survey timelines. This creates a ready-to-use foundation for 5G and future ICT infrastructure, helping embed digital connectivity into public infrastructure efficiently.

The guidelines for earmarking and use of street furniture are expected to be put in place by Department of Telecommunication (DoT)/TRAI in due course.

Some of the important aspects of use of street furniture which require consideration for effective ICT deployments are given below.

B-1.1 Structural and Positional Aspects

The aspects include, but are not limited to:

a) Load-bearing requirements to support equipment such as small cells and associated hardware;

b) Telecom equipment designs blend with urban aesthetics to avoid visual clutter;

c) Proximity to existing power sources;

d) Protection of pedestrian and vehicle traffic;

e) Public safety; and

f) Structural stability and safety considering the weight and required height for installation of equipment as well as sharing among service providers.

B-1.2 Administrative Aspects

The following aspects are applicable:

a) Easy right of way (RoW) for installation and maintenance and upgrades of the equipment;

b) Possibility of development of a GIS-mapped inventory of street furniture assets, detailing specifications like load capacity, power availability, and contact information for streamlined maintenance and coordination; and

c) Adherence to municipal guidelines and permissions for ICT installations on public or private street furniture.

ANNEX C

(*Clause* 3.5)

BUILDING RELATED INFORMATION AND DIGITAL CONNECTIVITY REQUIREMENTS

C-1 GENERAL INFORMATION

Sl No.	*Item*	*Description/ Response*
i)	Name of building/Project and address	
ii)	Property manager detail (name, contact etc)	
iii)	Type of building	
iv)	Number of floors (including parking floors)	
v)	Total built-up area (sq. meters)	
vi)	Total carpet area (*see* NOTE)	
vii)	Year of construction completion (it will same as occupancy certificate year)	
viii)	Building/Property layout	Attachment
ix)	Ownership type (owners/tenants/developer owned/shared space)	
x)	a) Occupancy classification: 1) Group A: Residential 2) Group B: Educational 3) Group C: Institutional b) Hospitals/Healthcare: 1) Group D: Assembly c) Public buildings: 1) Airports/Railway stations/Bus stands/Metro train stations/Taxi stands, etc d) Exhibition centers: 1) Group E: Business e) Commercial retail: f) Commercial office: 1) Group F: Mercantile 2) Group G: Industrial 3) Group H: Storage 4) Group I: Hazardous 5) Group J: Mixed-use buildings	
xi)	Projected date of completion	
NOTE — Digital connectivity coverage design will require all areas including open, lifts, corridors, underground parking floors, basement etc. Therefore, total area where mobile or Wi-Fi coverage is required will be important to capture.		

C-2 OCCUPANT/USER DETAILS

Sl No. (1)	*Item* (2)	*Description/Response* (3)
i)	Total number of units (flat, office etc)	
ii)	Estimated No. of occupants/ users	
iii)	Number of tenants/offices	
iv)	Occupant categories (residential, academic, business, public use etc)	

C-3 DIGITAL CONNECTIVITY REQUIREMENTS

Sl No. (1)	*Item* (2)	*Description/Response* (3)
i)	Number of internet and mobile service providers present in the area	
ii)	Expected number of internet connections per unit	
iii)	Typical internet speed requirements	
iv)	Number of devices (for example, mobile, tablets, laptop etc) per unit	
v)	Preference for neutral FTTx infrastructure (Yes or No)	
vi)	Need for redundant paths/Backup connectivity (Yes or No)	
vii)	Use of smart devices/Home automation (Yes or No)	
viii)	Cybersecurity requirements (Yes or No)	
ix)	IoT integration requirements (if any) (Yes or No)	
x)	Fibre connectivity requirement (Yes or No)	
xi)	Requirement of secure Wifi (Yes or No)	

C-4 INFRASTRUCTURE SUPPORT (APPLICABLE IN CASE OF EXISTING BUILDINGS)

Sl No. (1)	*Item* (2)	*Description/Response* (3)
i)	Centralized cable pathways availability	
ii)	Duct space and shaft accessibility and maintainability	
iii)	Existing server or telecommunication rooms	
iv)	Power backup with provision of uninterrupted power supply for ICT	

	Equipment in telecom room	
v)	Proposed upgrades (if any)	
vi)	Provision of future expansion (telecom Room, cable pathways, IoT etc)	
vii)	Provision of elevated structure for TI/Telecom room to address flood situations	
viii)	Redundant entry paths/Ducts for extending backhaul telecom connectivity by the service providers to the property	

Declaration

This information is collected for planning and designing telecommunication infrastructure. In case of unavailability of user-specific data, data from similar building typologies shall be used.

Signature of Property Manager/Owner: ________________________

Date: ______________

NOTE — It may be noted that in many cases, buildings or complexes are of mixed-use nature. The template provided for collecting building information may be used only as a reference document specifically for telecommunication infrastructure and services planning. The classification used in this template applies only to this section and has no relation to the occupancy classification given in any other part of this NBCS.

LIST OF STANDARDS

The following list records those standards which are acceptable as ‘good practice’ and ‘accepted standards’ in the fulfilment of the requirements of this NBCS. The latest version of a standard shall be adopted at the time of enforcement of this NBCS. The standards listed may be used for conformance with the requirements of the referred clauses in this NBCS.

In the following list, the number appearing in the first column within parentheses indicates the number of the reference in this Part/Section.

	IS No.	*Title*
(1)	IS 9537	Specification for conduits for electrical installations:
	(Part 2) : 1981	Rigid steel conduits
(2)	IS 9537	Specification for conduits for electrical installations:
	(Part 3) : 1983	Rigid plain conduits for insulating materials
	IS 3419 : 1988	Specification for fittings for rigid non-metallic conduits (*second revision*)
(3)	IS 9537	Conduits for electrical installations — Specification
	(Part 5) : 2000	Pliable conduits of insulating materials

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART E PLUMBING SERVICES
(INCLUDING SOLID WASTE MANAGEMENT)

SECTION 1 WATER SUPPLY

BUREAU OF INDIAN STANDARDS

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National Building Code Sectional Committee, CED 46

FOREWORD

This NBCS (Part E/Section 1) covers the requirements of water supply in buildings. The water supply provisions covered in this Section encompass the requirements of water supply, plumbing connected to public water supply, design of water supply systems, principles of conveyance and distribution of water within the premises, hot water supply system, inspection and maintenance of water supply systems. It also covers design of water supply systems in high altitudes and/or sub-zero temperature regions.

In the first version of the Code formulated in 1970, as part of the National Building Code of India, three separate sections of this Part on 'Plumbing Services' were brought out, namely, Section 1 'Water Supply', Section 2 'Drainage and Sanitation', and Section 3 'Gas Supply'. These sections were subsequently revised in 1983.

The major changes incorporated in the first revision in 1983 Section 1 Water Supply, were: Rationalization of definitions and addition of definitions for more terms; addition of universal pipe friction diagram and nomogram of Hazen and Willam's equation for discharge computation, deleting the discharge curves based on Chezy's formula; introduction of a detailed clause giving guidance on the design of water supply system for multi-storeyed buildings; modification to indicate that no separate storage need be provided for flushing and domestic purposes for health reasons and a single storage tank may be provided; modification/amplification of provisions relating to domestic hot water supply installations; introduction of a detailed clause covering recommendations to be considered while planning and designing water supply systems peculiar to high altitude and/or sub-zero temperature regions of the country; and addition of requirements relating to inspection, testing and maintenance applicable to hot water supply system.

As a result of experience gained in implementation of 1983 version of the Code and feedback received as well as revision of some of the standards based on which this Section was formulated, a need to revise this Section was felt then. The second revision of 2005 was therefore formulated to take care of these. In the revision, the erstwhile two sections were merged and a combined and comprehensive section, namely Section 1 Water supply, drainage and sanitation (including solid waste management), was brought out. Gas supply was brought out as Section 2. Following significant changes were incorporated in the second revision of Section 1 on water supply, drainage and sanitation, in respect to water supply: modification of provision of water supply requirement; addition of a new clause on water supply for other than residential purposes; addition of a new clause on quality of water, also including therein a sub-clause on waste water reclamation; modification of the provision regarding storage of water and introduction of guidelines for calculating storage capacity; modification, in the design of distribution system provisions for discharge computation, to include designed consumer pipes based on fixtures unit also taking into account probable simultaneous demand instead of earlier computation based on Reynold's Number; introduction of an alternative option of variable speed drive pumping system to hydro pneumatic system; addition of a new clause on backflow prevention; addition of provision for suitability of galvanized mild steel tanks on the basis of *p*H of the water; detailing of types of hot water heater; and restructuring of the section was done to make it more user friendly.

The second revision in 2005 also incorporated for the first time the provisions on solid waste management.

In the third revision in 2016, to address the various and distinct features related to the plumbing aspects and solid waste management comprehensively, this Part on 'Plumbing Services' was rearranged as follows:

Section 1 Water supply

Section 2 Drainage and sanitation

Section 3 Solid waste management

Section 4 Gas supply

The revision of Section 1 in 2016 incorporated several modifications; provisions on water supply requirements for buildings were related to the estimated occupancy in the chosen type of building; Table 1 on water requirements for buildings other than residences was updated concerning building types and included domestic and flushing requirements separately; water demand for landscaping purposes was included; requirements related to wastewater treatment and the usage of recycled wastewater were included; materials used for storage water tanks were updated; provisions regarding the quantity of water to be stored were revised; measures for protecting the water supply were included to prevent cross-connection between treated and raw water supplies, ensure backflow prevention, and secure identification of non-potable water supply pipes; the list of materials used for manufacturing pipes was updated; general requirements for the design of distribution systems were introduced; Table 2 on fixture units for different types of fixtures was updated; Table 3 on probable simultaneous demand was revised with demand values covering various intermediate and up to 10 000 fixture units, along with graphs for probable demand; maximum flow rate and flush volumes were specified; provisions concerning inadequate and excessive water pressure were introduced; guidance on water hammer effects was included; distribution system provisions for multi-storeyed buildings were updated with illustrations; provisions related to zoning of distribution systems were included; hot water supply systems were incorporated under the existing clause on hot water supply installations; detailed provisions for swimming pools were included; guidance on allowance for expansion of water pipes was provided; a new clause on colour coding for different types of water pipes was added; provisions were reviewed and updated to ensure accessibility for the elderly and persons with disabilities, duly giving cross-references to **13** of Part 3 'Development Control Rules and General Building Requirements'; certain terminologies were introduced and some were revised; and cross-references to Indian Standards were updated.

In this revision, this publication has been renamed as National Building Construction Standards (NBCS).

In this revision of the Section 1, the following significant changes have been incorporated:

a) Population requirements for residential buildings have been updated, in **4.1**;

b) Population requirement is introduced for warehouses and industrial occupancies, to arrive at their water demand;

c) Suggestive breakup of water for general consumption is included, in **4.1.1.1**;

d) Table 1 'Water requirements for buildings other than residences' now provides the quantity for various categories of hotels;

e) Storage requirement for hydro-pneumatic/pressurized water supply system have been included, in **4.4.10**; and

f) Terminology has been updated by including drinking water fountain, design flood elevation, demand recirculation water system, vacuum breaker, etc.

This Section is largely based on the following Indian Standards:

IS 1172 : 1993	Code of basic requirements for water supply, drainage and sanitation (*fourth revision*)
IS 2065 : 1983	Code of practice for water supply in buildings (*second revision*)
IS 6295 : 1986	Code of practice for water supply and drainage in high altitudes and or sub-zero temperature regions (*first revision*)
IS 7558 : 1974	Code of practice for domestic hot water installations
IS 12183 (Part 1) : 1987	Code of practice for plumbing in multi-storeyed buildings: Part 1 Water supply

A reference to SP 35 : 1987 'Handbook on water supply and drainage' may be useful, from where also, assistance has been derived.

All standards, whether given herein above or cross-referred to in the main text of this Section, are subject to revision. The parties to agreement based on this Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

In the formulation of this Section, reference has also been made to the following:

International Plumbing Code 2024, International Code Council, and

Uniform Plumbing Code 2024, International Association of Plumbing and Mechanical Officials

As the regulation of land development and buildings is a State subject and is dealt by the States and local bodies such as urban local bodies within their jurisdiction through building regulatory documents like building regulations, building byelaws, and fire regulations, this document is voluntary in nature and is non-binding. The implementation depends on adoption by concerned parties or stipulations in a contract or by appropriate adoption by the concerned authorities.

For the purpose of deciding whether a particular requirement of this Section is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 'Rules for rounding off numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this Section.

Important Explanatory Note for Users of this NBCS

In any Part/Section of this NBCS, where reference is made to **‘good practice’** in relation to design, constructional procedures or other related information, and where reference is made to **“accepted standard”** in relation to material specification, testing, or other related information, the Indian Standards listed at the end of the Part/Sec shall be used as a guide to the interpretation.

At the time of publication, the editions indicated in the standards were valid. All standards are subject to revision and parties to agreements based on any Part/Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

In the list of standards given at the end of a Part/Section, the number appearing within parentheses in the first column indicates the number of the reference of the standard in the Part/Section. For example:

a) Good practice [E-1(1)] refers to the Indian Standard(s) given at serial number (1) of the list of standards given at the end of this Part E/Section 1, that is, IS 10446 : 1983 ‘Glossary of terms relating to water supply and sanitation’.

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART E PLUMBING SERVICES
(INCLUDING SOLID WASTE MANAGEMENT)

SECTION 1 WATER SUPPLY

1 SCOPE

1.1 This Section covers the basic requirements of water supply for residential, business and other types of buildings, including traffic terminal stations. This Section also deals with general requirements of plumbing connected to public water supply and design of water supply systems along with general guidelines about expansion in piping systems, and swimming pools.

1.1.1 This Section does not take into consideration the requirements of water supply for industrial plants and processes, which have to be provided for separately. It also does not provide the requirements of water supply for other purposes, such as firefighting and street cleaning.

2 TERMINOLOGY

For the purpose of this Section, the following definitions shall apply in addition to the definitions given in accepted standard [E-1(1)].

2.1 Definitions Relating to Water Supply

2.1.1 *Access Panel* — A removable panel mounted in a frame, normally secured with screws and mounted in a wall or ceiling, to provide access to concealed valves or items which may require maintenance.

2.1.2 *Air Gap, Water Distribution* — Unobstructed vertical distance through the free atmosphere between the lowest opening from any pipe or faucet conveying water to a tank or plumbing fixture and flood level rim of the receptacle.

2.1.3 *Air Valve* — A valve that releases air from a pipeline automatically without loss of water or introduce air into a line automatically if the internal pressure becomes less than that of the atmosphere.

2.1.4 *Aspirator* — A device supplied with water or other fluid under positive pressure that passes through an integral orifice causing a vacuum. Aspirator is also referred as suction apparatus.

2.1.5 *Authority Having Jurisdiction* — The authority which has been created by a statute and which for the purpose of administering this NBCS/Part may authorize a committee or an official to act on its behalf; hereinafter called the 'Authority'.

2.1.6 *Available Head* — The head of water available at the point of consideration due to mains' pressure or overhead tank or any other source of pressure.

2.1.7 *Anti-siphon* — A device or mechanism to prevent siphonage.

2.1.8 *Backflow*

a) the flow of water or other liquids, mixtures or substances into the distributing pipes of a system of supply of potable water from any source or sources other than its intended source; and

b) the flow of a liquid in a direction reverse of that intended.

2.1.9 *Backflow Prevention Device* — Any approved measure or fitting or combination of fittings specifically designed to prevent backflow or back siphonage in a water service.

2.1.10 *Back Pressure Back Flow* — Due to an increased pressure above the supply pressure, which may be due to pumps, other equipment, gravity or other source of pressure.

2.1.11 *Back Siphonage* — The flowing back of used, contaminated, or polluted water from a plumbing fixture or vessel into a water supply due to a reduced pressure in such pipe (*see* **2.1.8**).

2.1.12 *Barrel* — This portion of a pipe in which the diameter and wall thickness remain uniform throughout.

2.1.13 *Base* — The lowest portion or lowest point of a stack of vertical pipe.

2.1.14 *Bath Room Group* — Group of fixtures consisting of water closet, lavatory, bath tub or shower and other fittings with a floor drain located together.

2.1.15 *Bedding* — The material on which the pipe is laid and which provides support for the pipe. Bedding can be concrete, granular material or the prepared trench bottom.

2.1.16 *Chair* — A bed of concrete or other suitable material on the trench floor to provide a support for the pipes at intervals.

2.1.17 *Channel* — The open waterway through which sewage, storm water or other liquid wastes flow at the invert of a manhole or an inspection chamber.

2.1.18 *Communication Pipe* — That part of a service pipe which vests in the water undertakes. It starts at the water main and terminate at a point which differs according to the circumstances of the case.

2.1.19 *Consumer* — Any person who uses or is supplied water or on whose application such water is supplied by the Authority.

2.1.20 *Consumer's Pipe* (*Service Pipe*) — The pipe taking up from the street main originating from the ferrule leading up to the water meter for supply of water to consumer. The portion of pipe used for service connection is not the property of the Authority (*see* Fig. 1).

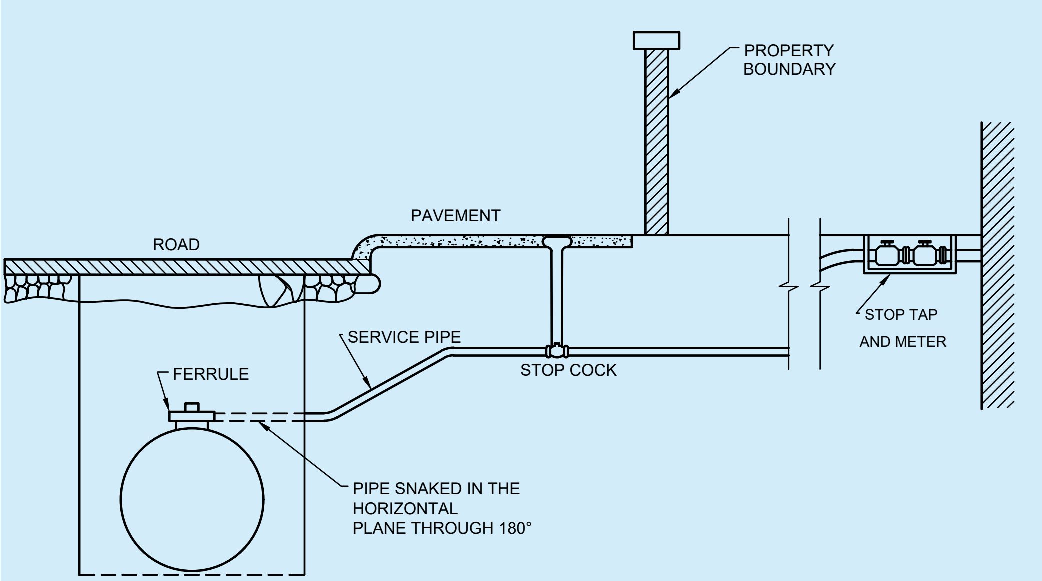


FIG. 1 CONSUMER'S PIPE CONNECTION

2.1.21 *Cover*

a) a removable plate for permitting access to a pipe, fitting, vessel or appliance; and

b) the vertical distance between the top of the barrel of a buried pipe or other construction and the surface of the ground.

2.1.22 *Cross-Connection* — Any physical connection or arrangement between the separate piping systems, one of which contains potable water and the other contains water of unknown or questionable safety, whereby water may flow from one system to the other, the direction of flow depending on the pressure differential between the two systems.

2.1.23 *Circulating Hot Water System —* A specifically designed hot water distribution system where one or more pumps are operated in the service hot water piping to circulate heated water from the water heating equipment to fixture supply and back to the water heating equipment

2.1.24 *Direct Tap* — A tap which is connected to a supply pipe and is subject to pressure from the water main.

2.1.25 *Demand Recirculation Water System —* A water distribution system within the built space where one or more pumps prime the service hot water piping with heated water upon a demand for hot water. Typically, this can be achieved by a timer or sensor.

2.1.26 *Design Flood Elevation* — The elevation of the 'design flood', including wave height, relative to the datum specified on the authorities legally designated flood hazard map. In areas designated as zone, the design flood elevation shall be the elevation of the highest existing grade of the building's perimeter plus the depth specified in the flood hazard map. In case the depth is not specified in the map the depth shall be taken as 610 mm.

2.1.27 *Drinking Water Fountain* — A plumbing fixture that is connected to the potable water distribution system and the drainage system. The fixture allows the user to obtain the potable water directly from a stream of flowing water without the use of any accessories.

2.1.28 *Down Take Tap* — A tap taken off from a storage tank situated at a higher elevation in the building.

2.1.29 *Effective Opening* — The minimum cross-sectional area at the point of water supply, measured or expressed in terms of,

a) the diameter of a circle; and

b) the diameter of a circle of equivalent cross-sectional area, if the opening is not circular.

2.1.30 *Feed Cistern* — A storage vessel used for supplying cold water to a hot water apparatus, cylinder or tanks.

2.1.31 *Fittings* — The appurtenances such as coupling, flange, branch, bend, tees, elbows, unions, waste (with or without plug), P or S trap (with or without vent), stop ferrule, bib tap, pillar tap, bath faucet, water meter, garden hydrant, valves and any other article used in connection with water supply, drainage and sanitation.

2.1.32 *Fixture Unit* — A quantity in terms of which the load producing effects on the plumbing system of different kinds of plumbing fixtures is expressed on some arbitrarily chosen scale.

2.1.33 *Float Operated Valve* — Ball valves or ball taps and equilibrium valves operated by means of a float.

2.1.34 *Flushing Cistern* — A cistern provided with a device for rapidly discharging the contained water and used in connection with a sanitary appliance for the purpose of cleaning the appliance and carrying away its contents into a drain.

NOTE — The nominal size of a cistern is the quantity of water discharged per flush.

2.1.35 *Flushometer Tank* — A tank integrated with an air accumulator vessel that is designed to discharge a predetermined quantity of water to fixtures for flushing purposes.

2.1.36 *Flow Pressure* — The pressure in the water supply pipe measured near the faucet or water outlet while the faucet or outlet is open or in use.

2.1.37 *Formation* — The finished level of the excavation at the bottom of a trench or heading prepared to receive the permanent work.

2.1.38 *Frost Line* — The line joining the points of greatest depths below ground level up to which the moisture in the soil freezes. Reference may be made to good practice [E-1(2)] for more details in this regard.

2.1.39 *General Washing Place* — A washing place provided with necessary sanitary arrangement and common to more than one tenement.

2.1.40 *Geyser* — An apparatus for heating water with supply control on the inlet side and delivering it from an outlet.

2.1.41 *Gridded Water Distribution System* — A water distribution system where every water distribution pipe is interconnected to provide two or more path to each fixture supply line.

2.1.42 *Haunching* — Outward sloping concrete support to the sides of a pipe or channel above the concrete bedding.

2.1.43 *Heel Rest Bend or Duck-Foot Bend* — A bend, having a foot formed integrally in its base, used to receive a vertical pipe.

2.1.44 *High Altitudes* — Elevations higher than 1 500 m above mean sea level (MSL).

2.1.45 *Highway Authority* — The public body in which is vested, or which is the owner of, a highway repairable by the inhabitants collectively; otherwise the body or persons responsible for the upkeep of the highway.

2.1.46 *Horizontal Pipe* — Any pipe of fitting which makes an angle of more than 45° with the vertical.

2.1.47 *Hot Water Tank* — A vessel for storing hot water under pressure greater than atmospheric pressure.

2.1.48 *Hydro-pneumatic System* — The water supply pumping system which operates automatically in conjunction with pump(s), pressure vessel and pressure switch.

2.1.49 *Junction Pipe* — A pipe incorporating one or more branches.

2.1.50 *Lagging* — Thermal insulation or pipes.

2.1.51 *Licensed* (*or Registered*) *Plumber* — A person licensed (or registered) under the provisions of this NBCS.

2.1.52 *Offset* — A pipe fitting used to connect two pipes whose axes are parallel but not in line.

2.1.53 *Period of Supply* — The period of the day or night during which water supply is made available to the consumer.

2.1.54 *Pipe Work* — Any installation of piping with its fittings.

2.1.55 *Plumbing*

a) the pipes, fixtures and other apparatus inside a building for bringing in the water supply and removing the liquid and water borne wastes; and

b) the installation of the foregoing pipes, fixtures and other apparatus.

2.1.56 *Plumbing System* — The plumbing system shall include the water supply and distribution pipes; plumbing fittings and traps; soil, waste, vent pipes and anti-siphonage pipes; building drains and building sewers including their respective connections, devices and appurtenances within the property lines of the premises; and water-treating or water-using equipment.

2.1.57 *Potable Water* — Water which is satisfactory for drinking, culinary and domestic purposes and meets the requirements of the Authority.

2.1.58 *Premises* — Premises shall include passages, buildings and lands of any tenure, whether open or enclosed, whether built on or not, and whether public or private in respect of which a water rate or charge is payable to the Authority or for which an application is made for supply of water.

2.1.59 *Pressure Balancing Valve* — Mixing valve that senses incoming hot and cold water pressures and compensates for fluctuations.

2.1.60 *Residual Head* — The head available at any particular point in the distribution system.

2.1.61 *Residual Pressure* — The pressure available at the fixture after allowance is made for pressure drop due to friction loss and head in the system during maximum demand periods.

2.1.62 *Saddle* — A purpose made fitting, so shaped as to fit over a hole cut in a sewer or drain used to form connections.

2.1.63 *Static Pressure* — The pressure exerted by a fluid that is not moving or flowing.

2.1.64 *Stop-Cock* — A cock fitted in a pipe line for controlling the flow of water.

2.1.65 *Stop Tap* — Stop tap includes stop-cock, stop valve or any other device for stopping the flow of water in a line or system of pipes at will.

2.1.66 *Storage Tank* — A container used for storage of water which is connected to the water main or tube-well by means of supply pipe.

2.1.67 *Studio Apartment* — An apartment unit consisting of a single room and a bathroom, the single room functioning as living room, bedroom and kitchen.

2.1.68 *Subsoil Water* — Water occurring naturally in the subsoil.

2.1.69 *Subsoil Water Drain*

a) a drain intended to collect and carry away subsoil water; and

b) a drain intended to disperse into the subsoil from a septic tank.

2.1.70 *Sub-zero Temperature Regions* — Regions where temperatures fall below 0 °C and freezing conditions occur.

2.1.71 *Supply Pipe* — The water pipe that is owned by the owner of the building and lies within the boundary of the property. It connects via the communication pipe to the water main.

2.1.72 *Supports* — Hangers and anchors or devices for supporting and securing pipe and fittings to walls, ceilings, floors or structural members.

2.1.73 *Surface Water* — Natural water from the ground surface, paved areas and roofs.

2.1.74 *Surface Water Drain* — A drain conveying surface water including storm water.

2.1.75 *Thermostatic/Pressure Balancing Valve* — Mixing valve that senses outlet temperature and incoming hot and cold water pressure and compensates for fluctuations for stabilization.

2.1.76 *Vertical Pipe* — Any pipe or fitting which is installed in a vertical position or which makes an angle or not more than 45° with the vertical.

2.1.77 *Vacuum Breaker* — Type of back flow preventer installed on openings subject to normal atmospheric pressure that prevents back flow by admitting atmospheric pressure through ports to the discharge side of device.

2.1.78 *Warning Pipe* — An overflow pipe so fixed that its outlet, whether inside or outside a building, is in a conspicuous position where the discharge of any water there from can be readily seen.

2.1.79 *Wash-Out Valve* — A device located at the bottom of the tank for the purpose of draining a tank for cleaning, maintenance, etc.

2.1.80 *Water Hammer Arrestor* — A device designed to provide protection against hydraulic shock in the building water supply system.

2.1.81 *Water Main* (*Street Main*) — A pipe laid by the water undertakers for the purpose of giving a general supply of water as distinct from a supply to individual consumers and includes any apparatus used in connection with such a pipe.

2.1.82 *Water Outlet* — A water outlet, as used in connection with the water distributing system, is the discharge opening for the water: (a) to a fitting; (b) to atmospheric pressure (except into an open tank which is part of the water supply system); and (c) to any water-operated device or equipment requiring water to operate.

2.1.83 *Water Supply System* — Water supply system of a building or premises consists of the water service pipe, the water distribution pipes, and the necessary connecting pipes, fittings, control valves, and all appurtenances in or adjacent to the building or premises.

2.1.84 *Waterworks* — Waterworks for public water supply include a lake, river, spring, well, pump with or without motor and accessories, reservoir, cistern, tank, duct whether covered or open, sluice, water main, pipe, culvert, engine and any machinery, land, building or a thing used for storage, treatment and supply of water.

2.1.85 *Wholesome Water* — Water that is safe and suitable for drinking, cooking, and other domestic purposes and free from harmful microorganisms and chemical contaminants, meets regulatory quality standards, and has a pleasant taste.

2.2 Definitions Relating to Swimming Pool

2.2.1 *Appurtenance* — An accessory facility or feature at a swimming pool, such as a diving board, slide, wading pool, plunge pool, spray pool.

2.2.2 *Bather Load* — The maximum number of persons that may be allowed in the pool area at one time without creating undue health or safety hazards.

2.2.3 *Deep Area* — An area of a swimming pool in which the water depth exceeds five feet.

2.2.4 *Diving Pool* — A pool designed and intended for use exclusively for diving.

2.2.5 *Inlet* — An opening or fitting through which filtered water enters the pool.

2.2.6 *Main Drain* — The outlet or outlets for drain provided in the pool.

2.2.7 *Make-up Water* — The water added to a pool to replace that which is lost.

2.2.8 *Pool* — A swimming pool or other recreational water basin utilized in conjunction with or as an appurtenance to a swimming pool.

NOTE — The term does not refer to spas and therapy pools not designed or intended for swimming or to basins for individual use that are drained after each use.

2.2.9 *Pool Depth* — The vertical distance between the pool floor and the water level.

2.2.10 *Shallow Area* — An area in a swimming pool, in which the water depth does not exceed 1.5 m at any point.

2.2.11 *Skimmer* — A mechanical device connected to the recirculation piping which is used to skim the pool surface.

2.2.12 *Swimming Pool User Load* — The number of bathers using the pool in a 24 h period for which a certain per capita capacity is often considered.

NOTE — The capacity of a swimming pool in terms of its user load is dictated by the capacity of water treatment equipment.

2.2.13 *Transition Point* — A location in a shallow area of a swimming pool where an area, having a floor slope of no more than 300 mm vertical in 3.65 m horizontal, adjoins an area where the floor slope exceeds 1 in 12.

2.2.14 *Turnover Period* — The time required to recirculate a volume of water equivalent to the water volume of the pool through the filtration system.

2.2.15 *Wading Pool* — A pool having a maximum water depth not exceeding 76 cm.

2.2.16 *Water Level* — The level of the overflow lip of a perimeter overflow system or the mid-level of surge weirs, if present, or the mid-level of the skimmer operating range.

2.2.17 *Zero-Depth Edge* — That portion of the perimeter of a zero-depth pool where the pool floor intersects the pool water surface.

2.2.18 *Zero-Depth Pool* — A swimming pool where the pool floor intersects the water surface along a portion of its perimeter.

3 GENERAL

3.1 Basic Principles

The design of water supply takes the following into consideration:

a) number of occupants;
b) minimum water requirements for different purposes;
c) treatment of water based on the quality of water;
d) quantity of water stored; and
e) sizing of pipes.

The basic principles of water supply, drainage and sanitation are given below, and the design of water supply should in general be guided by the applicable principles.

3.1.1 *Potable Water*

All premises intended for human habitation, occupancy, or use shall be provided with supply of potable water. This water supply shall not be connected with unsafe water resources, nor shall it be subject to the hazards of backflow.

3.1.2 *Water Provision*

Plumbing fixtures, devices and appurtenances shall be provided with water in sufficient volume and at pressures adequate to enable them to function properly and without undue noise under normal conditions of use.

There should be at least a residual head of 0.018 N/mm^2 (0.18 bar) at the consumer's tap. There may be certain fixtures or appliances in the installation that may require a higher pressure, such as 0.05 N/mm^2 (0.5 bar) or even higher pressure [such as 0.1 N/mm^2 (1.0 bar) in case of flush valves], in which case the system shall be designed using pumps, tanks or both to achieve the required minimum pressure.

NOTE — The residual head shall be taken at the highest/farthest outlets in the building.

3.1.3 *Water Efficiency*

Plumbing system shall be designed, installed and adjusted to use the optimum quantity of water consistent with proper performance and cleaning.

3.1.4 *Safety Devices*

Plumbing system shall be designed and installed with safety devices to safeguard against dangers from contamination, explosion, overheating, etc.

3.1.5 *Minimum Water Amenities*

It is recommended that each dwelling unit should have at least one water closet, one lavatory, one kitchen wash place or a sink, and one bathing place or shower to meet the basic requirements of sanitation and personal hygiene.

In case of a group housing, the requirements relating to toilet or sanitary room and kitchen as given in good practice [E-1(3)] shall also be complied with.

3.1.6 *Drainage System*

The drainage system shall be designed, installed and maintained to guard against fouling, deposit of solids and clogging and with adequate cleanouts so arranged that the pipes may be readily cleaned.

3.1.7 *Materials and Workmanship*

The plumbing system shall have durable material, free from defective workmanship and so designed and installed as to give satisfactory service for its reasonable expected life. The accessories of the plumbing system should be of such specifications as to meet the functional requirements of the installation, so as to also avoid any inconsistency leading to leakage and resultant seepage.

3.1.8 *Fixture Traps and Ventilating Pipes*

Each fixture directly connected to the drainage system shall be equipped with a liquid seal trap. Trap seals shall be maintained to prevent sewer gas, other potentially dangerous or noxious fumes, or vermin from entering the building. Further, the drainage system shall be designed to provide an adequate circulation of air in all pipes with no danger of siphonage, aspiration, or forcing of trap seals under conditions of ordinary use by providing ventilating pipes throughout the system.

3.1.9 *Foul Air Exhaust*

Each vent terminal shall extend to the outer air and be so installed as to minimize the possibilities of clogging and the return of foul air to the building, as it conveys potentially noxious or explosive gases to the outside atmosphere. All ventilating pipes shall be provided with a cowl.

3.1.10 *Testing*

The plumbing system shall be subjected to required tests to effectively disclose all leaks and defects in the work or the material.

3.1.11 *Exclusion from Plumbing System*

No substance that will clog or accentuate clogging of pipes, produce explosive mixtures, destroy the pipes or their joints, or interfere unduly with the sewage-disposal process shall be allowed to enter the drainage system.

3.1.12 *Light and Ventilation*

Wherever water closet or similar fixture is located in a room or compartment, it should be properly lighted and ventilated.

3.1.13 *Individual Sewage Disposal Systems*

If water closets or other plumbing fixtures are installed in buildings where connection to public sewer is not possible, suitable provision shall be made for acceptable treatment and disposal.

3.1.14 *Maintenance*

Plumbing systems shall be maintained in a safe and serviceable condition.

3.1.15 *Approach for Use and Cleaning*

All plumbing fixtures shall be so installed with regard to spacing as to be approachable for their intended use and for cleaning. All doors, windows and any other device needing access within the toilet shall be so located that they have proper approach.

3.1.16 *Accessibility for Persons with Disabilities*

All doors, windows and fixtures, including WC, urinals, grab bars, washbasin, mirror and all other accessories for use by persons with disabilities shall be so installed/located that they have proper access with appropriate width, height, space, centrelines, and ease of operation {*see* good practice [E-1(3)]}.

3.1.17 *Structural Safety*

Plumbing system shall be installed with due regard to preservation of the structural members and prevention of damage to walls and other surfaces.

3.1.18 *Protection of Ground and Surface Water*

Sewage or other waste shall not be discharged into surface or sub-surface water without acceptable form of treatment.

3.2 Water Supply Connection

3.2.1 *Application for Obtaining Supply Connection*

Every consumer, requiring a new supply of water or any extension or alteration to the existing supply shall apply in writing in the prescribed form (*see* Annex A) to the Authority.

3.2.2 *Bulk Supply*

In the case of large housing colonies or campuses, or where new services are so situated that it will be necessary for the Authority to lay new mains or extend an existing main, full information about the proposed scheme shall be furnished to the Authority. Information shall also be given regarding their phased requirements of water supply with full justification. Such information shall include site plans, showing the layout of roads, footpaths, building and boundaries and indicating thereon the finished line and level of the roads or footpaths and water supply lines and appurtenances.

3.2.3 *Completion Certificate*

On completion of the plumbing work for the water supply system, the licensed/registered plumber shall give a completion certificate in the prescribed form (*see* Annex B) to the Authority for getting the water connection from the mains.

3.3 Licensing/Registration of Plumbers

3.3.1 *Execution of Work*

The work which is required to be carried out under the provisions of this Section, shall be executed only by a licensed/registered plumber under the control of the Authority and shall be responsible to carry out all lawful directions given by the Authority. No individual shall engage in the business of plumbing unless so licensed/registered under the provisions of this Section.

3.3.1.1 No individual, firm, partnership or corporation shall engage in the business of installing, repairing or altering plumbing unless the plumbing work performed in the course of such business is under the direct supervision of a licensed/registered plumber.

3.3.2 *Examination and Certification*

The Authority shall establish standards and procedure for the qualification, examination and licensing/registration of plumbers and shall issue licences to such persons who meet the qualifications thereof and successfully pass the examination.

3.3.3 For guidelines for registration of plumbers including the minimum standards for qualifications for the grant of licences/registration, reference may be made to good practice [E-1(4)]. The Authority may also utilize the services of the certified plumbers who are certified for the required skill level under the appropriate scheme of the Government.

4 WATER SUPPLY

4.1 Water Supply Requirements for Buildings

The total quantity of water per day is estimated based on the proposed occupancy and activities catered. Designer has to identify all the possible sources for augmenting the shortfall in water supply. The analysis of available water is done to decide the treatment for consumption and treatment process depends on the quality of water and the purpose for which it is used.

Projection of population for each building shall be made on the basis of its usage. Population for each type of building shall be estimated on the basis of information obtained from the users. Alternatively, population may be worked on the following basis, for different type of buildings:

a) *Residential buildings*

Sl No. (1)	*Accommodation* (2)	*Population Requirements* (3)
i)	1 bedroom dwelling unit	3
ii)	2 bedroom dwelling unit	4
iii)	3 bedroom dwelling unit	5
iv)	4 bedroom dwelling unit and above	6

NOTES

1 The above figures consider a domestic household including support personnel, wherever applicable.

2 For plotted development, the population may be arrived at after due consideration of the expected number and type of domestic household units.

3 Dwelling unit under EWS category shall have population requirement of 4 and studio apartment shall have population requirement of 2.

b) *Other than residential buildings*

Sl No. (1)	*Occupancy* (2)	*Population Requirement* (3)
i)	Offices	1 person per 10 m^2 of floor area (*see* Note 1)
ii)	Schools	Strength of school + teaching and non-teaching staff
iii)	Hostels	Number of beds + 4.5 × (warden's residence) + staff
iv)	Hotels	Number of beds + staff + requirement of restaurant seats
v)	Hospitals	Number of beds + staff + patient attendants (generally population density per bed in secondary care hospital is 5, tertiary care is 7 and quaternary care is 9)
vi)	Mercantile	1 person per 3 m^2 of street floor and sales basement areas + 1 person per 6 m^2 of upper sale floors (Total population may be segregated into 10 percent for fixed and 90 percent for floating/visitors)

Sl No. (1)	*Occupancy* (2)	*Population Requirement* (3)
vii)	Traffic terminal stations	Average number of users per day (Total annual passenger traffic/365) + Staff + Vendors
viii)	Ware house	1 person per 20 m^2 of floor area (*see* Note 1)
ix)	Industrial/Hazardous	1 person per 10 m^2 of floor area
x)	Storage	1 person per 30 m^2 of floor area
xi)	Assembly (*maximum should be as per Part F 'Fire and Life Safety' of this NBCS*).	
	a) Concentrated use without fixed seating	1 person per 0.65 m^2 of floor area
	b) Less concentrated use without fixed seating	1 person per 1.2 m^2 of floor area
	c) Fixed seating	1.2 × Number of fixed seats
	d) Dining area and restaurants with seating and tables	1 person per 1.8 m^2 of floor area

NOTES

1 Wherever there are multiple work shifts, the number of users within a 24 h period may be considered as per actuals.

2 Population of 5 percent to 15 percent, depending on the usage of building, shall be considered for visitors and floating population likely to use the building's facilities.

4.1.1 Water *Supply for Residences*

A minimum of 70 litre to 100 litre per head per day may be considered adequate for domestic and flushing needs of urban communities (which varies based on type of building occupancy). As a general rule the following rates per capita per day may be considered for domestic and non-domestic needs:

a) For urban communities: 135 LPCD

b) For urban communities using water efficient fixtures in buildings: 100 LPCD (*see* Note 1)

c) For rural communities, water demand of 70 LPCD may be considered including 15 LPCD as flushing water demand.

NOTES

1 For buildings using water efficient fixtures, reference may be made to accepted standard [E-1(5)].

2 Usage of high flow or high pressure fixtures is not recommended from the point of view of water conservation and sustainable development.

4.1.1.1 Out of the per capita demand as mentioned in 4.1.1 (a) and 4.1.1 (b), 30 litre per head per day shall be taken for flushing requirements and the remaining quantity for other domestic purposes. The following depicts the general breakdown of the water consumption in residential buildings:

Sl No. (1)	*Description* (2)	For Urban Communities (*Residential*) (3)	For Urban Communities Using Water Efficient Fixtures (*Residential*) (4)
i)	Drinking	5	5
ii)	Bathing (*Suggested cold and hot water is 60:40*)	35	25
iii)	Cooking	10	5
iv)	Washing utensils	20	15

Sl No. (1)	*Description* (2)	For Urban Communities (*Residential*) (3)	For Urban Communities Using Water Efficient Fixtures (*Residential*) (4)
v)	Floor cleaning	10	5
vi)	Washing clothes	25	15
	Total	**105**	**70**

4.1.2 *Water Supply for Buildings Other than Residences*

Minimum requirements for water supply for buildings other than residences shall be in accordance with Table 1.

The water demand for the laboratory facilities will depend on actual requirements based on functional point of view.

Table 1 Water Requirements for Buildings Other than Residences
(*Clause* 4.1.2 *and* 4.1.3)

Sl No. (1)	**Type of Building** (2)	**Domestic per Day** litre (3)	**Flushing per Day** litre (4)	**Total Consumption per Day** litre (5)
i)	Factories including canteen where bathrooms are required to be provided	30 per head	15 per head	45 per head
ii)	Factories including canteen where no bathrooms are required to be provided	20 per head	10 per head	30 per head
iii)	Hospital (excluding laundry and kitchen) (*see* Note 2):			
	a) Number of beds not exceeding 100	a) 230 per bed	a) 110 per bed	a) 340 per bed
	b) Number of beds exceeding 100	b) 300 per bed	b) 150 per bed	b) 450 per bed
	c) Outpatient department (OPD)	c) 10 per bed	c) 5 per bed	c) 15 per bed
	d) Hospital with secondary care			d) 800 per bed
	e) Super speciality hospital			e) 950 per bed
iv)	Nurses’ homes and medical quarters	90 per head	45 per head	135 per head
v)	Hostels	90 per head	45 per head	135 per head
vi)	Hotel (up to 3 star) excluding laundry, kitchen, staff and water bodies without bathtub (*see* Note 7)	120 per head	60 per head	180 per head
vii)	Hotel (4 Star and above) excluding laundry, kitchen, staff and water bodies and excluding bathtub (*see* Note 7)	260 per head	60 per head	320 per head
viii)	Hotel with bathtub (*see* Note 7)	320 per head	60 per head	380 per head
ix)	Banquet area	30 per head	15 per head	45 per head
x)	Health club			
	a) with shower	25 per head	20 per head	45 per head
	b) without shower	15 per head	10 per head	25 per head

Table 1 Water Requirements for Buildings Other than Residences

(*Clause* 4.1.2 *and* 4.1.3)

Sl No. (1)	Type of Building (2)	Domestic per Day litre (3)	Flushing per Day litre (4)	Total Consumption per Day litre (5)
xi)	Indoor Sports Facility	10 per head	5 per head	15 per head
xii)	Offices (including canteen)	25 per head	20 per head	45 per head
xiii)	Restaurants and food court including water requirement for kitchen:			
	a) Restaurants	55 per seat	15 per seat	70 per seat
	b) Food court	25 per seat	10 per seat	35 per seat
xiv)	Clubhouse	25 per head	20 per head	45 per head
xv)	Cinemas, concert halls and theatres and multiplex	5 per seat	10 per seat	15 per seat
xvi)	Schools/Educational institutions:			
	a) Without boarding facilities	a) 25 per head	a) 20 per head	a) 45 per head
	b) With boarding facilities	b) 90 per head	b) 45 per head	b) 135 per head
xvii)	Shopping and retail (mall)			
	a) Staff	25 per head	20 per head	45 per head
	b) Visitors	5 per head	10 per head	15 per head
xviii)	Traffic terminal stations (*see* Notes 3 and 4)			
	a) Airports	40 per head	30 per head	70 per head
	b) Railway stations (Junctions) with bathing facility	40 per head	30 per head	70 per head
	c) Railway stations (Junctions) without bathing facility	30 per head	15 per head	45 per head
	d) Railway Stations (Intermediate) with bathing facility	25 per head	20 per head	45 per head
	e) Railway Stations (Intermediate) without bathing facility	15 per head	10 per head	25 per head
	f) Interstate bus terminals	25 per head	20 per head	45 per head
	g) Intrastate Bus Terminals/Metro Stations/ High speed rail stations	10 per head	5 per head	15 per head

NOTES

1 For calculating water demand for visitors, consumption of 15 litre per head per day may be taken.

2 The water demand includes requirements of patients, attendants, visitors and staff. Additional water demand for kitchen, laundry and clinical water shall be computed as per actual requirements.

3 The number of persons shall be determined by the average number of passengers handled by stations, with due consideration given to the staff and vendors who are using these facilities.

4 Consideration should be given to seasonal average peak requirements.

5 The hospitals may be categorized as Category A (25 to 50 beds), Category B (51 to 100 beds), Category C (101 to 300 beds), Category D (301 to 500 beds) and Category E (501 to 750 beds).

6 Total water demand can be reduced by 25 percent if the building is equipped with 100 percent 3-star rated fixtures and fittings as per good practice [E-1(5)].

7 Bathtub water volume may be considered additionally based on size

4.1.3 *Water Supply Requirements of Traffic Terminal Stations*

The water supply requirements of traffic terminal stations (railway stations, bus stations, harbours, airports, etc) include provisions for waiting rooms and waiting halls. They do not, however, include requirements for retiring rooms. Requirements of water supply for traffic terminal stations shall be as per Table 1.

4.1.4 *Water Supply for Firefighting Purposes*

4.1.4.1 Provisions shall be made to meet the water supply requirements for firefighting in the city/area, depending on the population density and types of occupancy. *See also* Part F 'Fire and Life Safety' of this NBCS.

4.1.4.2 Provisions shall be made for water supply requirements for firefighting purposes within the building, depending upon the height and occupancy of the building. *See also* Part F 'Fire and Life Safety' of this NBCS.

4.1.4.3 Provisions shall be made regarding water supply in storage tanks, capacity of fire pumps, arrangements of wet riser-cum-down comer and wet riser installations for buildings, depending upon the occupancy use and other factors as applicable. *See also* Part F 'Fire and Life Safety' of this NBCS.

4.1.5 *Water Supply for Other Purposes*

4.1.5.1 Water supply in many buildings is also required for many other applications other than domestic use, which shall be identified in the initial stages of planning so as to provide the requisite water quantity, storage capacity and pressure as required for each application. In such instances information about the water use and the quality required may be obtained from the users. Some typical uses other than domestic use and firefighting purposes are air conditioning, swimming pools and water bodies, and gardening. Treated water from sewage treatment plant, with suitable tertiary treatment, should be used for flushing purpose (with dual piping system), gardening purpose, cooling tower make up, and/or for other non-potable usage.

4.1.5.2 The water demand for landscaping purposes is generally taken as 6 litre/m^2/day to 8 litre/m^2/day for lawns. For shrubs and trees the above value can be reduced considerably.

4.2 Water Sources and Quality

4.2.1 *Sources of Water*

The origin of all sources of water is rainfall. Water can be collected as it falls as rain before it reaches the ground; or as surface water when it flows over the ground or is pooled in lakes or ponds; or as ground water when it percolates into the ground and flows or collects as ground water; or from the sea.

Contamination of water supplies can occur in the source water as well as in the distribution system after water treatment has already occurred. There are many sources of water contamination, including naturally occurring chemicals and minerals (for example, arsenic, radon, uranium), local land use practices (fertilizers, pesticides, concentrated animal feeding operations), manufacturing processes, and sewer overflows or wastewater releases. The presence of contaminants in water can lead to adverse health effects, including gastrointestinal illness, reproductive problems, and neurological disorders.

4.2.2 The water supplied shall be free from pathogenic organisms, clear, free from undesirable taste and odour, neither corrosive nor scale forming and free from minerals which could produce undesirable physiological effects. The quality of water to be used for drinking shall be as per accepted standard [E-1(6)].

4.2.3 For purposes other than drinking, water if supplied separately, shall be absolutely safe from bacteriological contamination so as to ensure that there is no danger to the health of the users due to such contaminants.

For purposes other than drinking, where there is an overall risk of legionella growth, it is advisable that for cold water supplies, the temperature does not exceed 20 °C and a minimum temperature of 50 °C for hot water supplies be maintained at all points of network so as to ensure that it is absolutely safe from bacteriological contamination and there is no danger to the health of the users due to such contaminants.

4.2.4 *Waste Water Reclamation*

Treated sewage or other waste water of the community may be utilized for non-domestic purposes such as water for flushing, landscape irrigation, cooling towers of HVAC system, in fountains and recreational lakes where swimming is not allowed, and for certain industrial purposes after its necessary treatment to suit the nature of the use. This supply system shall be allowed in residences only if proper provision is made to avoid any cross-connection of this treated waste water with domestic water supply system for which it is recommended to use dual piping system.

4.2.4.1 *Treatment of waste water and usage of recycled water*

Waste water is generated by residential and other establishments like institutional, business, mercantile and industrial. It includes household waste liquid from toilets, baths, showers, kitchens and sinks that is disposed of *via* sewers. Waste water treatment is the process of removing contaminants from wastewater, including household sewage and runoff (effluents). It includes physical, chemical, and biological processes to remove contaminants. Treatment of waste water and usage of recycled waste water may be done to make it usable for appropriate applications. The objective is to produce an environmentally safe fluid waste stream (or treated effluent) and a solid waste (or treated sludge) suitable for disposal or reuse.

Separation of household waste into grey water and black water (and draining of black water into sewerage system) is becoming more common with grey water being permitted to be used for watering plants or recycled for flushing toilets after proper treatment. Waste water collection and treatment is typically subject to statutory regulations. Treatment depends on the characteristics of influent and the treatment requirements that are needed for treating the same. Waste water treatment generally involves the following three stages:

a) *Primary treatment* — It consists of temporarily holding the wastewater for settlement of heavy solids at the bottom while oil, grease and lighter solids float to the surface;

b) *Secondary treatment* — It removes dissolved and suspended biological matter; and

c) *Tertiary treatment* — It is more intensive treatment done in order to allow rejection into a highly sensitive or fragile ecosystem. The tertiary treatment is generally followed by disinfection.

4.2.5 *Water Conservation, Water Balance and Use of Recycled Water*

Water conservation encompasses the policies, strategies and activities to manage fresh water as a sustainable resource, to protect the water environment and to meet current and future demand. Population, household size, and growth and affluence all affect the quantity of water used. Water balance studies should be carried out to study the availability of water from different sources and its usage for different purposes.

4.2.6 Whenever a building is used after long intervals, the water quality of the stored water shall be checked so as to ensure that the water is safe for use as per water quality requirements specified in this NBCS.

4.3 Estimate of Demand Load

4.3.1 Estimates of total water supply requirements for buildings shall be based on the occupant load consistent with the provisions of **4.1**.

4.3.2 In making assessment of water supply requirements of large complexes, the future occupant load shall be kept in view. The following methods may be used for estimating future requirements:

a) demographic method of population projection;

b) arithmetic progression method;

c) geometrical progression method;

d) method of varying increment or incremental increase;

e) logistic method;

f) graphical projection method; or

g) graphical comparison method.

4.4 Storage of Water

4.4.1 In a building, provision is required to be made for storage of water for the following reasons:

a) to provide against interruptions of the supply caused by repairs to mains, etc;

b) to reduce the maximum rate of demand on the mains;

c) to tide over periods of intermittent supply; and

d) to maintain storage for the firefighting requirement of the building (taking into consideration the water for sprinklers and hydrants separately, apart from domestic water requirements).

4.4.2 The water may be stored in overhead tanks (OHT) and/or underground tanks (UGT).

4.4.3 *Materials Used*

Reservoirs and tanks for the storage of water shall be constructed of reinforced concrete, brick masonry, ferrocement, mild steel, stainless steel, or plastic or glass reinforced panels.

4.4.3.1 Tanks made of steel may be of welded, riveted or panel/pressed construction. The metal shall be galvanized or coated externally with a good quality anti-corrosive weather-resisting paint. Lead-based paint shall not be used in the tank. Lead-lined tanks shall not be used. Rectangular pressed steel tanks shall conform to good practice [E-1(7)].

4.4.4 Each tank shall be provided with the following:

a) *Manholes* — Adequate number of manholes for access and repair. The manholes shall be made of corrosion resistant material (for example, cast iron, reinforced cement concrete, steel fibre reinforced concrete, galvanized steel, high density polyethylene, fibre glass reinforced plastic or such other materials) acceptable to the Authority. Manholes shall be provided with locking arrangement to avoid misuse and tampering;

b) *Ladders* — Tanks higher than 900 mm deep shall be provided with corrosion resistant ladders according to the depth to enable a person to reach the bottom of the tank;

c) *Overflow pipe* — Each tank shall be provided with an overflow pipe terminating above the ground/terrace level to act as a 'Warning Pipe' to indicate overflow conditions. The size of the overflow pipe shall be adequate to accept the flow. Normally the overflow pipe size shall be one size higher than the inlet pipe. When the inlet pipe diameter is large, two or more overflow pipes of equivalent cross-section may be provided;

d) *Vent pipes* — Tanks larger than 5 000 litre capacity shall be provided with vent pipes to prevent development pressure in the tank which might result in 'NO FLOW' condition or inward collapse of the tank;

e) *Scour pipe* — Each tank shall be provided with a scour pipe with an accessible valve for emptying the tank

f) *Connection of overflow and scour pipe* — Under no circumstances tank overflow and scour pipe shall be connected to any drain, gully trap or manhole to prevent back flow and contamination of the water. All such connections shall be discharged over a grating with an air gap of 50 mm. All overflow and vent pipes shall be provided with a mosquito proof brass grating to prevent ingress of mosquito, vermin and other insects;

g) The top slab of the tank shall be suitably sloped away from its centre for proper drainage of the rainwater; and

h) Tanks on terraces and above ground shall be supported by appropriate structural members so as to transfer the load of the tank and the water directly on the structural members of the building.

4.4.5 Every storage tank shall be easily accessible and placed in such a position as to enable thorough inspection and cleaning to be carried out. If the storage capacity required is more than 5 000 litre, it is advantageous to arrange it in a series of tanks so interconnected that each tank can be isolated for cleaning and inspection without interfering with the supply of water. In large storage tanks, the outlet shall be at the end opposite the inlet to avoid stagnation of the water.

4.4.6 The outlet pipe shall be fixed 50 mm to 75 mm above the bottom of the tank and fitted with a strainer, preferably of brass.

4.4.7 In the case of underground storage tanks, the design of the tank shall be such as to provide for the draining of the tank when necessary and water shall not be allowed to collect around the tank. The tank shall be perfectly water-proof and shall be provided with a cement concrete cover, having a manhole opening, with a properly fitting hinged cast iron cover on a leak-proof cast iron frame.

The underground tanks should not be located in low lying areas or near any public or private sewer, septic tank, leaching pool or soakage pit to prevent any contamination. The overflow of the tank should be well above (preferably 600 mm) the external surface level and terminate as a warning pipe with a mosquito proof grating. Care shall be taken to prevent backflow of local surface water into the tank in case of local flooding. Otherwise the overflow shall be terminated in a safer manner as per the site conditions. For tanks with at least one side exposed to a basement, it is safer to discharge the overflow into the basement level.

The tank top slab shall also be designed to carry the load due to fire tender movement where anticipated as in the case of an extended basement.

There should be no common wall between the tanks storing safe water and tanks storing water from unsafe sources.

4.4.8 In case of overhead tanks, bottom of the tanks shall be placed clear off the terrace slab such that the elevation difference between the outlet pipe of the tank and the highest fixture at the top floor of the building is minimum 2 m, which shall also prevent leakage into the structural slab. In tall buildings, the top of the tank shall be provided with the safe ladder or staircase. The top slab shall be provided with railing or a parapet wall.

4.4.9 For jointing steel pipe to a storage tank, the end of the pipe shall be screwed, passed through a hole in the tank and secured by backnuts, both inside and outside. The pipe end shall be flush with the face of the inside backnut. For jointing copper pipe to steel or copper tank, a connector of non-ferrous material shall be used. The connector shall have a shoulder to bear on the outside of the tank and shall be secured by a backnut inside.

4.4.10 The quantity of water to be stored shall be calculated taking into account the following factors:

a) hours of supply at sufficiently high pressure to fill up the overhead storage tanks;
b) frequency of replenishment of overhead tanks, during the 24 h;
c) rate and regularity of supply; and
d) consequences of exhausting storage particularly in case of public buildings like hospitals.

In case of intermittent water supply, the following guidelines should be adopted for calculation of capacity:

1) when the supply is from main OHT, such as in case of plotted development, the capacity of individual OHT may be taken as half a day demand;
2) in case of all the other buildings (apartments, hotels, hospitals, and commercial), the capacity of UGT and OHT may be taken as one and a half days and half a day demand. Wherever raw water and treated water are stored in separate UGTs, the combined storage capacity shall be of one and a half day's demand; and
3) in case of sewage treatment plant, for treated water storage in respect of flushing, one-day flushing demand shall be stored in UGT or treated effluent storage tank, which is part of the plant, and half a day demand shall be stored in OHT.

NOTES

Minimum requirements for calculation of capacity of these storage tanks are as follows:

1 In case only OHT is provided, it may be taken as 33.33 to 50 percent of one day's requirement.

2 In case of combined storage, that is UGT and OHT with gravity water supply system is provided, it may be taken as 150 percent of one day's requirement for UGT and 50 percent of one day's requirement for OHT.

3 In the case of hydro-pneumatic/pressurized water supply system from UGT, the storage of water in UGT to be considered as 200 percent of one day's requirement.

For additional requirement of water storage for firefighting purposes, reference may be made to Part F 'Fire and Life Safety' of this NBCS.

4.4.11 Where the water supply distribution system is catering for separate potable water and flushing water supply, and where reclaimed or recycled treated water is being used within the building, it shall be considered as dual water supply system. In such cases, storages for flushing/reclaimed/recycled water shall be separated proportionately. Adequate measures and precautions shall be taken for physical segregation for sanitary purposes and to avoid cross-contamination in the distribution system and to prevent back contamination of water supply sources (*see* **4.5**).

4.4.12 When only one communication pipe is provided for water supply to a building, it is not necessary to have separate storage for flushing and sanitary purposes for health reasons. In such cases when only one storage tank has been provided, tapping of water may be done at two different levels (the lower tapping for flushing) so that a part of the water will be exclusively available for flushing purposes.

4.5 Protection of Water Supply

4.5.1 *General*

The water supply system shall be designed, installed and maintained in such a manner so as to prevent contamination from non-potable liquids, solids or gases being introduced into the potable water supply system through cross-connections or any other connection to the system.

4.5.2 *Plumbing Fixtures*

The water supply lines and fittings for plumbing fixtures shall be installed so as to prevent back flow and shall provide required back flow protections in accordance with **4.11**.

The devices, appurtenance intended for special function such as sterilization, processing, distillation, etc, shall be provided with back flow protection devices.

The water supply for hospital fixtures shall be protected against backflow with a reduced pressure principle back flow assembly, an atmospheric or spill resistant vacuum breaker assembly, or an air gap. Vacuum breakers for bed pan washer hoses shall not be located less than 1 525 mm above floor. Vacuum breakers for hose connections in health care or laboratory areas shall not be less than 1 800 mm above floor.

4.5.3 *Cross-Connection Control*

Cross-connections shall be prohibited, except where approved back flow prevention assemblies/devices are installed to protect the potable water supply (*see* **4.11**).

Potable water outlets and combination stop and waste valves shall not be installed underground or below grade. Freeze proof yard hydrants that drain the riser into the ground are considered to be stop and waste valves.

Back flow prevention can be achieved by means of providing proper air gap, reduced pressure principle back flow prevention assemblies, back flow preventer with intermediate atmospheric vent, barometric loop, pressure vacuum breaker assemblies, atmospheric type vacuum breakers, double check back flow prevention assemblies, spill resistant pressure vacuum breaker, dual check back flow preventer, etc.

4.5.4 *Identification of Non-potable Water Systems*

Where non-potable water systems are installed, the piping conveying the non-potable water shall be identified either by colour marking, metal tags or tapes in accordance with the relevant standards and good engineering practices.

4.6 Materials, Fittings and Appliances

4.6.1 *Standards for Materials, Fittings and Appliances*

All materials, water fittings and appliances shall conform to Part B ‘Building Materials’ of this NBCS.

4.6.2 *Materials for Pipes*

Pipes may be of any of the following materials:

a) Cast iron, vertically cast or centrifugally (spun) cast;
b) Steel (internally lined or coated with bitumen or a bituminous composition, and out-coated with cement concrete or mortar, where necessary);
c) Ductile iron, internally lined;
d) Reinforced concrete;
e) Prestressed concrete;
f) Galvanized mild steel tubes;
g) Copper;
h) Brass;
j) Wrought iron;
k) Stainless steel;
m) Polyethylene;
n) High density polyethylene (HDPE);
p) Unplasticized PVC;
q) Chlorinated PVC;
r) Polypropylene-random copolymer (PPR);
s) Composite pipes (PE-AL-PE) or any other combination;
t) Cross-linked polyethylene (PEX); or
u) Polybutylene pipe.

4.6.2.1 The material chosen shall be resistant to corrosion, both inside and outside or shall be suitably protected against corrosion.

4.6.2.2 Polyethylene and unplasticized PVC pipes shall not be installed near hot water pipes or near any other heat sources. For temperature limitations in the use of polyethylene and unplasticized PVC pipes to convey water, reference may be made to accepted standards [E-1(8)].

4.7 Design of Distribution Systems

4.7.1 *General*

For designing the distribution system, the following guidelines, in addition to those given in 4.7.2 to 4.7.6 shall be followed:

a) All plumbing systems in buildings shall conform to the general requirements given in 3.1;
b) Peak factor for calculation in case of intermittent flows may generally be adopted in design as 2 to 3; and
c) The residual head at consumer's tap shall be as per 3.1.2.

4.7.2 *Rate of Flow*

One of the important items that needs to be determined before the sizes of pipes and fittings for any part of the water piping system may be decided upon, is the rate of flow in the service pipe which in turn depends upon the number of hours for which the supply is available at sufficiently high pressure. If the number of hours for which the supply is available is less, there will be large number of fittings in use simultaneously and the rate of flow will be correspondingly large.

The data required for determining the size of the communication and service pipes are:

a) the maximum rate of discharge required;

b) the length of the pipe; and

c) the head loss by friction in pipes, fittings and meters.

4.7.3 *Discharge Computation*

4.7.3.1 *Design of consumer's pipes based on fixture units*

The design of the consumers' pipes or the supply pipe to the fixtures is based on:

a) the number and kind of fixtures installed;

b) the fixture unit flow rate; and

c) the probable simultaneous use of these fixtures.

The rates at which water is desirably drawn into different types of fixtures are known. These rates become whole numbers of small size when they are expressed in fixture unit.

The water supply fixture units (WSFU) for different sanitary appliances or groups of appliances are given in Table 2.

4.7.3.2 *Probable simultaneous demand*

The possibility that all water supply taps in any system in domestic and commercial use will draw water at the same time is extremely remote. Designing the water mains for the gross flow will result in bigger and uneconomical pipe mains and may not be necessary. A probability study made by Hunter suggests the relationship shown in Fig. 2 and Table 3. In the absence of similar studies in India, the curves based on Hunter's study may be followed. In making use of these curves, special allowances are made as follows:

a) demands for service sinks are ignored in calculating the total fixture demand;

b) demands of supply outlets such as hose connections and air conditioners through which water flows more or less continuously over a considerable length of time shall be added to the probable flow rather than the fixture demand; and

c) fixtures supplied with both hot and cold water exert reduced demands upon main hot water and cold water branches (not fixture branches).

Table 2 Water Supply Fixture Units (WSFU) for Different Fixtures with Minimum Pipe Sizes

(*Clause* 4.7.3.1)

Sl No. (1)	Type of Fixture (2)	Application		Minimum Pipe Size mm (6)
		Private (3)	Public (4)	
i)	Bath tub	4	–	15
ii)	Ablution faucet/Bidet	1	1	15
iii)	Clothes washer	4	4 (*see* Note 7)	15

Table 2 Water Supply Fixture Units (WSFU) for Different Fixtures with Minimum Pipe Sizes

(*Clause* 4.7.3.1)

Sl No.	Type of Fixture	Application		Minimum Pipe Size mm
		Private	Public	
(1)	(2)	(3)	(4)	(6)
iv)	Dishwasher	1.5	1.5	15
v)	Drinking fountain	–	0.5 (0.75)	15
vi)	Hose bib	2.5	2.5	15
vii)	Wash basin (with metered faucet)	1	1	15
viii)	Wash basin (with standard faucet)	1.5	1.5 (2)	15
ix)	Service sink	–	3	15
x)	Kitchen sink	2	4	15
xi)	Surgical sink	–	2	15
xii)	Scrub station in hospital (per outlet)	–	3	15
xiii)	Shower	2	3	15
xiv)	Bathroom group (flush tank)	5	6	20
xv)	Bathroom group (flush valve)	8	10	25/32
xvi)	Urinal (flush valve)	3	5 (6)	20
xvii)	Urinal (flush tank)	2	2 (3)	15
xviii)	Urinal (sensor operated)	2	2 (3)	15
xix)	Water closet (flush valve)	5	5(8)	25/32
xx)	Water closet (flush tank)	2	3 (5)	15
xxi)	Combination fixture (faucet)	3	–	15
xxii)	Laundry trays (faucet)	3	–	15

NOTES

1 The above table is based on Hunter’s method.

2 Hunter’s method of estimating load in plumbing systems is based on assigning a fixture unit (FU) weight to the plumbing fixtures and then converting these to equivalent litres per minute, based on the theory of probability of usage and based on the observation that all fixtures are not used simultaneously.

3 The fixture unit concept is a method of calculating maximum probable water demand within large buildings based on theory of probability. The method is based on assigning a fixture unit (FU) value to each type of fixture based on its rate of water consumption, on the length of time it is normally in use and on the average period between successive uses.

4 The values of probable demand will not change in respect of systems with flush valves and flush tanks for fixture units more than 1 000.

5 The fixtures or appliances which are not included in the above table may be sized referring to fixtures having similar flow rate and frequency of usage.

6 The minimum supply branch pipe sizes for individual fixtures are nominal sizes.

7 The clothes washer for public does not include large washer extractors, and in such cases the pipe sizing shall be determined as per manufacturer’s recommendations.

8 For more information on bathroom groups, reference may be made to specialist literature.

9 The fixture units listed in the above table represent the load for cold water service. The separate cold and hot water fixture unit value for fixtures having both hot and cold water connections may each be taken as three quarter of the listed total value of fixture.

10 A shower head over a bath tub does not increase the fixture unit value.

11 The values given in parantheses pertain to such public use buildings where an enhanced requirement is expected to be encountered as compared to the normal maximum use in public use buildings.

Table 3 Probable Simultaneous Demand

(*Clause* 4.7.3.2)

Sl No. (1)	Demand in Fixture Units (2)	Demand with Flush Tanks litre/min (3)	Demand with Flush Valves litre/min (4)
i)	1	0	–
ii)	2	3.8	–
iii)	3	11.4	–
iv)	4	15.1	–
v)	5	22.7	–
vi)	6	25.5	–
vii)	8	28.1	–
viii)	10	30.3	102.20
ix)	20	53.0	132.48
x)	30	75.7	155.19
xi)	40	94.6	177.90
xii)	50	109.8	196.82
xiii)	60	121.1	208.18
xiv)	70	132.5	223.32
xv)	80	143.8	234.67
xvi)	90	155.2	246.03
xvii)	100	166.5	257.38
xviii)	140	200.6	295.23
xix)	180	230.9	329.30
xx)	200	246.0	348.22
xxi)	250	283.9	382.29
xxii)	300	321.7	416.35
xxiii)	400	397.4	476.91
xxiv)	500	473.1	537.47
xxv)	750	643.5	673.73
xxvi)	1 000	787.3	787.28
xxvii)	1 250	908.4	908.40
xxviii)	1 500	1 010.6	1 010.60
xxix)	1 750	1 112.8	1 112.79
xxx)	2 000	1 215.0	1 214.99
xxxi)	2 500	1 419.4	1 419.38
xxxii)	3 000	1 635.1	1 635.12
xxxiii)	3 500	1 811.1	1 811.12
xxxiv)	4 000	1 987.1	1 987.13
xxxv)	4 500	2 115.8	2 115.82
xxxvi)	5 000	2 244.5	2 244.51
xxxvii)	5 500	2 312.6	2 312.64
xxxviii)	6 000	2 380.8	2 380.77
xxxix)	6 500	2 411.0	2 411.05
xl)	7 000	2 479.2	2 479.18
xli)	7 500	2 547.3	2 547.31
xlii)	8 000	2 615.4	2 615.44

Table 3 (*Concluded*)

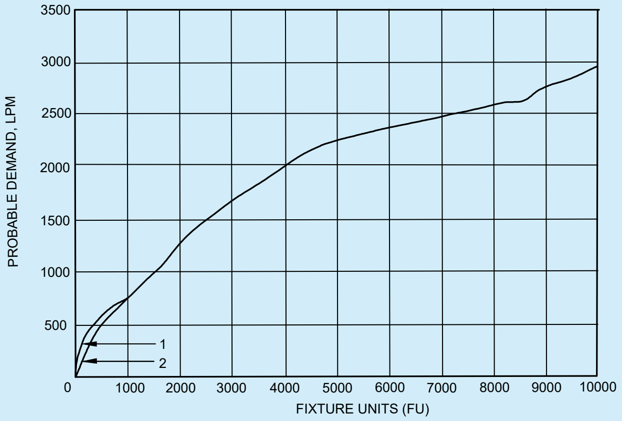
Sl No. (1)	**Demand in Fixture Units** (2)	**Demand with Flush Tanks** litre/min (3)	**Demand with Flush Valves** litre/min (4)
xliii)	8 500	2 683.6	2 683.57
xliv)	9 000	2 751.7	2 751.70
xlv)	9 500	2 831.2	2 831.18
xlvi)	1 000 0	2 910.7	2 910.67

NOTE — For any water line other than flushing line, refer flush tank column to arrive at flow.

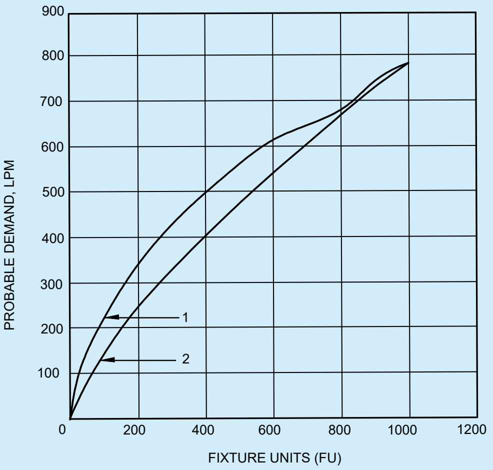
4.7.3.3 The maximum flow rate and flush volumes shall be as below:

Sl No. (1)	*Plumbing Fixtures/Fittings* (2)	*Baseline* (*Max*) *Flow Rate* (3)	*Max. Flow Rate for* 1 *or* 2- *or* 3-*Star Water Efficient Fixture/Fitting* [accepted standards [E-1(5)]] (4)
i)	Water closets	6 litre/flush	6.0/4.8/4.0 litre/full flush and 3.0/2.8/2.0 litre/reduced flush
ii)	Urinals	3.8 litre/flush	3.0/2.0/1.0 litre/flush
iii)	Lavatory, metered faucet (Public)	1 litre/use	1.0/0.8/0.6 litre/use
iv)	Lavatory, faucet (Private)	8 litre/min	8.0/6.0/3.0 litre/min
v)	Sink, faucet	8 litre/min	8.0/6.0/4.5 litre/min
vi)	Bidet, hand-held spray	8 litre/min	6.0/5.0/4.0 litre/min
vii)	Shower head	10 litre/min	10.0/8.0/6.8 litre/min

NOTE — The maximum flow rates of plumbing fixtures and fittings provided are at the pressure of 0.42 N/mm^2. Water closets with dual flush cisterns and urinals with reduced flush volumes are recommended. Users/designers are encouraged to use low-flow fixtures.



2A GRAPH FOR PROBABLE DEMAND UP TO 10 000 FU



CURVE 1 - SYSTEM WITH FLUSH VALVES
CURVE 2 - SYSTEM WITH FLUSH TANKS

2B GRAPH FOR PROBABLE DEMAND UP TO 1000 FU

FIG. 2 GRAPH FOR PROBABLE DEMAND

4.7.4 *Pipe Size Computation*

Commercially available standard sizes of pipes are only to be used against the sizes arrived at by actual design. Therefore, several empirical formulae are used, even though they give less accurate results. The Hazen and William's formula and the charts based on the same may be used without any risk of inaccuracy in view of the fact that the pipes normally to be used for water supply are of smaller sizes. Nomogram of Hazen and William's equation has been provided in Annex C.

4.7.5 *Adequate and Excessive Water Pressure*

The requirements shall be as follows:

a) *Adequate water pressure* — A minimum water pressure in accordance with **3.1.2** shall be ensured in the distribution system. The maximum pressure shall be maintained at 0.42 N/mm^2. Also, while designing, the maximum/minimum pressure required for operation of special fixtures and fittings is to be maintained as per the technical data sheet; and

b) *Excessive water pressure* — Whenever pressure exceeds 0.42 N/mm^2, and the distribution system may not be able to withstand the same, pressure reducing valves shall be installed for reduction of pressure.

4.7.6 *Water Hammer Effects*

Water hammer is a pressure wave phenomenon created by a relatively sudden changes in the water velocity or its direction. It is also observed when valves are shut off. Water hammer arrestors may be used to absorb high pressures resulting from sudden closure of valves/taps.

4.8 Distribution Systems in Multi-Storeyed Buildings

4.8.1 There are following four basic methods of distribution of water to a multi-storeyed building:

a) direct supply system from mains – public or private;

b) gravity distribution system;

c) pressurized distribution system (Hydro-pneumatic pumping system); and

d) combined distribution system.

4.8.2 *Direct Supply System from Mains — Public or Private*

This system is adopted when adequate pressure is available in the mains to supply water at adequate pressure at the topmost floor. With limited pressure available in most city mains, water from direct supply is normally not available above two or three floors. However, in gated communities or large campuses, this system can be adopted for taller buildings by incorporating design parameters such as elevated centralized water tank(s) or central hydro-pneumatic pumping system(s). For details of this system, reference may be made to good practice [E-1(9)] may be referred.

4.8.3 *Gravity Distribution System*

This is the most common water distribution system. The system comprises pumping water to one or more overhead water tanks. Water transferred to overhead tank(s) is distributed by gravity to various parts of the building by the system of piping network.

4.8.4 *Pressurized Distribution System* (*Hydro-pneumatic Pumping System*)

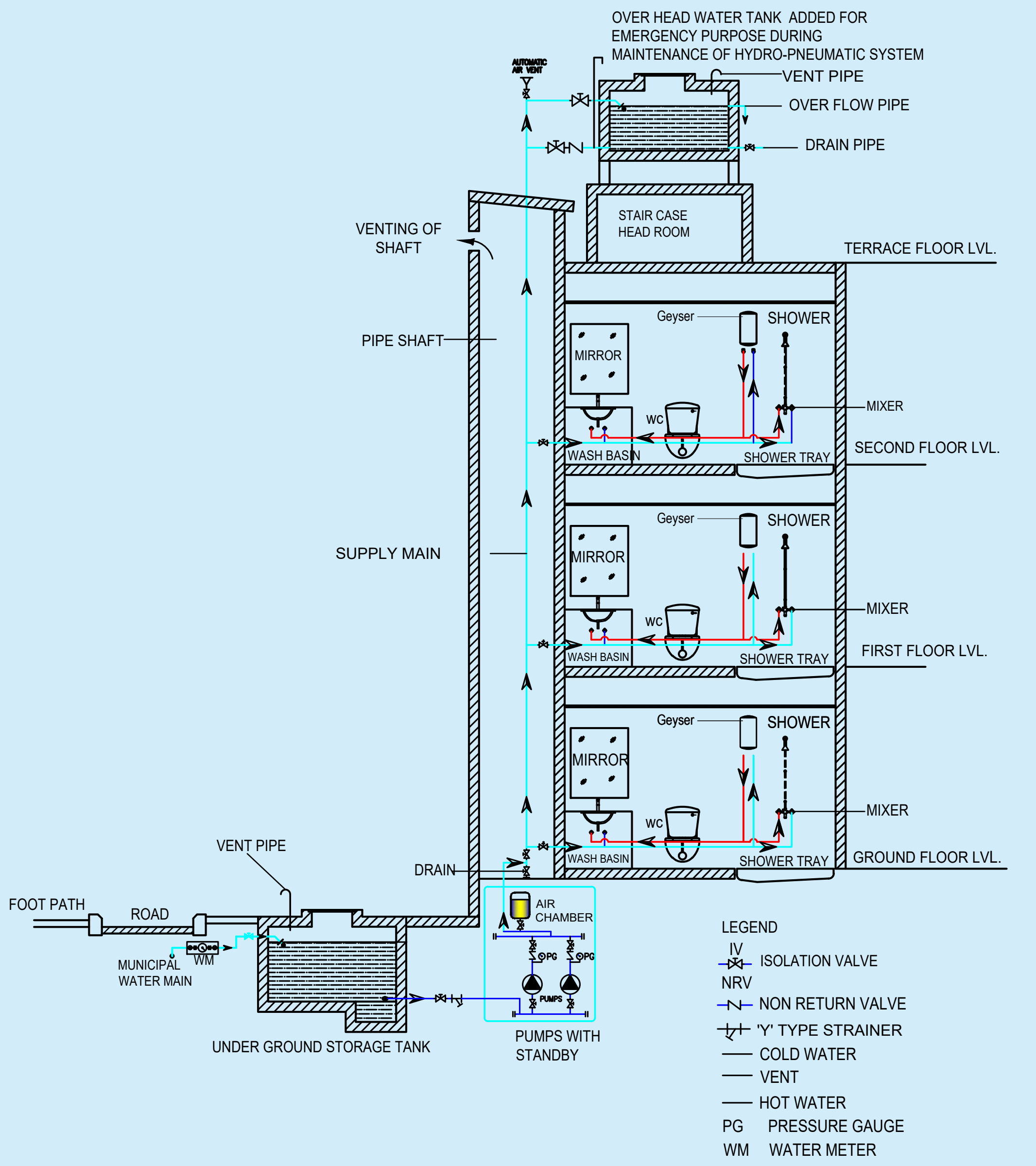
4.8.4.1 Pressurized distribution system is a direct pumping system incorporating a recharge diaphragm vessel.

4.8.4.2 The system may incorporate multiple pumps with suction and discharge manifolds and a control panel to facilitate automatic operation. Total discharge capacity required may be shared by a number of pumps, where the pumps operate in duty, assist and standby configuration.

4.8.4.3 The system shall also incorporate automatic sequencing of pumps to ensure even wear and tear also a low level cut-off, to prevent dry run of the pumps. The system shall be provided with continuous power supply with provision of emergency power backup.

4.8.4.4 Modern hydro-pneumatic systems are available with variable frequency drive, where the pump is efficiently used to deliver water at rates of flow as required by the system, by varying its speed with the assistance of an electronic device, thereby meeting the demand flow through variation in speed of the motor. With this arrangement, the same pump can deliver water at required pressure and flow as required at different times of the day. The system consumes energy in proportion to the work done and helps in controlling the water surge in the distribution line.

4.8.4.5 Hydro-pneumatic system generally eliminates the need of an overhead tank. As a good engineering practice and to take care of emergencies, an overhead of smaller capacity should be provided which feeds by gravity to the system (*see* Fig. 3).


OVER HEAD WATER TANK ADDED FOR EMERGENCY PURPOSE DURING MAINTENANCE OF HYDRO-PNEUMATIC SYSTEM
AUTOMATIC AIR VENT
VENT PIPE
OVER FLOW PIPE
DRAIN PIPE
STAIR CASE HEAD ROOM
VENTING OF SHAFT
TERRACE FLOOR LVL.
PIPE SHAFT
Geyser
SHOWER
MIRROR
WC
MIXER
WASH BASIN
SHOWER TRAY
SECOND FLOOR LVL.
SUPPLY MAIN
Geyser
SHOWER
MIRROR
WC
MIXER
WASH BASIN
SHOWER TRAY
FIRST FLOOR LVL.
Geyser
SHOWER
MIRROR
WC
MIXER
VENT PIPE
WASH BASIN
SHOWER TRAY
GROUND FLOOR LVL.
DRAIN
FOOT PATH
ROAD
MUNICIPAL WATER MAIN
WM
AIR CHAMBER
PG
PG
PUMPS
UNDER GROUND STORAGE TANK
PUMPS WITH STANDBY
LEGEND
IV ISOLATION VALVE
NRV NON RETURN VALVE
'Y' TYPE STRAINER
COLD WATER
VENT
HOT WATER
PG PRESSURE GAUGE
WM WATER METER

NOTES

1 HOT WATER SUPPLY TO BE PLANNED AS PER REQUIREMENT BY PROVISION OF GEYSER AND HOT WATER PIPING.
2 FLUSHING WATER SUPPLY FROM WC TO BE PLANNED IN CASE OF AVAILABILITY OF RECYCLED WASTE WATER.
3 FOR LARGE AND COMMERCIAL BUILDINGS, WATER SUPPLY TO BE BASED ON ZONE-BASED DISTRIBUTION FOR DOMESTIC AND FLUSHING WATER SUPPLY.
4 PRESENTATION OF LAYOUT AND LOCATION OF FIXTURES/APPLIANCES ARE ONLY TYPICAL IN NATURE.

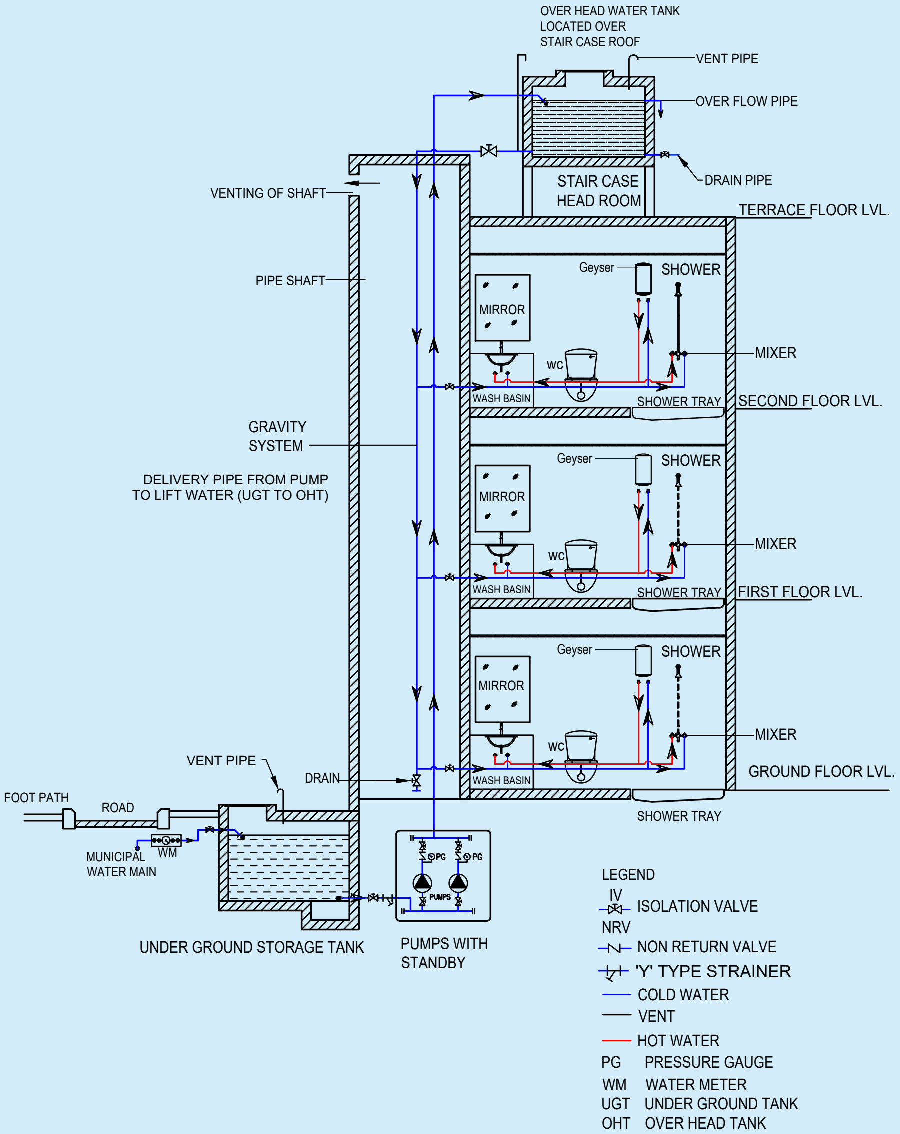
Fig. 3 Hydro-Pneumatic System

4.8.5 *Combined Distribution System*

4.8.5.1 In this system, a combination of gravity and pressurized distribution is adopted. A few upper floors are provided with a pressure booster pumping system to achieve the desired residual pressure, while the lower floors are fed by gravity supply.

4.8.5.2 Water collected in the overhead tank is distributed to the various parts of the building. To achieve required residual pressure for top 2 to 4 floors for proper functioning of the fixtures, a pressure booster pumping system is installed on the dedicated outlet from overhead tank with its own distribution piping serving the top 2 floors to 4 floors. For lower floors, water is distributed by gravity system.

4.8.5.3 Water distribution is accomplished by providing down take pipes in the shaft from the terrace ring mains (*see* Fig. 4).


OVER HEAD WATER TANK
LOCATED OVER
STAIR CASE ROOF
VENT PIPE
OVER FLOW PIPE
DRAIN PIPE
STAIR CASE
HEAD ROOM
TERRACE FLOOR LVL.
VENTING OF SHAFT
PIPE SHAFT
Geyser
SHOWER
MIRROR
WC
MIXER
WASH BASIN
SHOWER TRAY
SECOND FLOOR LVL.
GRAVITY
SYSTEM
DELIVERY PIPE FROM PUMP
TO LIFT WATER (UGT TO OHT)
FIRST FLOOR LVL.
VENT PIPE
DRAIN
GROUND FLOOR LVL.
FOOT PATH
ROAD
WM
MUNICIPAL
WATER MAIN
PG
PUMPS
UNDER GROUND STORAGE TANK
PUMPS WITH
STANDBY
LEGEND
IV ISOLATION VALVE
NRV NON RETURN VALVE
'Y' TYPE STRAINER
COLD WATER
VENT
HOT WATER
PG PRESSURE GAUGE
WM WATER METER
UGT UNDER GROUND TANK
OHT OVER HEAD TANK

NOTES

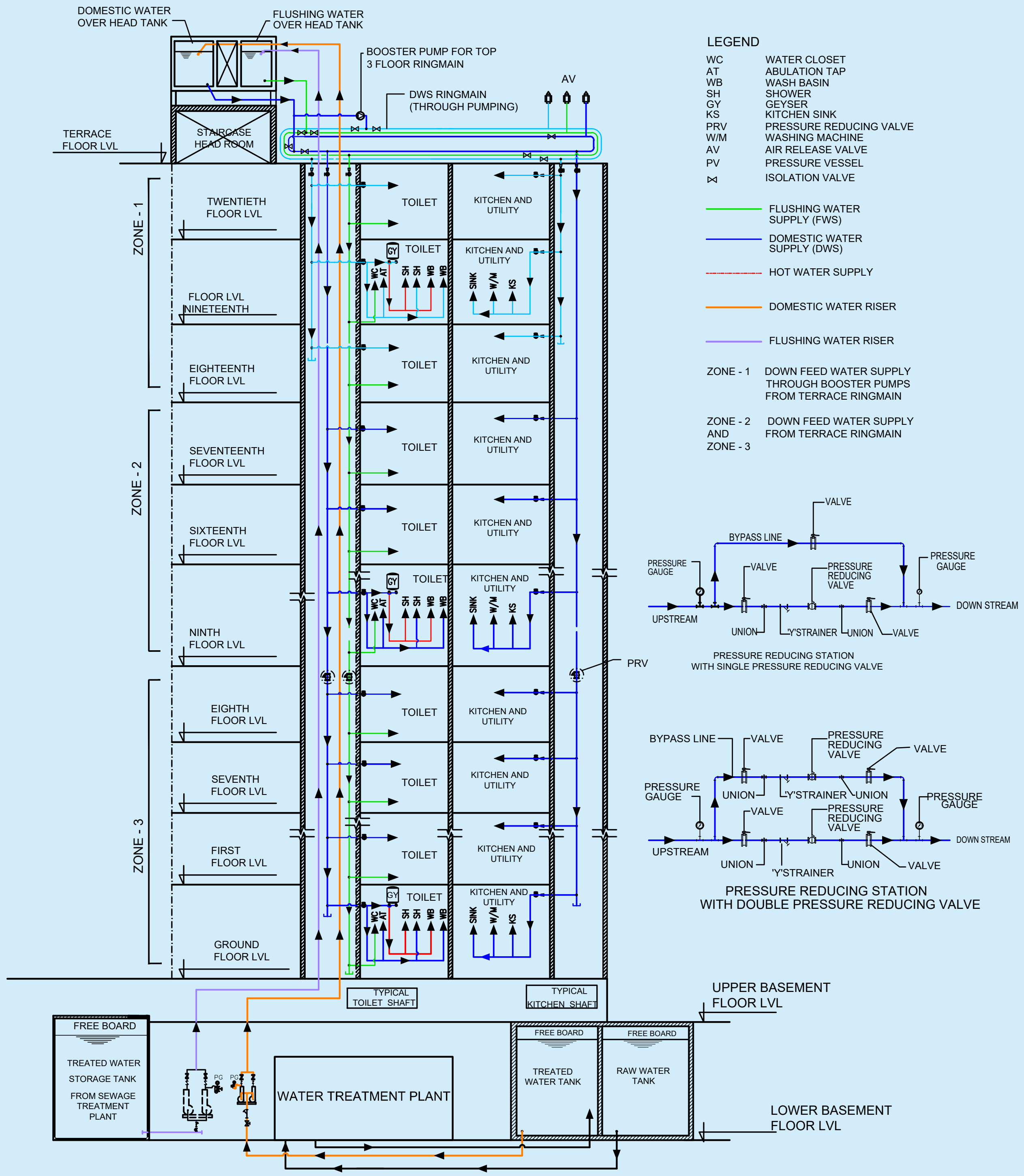
1 PUMP OPERATION TO BE BY LEVEL CONTROLLER OR AIR VESSEL/PRESSURE SWITCH AT MOTORIZED VALVE AT OHT.
2 HOT WATER SUPPLY TO BE PLANNED AS PER REQUIREMENT BY PROVISION OF GEYSER AND HOT WATER PIPING.
3 FLUSHING WATER SUPPLY FROM WC TO BE PLANNED IN CASE OF AVAILABILITY OF RECYCLED WASTE WATER.
4 FOR LARGE AND COMMERCIAL BUILDINGS, WATER SUPPLY TO BE BASED ON ZONE-BASED DISTRIBUTION FOR DOMESTIC AND FLUSHING WATER SUPPLY.
5 PRESENTATION OF LAYOUT AND LOCATION OF FIXTURES/APPLIANCES ARE ONLY TYPICAL IN NATURE.

FIG. 4 OVER HEAD TANK DISTRIBUTION

4.8.6 *Zoning of Distribution Systems*

The zoning of water distribution network may be adopted for 7 floors to 9 floors, while conforming to the adequate pressure requirements and excessive pressure limitations in the hydraulic design (*see* **4.7.5**). *See* Fig. 5 and Fig. 6 for zoning of gravity distribution system and pressurized distribution system (hydro-pneumatic pumping system), respectively.

The recommended maximum permissible velocity is 2.4 m/s for water distribution. In case of hot water distribution through copper pipes, the velocity is restricted to 1.5 m/s due to concern of erosion of the piping material.

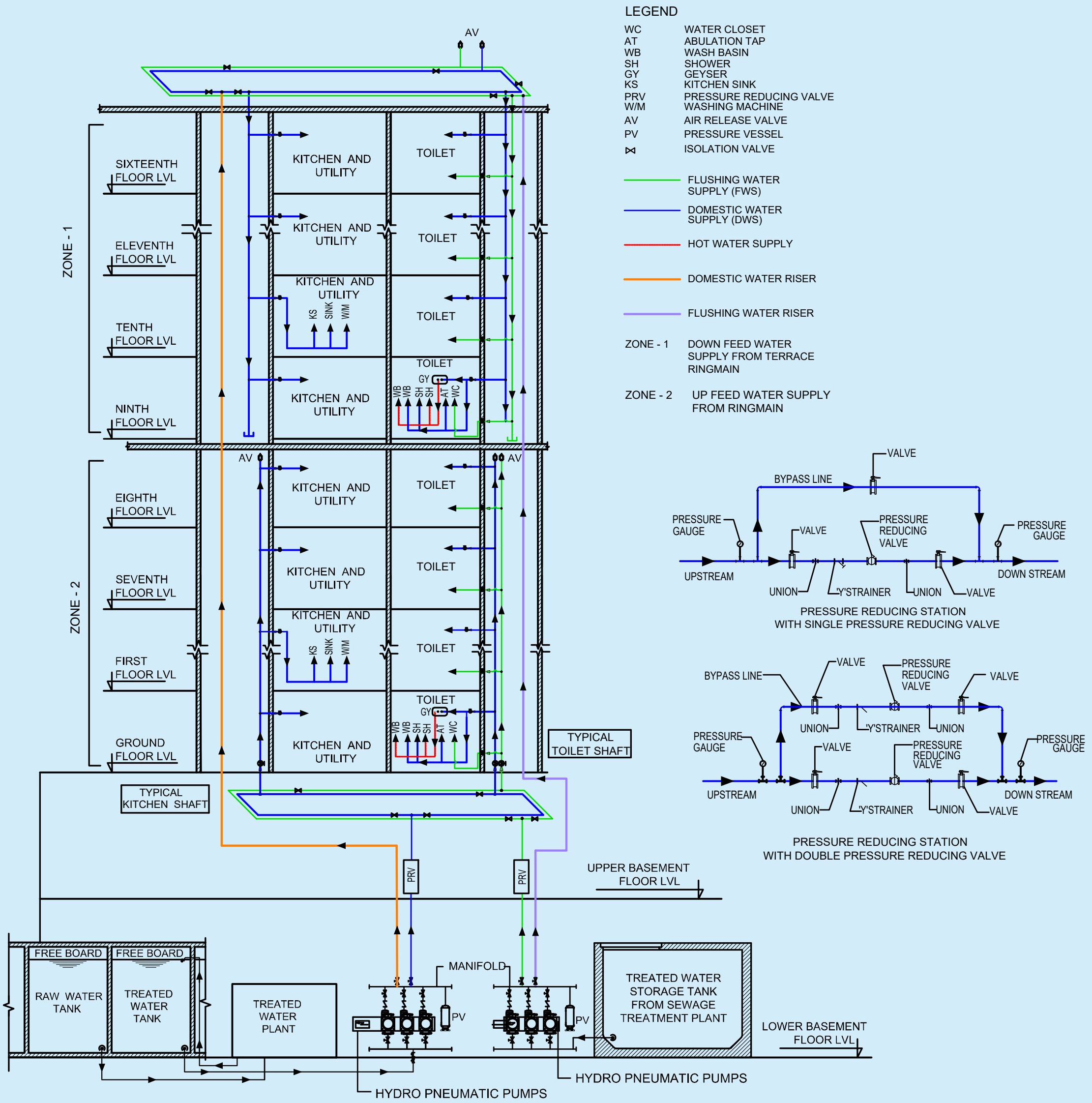

DOMESTIC WATER OVER HEAD TANK
FLUSHING WATER OVER HEAD TANK
BOOSTER PUMP FOR TOP 3 FLOOR RINGMAIN
DWS RINGMAIN (THROUGH PUMPING)
AV
TERRACE FLOOR LVL
STAIRCASE HEAD ROOM
ZONE - 1
ZONE - 2
ZONE - 3
TWENTIETH FLOOR LVL
FLOOR LVL NINETEENTH
EIGHTEENTH FLOOR LVL
SEVENTEENTH FLOOR LVL
SIXTEENTH FLOOR LVL
NINTH FLOOR LVL
EIGHTH FLOOR LVL
SEVENTH FLOOR LVL
FIRST FLOOR LVL
GROUND FLOOR LVL
TOILET
KITCHEN AND UTILITY
GY
WC
AT
SH
WB
SINK
W/M
KS
PRV
TYPICAL TOILET SHAFT
TYPICAL KITCHEN SHAFT
UPPER BASEMENT FLOOR LVL
LOWER BASEMENT FLOOR LVL
FREE BOARD
TREATED WATER STORAGE TANK FROM SEWAGE TREATMENT PLANT
PG
WATER TREATMENT PLANT
TREATED WATER TANK
RAW WATER TANK
LEGEND
WC WATER CLOSET
AT ABULATION TAP
WB WASH BASIN
SH SHOWER
GY GEYSER
KS KITCHEN SINK
PRV PRESSURE REDUCING VALVE
W/M WASHING MACHINE
AV AIR RELEASE VALVE
PV PRESSURE VESSEL
⋈ ISOLATION VALVE
FLUSHING WATER SUPPLY (FWS)
DOMESTIC WATER SUPPLY (DWS)
HOT WATER SUPPLY
DOMESTIC WATER RISER
FLUSHING WATER RISER
ZONE - 1 DOWN FEED WATER SUPPLY THROUGH BOOSTER PUMPS FROM TERRACE RINGMAIN
ZONE - 2 AND ZONE - 3 DOWN FEED WATER SUPPLY FROM TERRACE RINGMAIN
VALVE
BYPASS LINE
PRESSURE GAUGE
PRESSURE REDUCING VALVE
UPSTREAM
DOWN STREAM
UNION
'Y'STRAINER
PRESSURE REDUCING STATION WITH SINGLE PRESSURE REDUCING VALVE
PRESSURE REDUCING STATION WITH DOUBLE PRESSURE REDUCING VALVE

NOTES

1 APPURTENANCE, SUCH AS PRV SHOULD BE PLANNED IN MAIN PIPING NETWORK OR BRANCH PIPING, AS REQUIRED, TO RESTRAIN PRESSURE TO UPPER LIMITS.

2 REQUIREMENTS FOR STORAGE AND USAGE OF FIRE WATER SHOULD BE AS PER PART F 'FIRE AND LIFE SAFETY' OF THIS NBCS.

FIG. 5 SCHEMATIC DIAGRAM SHOWING THE DISTRIBUTION SYSTEM IN RESPECT OF GRAVITY SYSTEM FOR A MULTI-STOREYED BUILDING


LEGEND
WC WATER CLOSET
AT ABULATION TAP
WB WASH BASIN
SH SHOWER
GY GEYSER
KS KITCHEN SINK
PRV PRESSURE REDUCING VALVE
W/M WASHING MACHINE
AV AIR RELEASE VALVE
PV PRESSURE VESSEL
ISOLATION VALVE
FLUSHING WATER SUPPLY (FWS)
DOMESTIC WATER SUPPLY (DWS)
HOT WATER SUPPLY
DOMESTIC WATER RISER
FLUSHING WATER RISER
ZONE - 1 DOWN FEED WATER SUPPLY FROM TERRACE RINGMAIN
ZONE - 2 UP FEED WATER SUPPLY FROM RINGMAIN
AV
ZONE - 1
SIXTEENTH FLOOR LVL
ELEVENTH FLOOR LVL
TENTH FLOOR LVL
NINTH FLOOR LVL
ZONE - 2
EIGHTH FLOOR LVL
SEVENTH FLOOR LVL
FIRST FLOOR LVL
GROUND FLOOR LVL
KITCHEN AND UTILITY
TOILET
KS
SINK
W/M
GY
WB
SH
AT
WC
TYPICAL TOILET SHAFT
TYPICAL KITCHEN SHAFT
PRV
UPPER BASEMENT FLOOR LVL
FREE BOARD
RAW WATER TANK
TREATED WATER TANK
TREATED WATER PLANT
MANIFOLD
PV
TREATED WATER STORAGE TANK FROM SEWAGE TREATMENT PLANT
LOWER BASEMENT FLOOR LVL
HYDRO PNEUMATIC PUMPS
VALVE
BYPASS LINE
PRESSURE GAUGE
PRESSURE REDUCING VALVE
UPSTREAM
DOWN STREAM
UNION
'Y'STRAINER
PRESSURE REDUCING STATION WITH SINGLE PRESSURE REDUCING VALVE
PRESSURE REDUCING STATION WITH DOUBLE PRESSURE REDUCING VALVE

NOTES

1 THE GIVEN EXAMPLE IS FOR 16 STORIES BUILDING WITH CONCEPT OF UPFEED AND DOWN FEED RINGMAINS. THE CHOICE OF RINGMAIN IS ON DESIGNER PROPOSAL. FOR TALLER BUILDING, ZONES AND RINGMAINS SHALL BE PLANNED TO MEET MAXIMUM AND MINIMUM PRESSURE REQUIREMENTS. APPURTENANCE, SUCH AS PRV SHOULD BE PLANNED IN MAIN PIPING NETWORK OR BRANCH PIPING, AS REQUIRED, TO RESTRAIN PRESSURE TO UPPER LIMITS.

2 GUIDANCE REGARDING REQUIREMENTS FOR STORAGE AND USAGE OF FIRE WATER MAY BE AS PER PART F 'FIRE AND LIFE SAFETY' OF THIS NBCS.

FIG. 6 SCHEMATIC DIAGRAM SHOWING THE DISTRIBUTION SYSTEM IN RESPECT OF HYRDO PNEUMATIC SYSTEM FOR A MULTI-STOREYED BUILDING

4.9 General Requirements for Pipe Work

4.9.1 *Mains*

The following principles shall apply for the mains:

a) Service mains shall be of adequate size to give the required rate of flow.

b) Mains shall be divided into sections by the provisions of sluice valves and other valves so that water may be shut off for repairs.

c) To avoid dead ends, the mains shall be arranged in a grid formation or in a network.

d) Where dead ends are unavoidable, a hydrant shall be provided to act as a wash-out.

e) Wash-out valve shall not discharge directly into a drain or sewer, or into a manhole or chamber directly connected to it; an effectively trapped chamber shall be interposed, into which the wash-out shall discharge.

f) Air valves shall be provided at all summits, and wash-out at low points between summits.

g) Mains need not be laid at unvarying gradients, but may follow the general contour of the ground. They shall, however, fall continuously towards the washout and rise towards the air valves. The gradient shall be such that there shall always be a positive pressure at every point under working conditions.

h) Cover for the mains shall be at least 900 mm under roadways and 750 mm in the case of footpaths. This cover shall be measured from the top of the pipe to the surface of the ground.

j) Mains shall be located sufficiently away from other service lines like electric and telegraph cables to ensure safety and where the mains cannot be located away from such lines, suitable protective measures shall be accorded to the mains. As far as possible, water supply and sewerage mains should be isolated from each other with certain minimum horizontal distance as per good engineering practice.

4.9.2 *Communication Pipes*

a) Every premises that is supplied with water by the Authority shall have its own separate communication pipe. In the case of a group or block of premises belonging to the same owner the same communication pipe may supply water to more than one premises with the prior permission of the Authority.

b) The communication pipe between the water main and the stop-cock at the boundary of the premises shall be laid by the Authority.

c) Connections up to 50 mm diameter may be made on the water main by means of screwed ferrules, provided the size of the connections does not exceed one third the size of the water main. In all other cases, the connection shall be made by a T-branch off the water main.

d) As far as practicable, the communication pipe and the underground service pipe shall be laid at right angles to the main and in approximately straight lines to facilitate location for repairs. It is also recommended that the communication pipe be laid in a pipe in pipe sleeve of larger diameter made of non-corrosive material to protect the communication pipe.

e) Every communication pipe shall have a stop-cock and meter inserted in it. The waterway of each such fitting shall not be less than the internal sectional area of the communication pipe and the fittings shall be located within the premises at a conspicuous place accessible to the Authority which shall have exclusive control over it.

4.9.3 *Consumer Pipes*

a) No consumer pipe shall be laid in the premises to connect the communication pipe without the approval of the Authority.

b) The consumer pipe within the premises shall be laid underground with a suitable cover to safeguard against damage from traffic and extremes of weather.

c) To control the branch pipe to each separately occupied part of a building supplied by a common service pipe, a stop valve shall be fixed to minimize the interruption of the supply during repairs. All such stop valves shall be fixed in accessible positions and properly protected. To supply water for drinking or for culinary purposes, direct taps shall be provided on the branch pipes connected directly to the consumer pipe. In the case of multi-storeyed buildings, down take taps shall be supplied from overhead tanks.

d) Pumps shall not be allowed on the service pipe, as they cause a drop in pressure on the suction side, thereby affecting the supply to the adjoining properties. In cases where pumping is required, a properly protected storage tank of adequate capacity shall be provided to feed the pump.

e) No direct boosting (by booster pumps) shall be allowed from the service pipes (communication and consumer pipes).

f) Consumer pipes shall be so designed and constructed as to avoid air-locks. Draining taps shall be provided at the lowest points from which the piping shall rise continuously to draw-off taps.

g) Consumer pipes shall be so designed as to reduce the production and transmission of noise as much as possible.

h) Consumer pipes in roof spaces and unventilated air spaces under floors or in basements shall be protected against corrosion.

j) Consumer pipes shall be so located that they are not unduly exposed to accidental damage and shall be fixed in such positions as to facilitate cleaning and avoid accumulations of dirt.

k) All consumer pipes shall be so laid as to permit expansion and contraction or other movements.

4.9.4 *Prohibited Connections*

a) A service pipe shall not be connected into any distribution pipe; such connection may permit the backflow of water from a cistern into the service pipe, in certain circumstances, with consequent danger of contamination and depletion of storage capacity. It might also result in pipes and fittings being subjected to a pressure higher than that for which they are designed, and in flooding from overflowing cisterns.

b) No pipe for conveyance or in connection with water supplied by the Authority shall communicate with any other receptacle used or capable of being used for conveyance other than water supplied by the Authority.

c) Where storage tanks are provided, no person shall connect or be permitted to connect any service pipe with any distributing pipe.

d) No service or supply pipe shall be connected directly to any water-closet or a urinal. All such supplies shall be from flushing cisterns/flush valves which shall be supplied from storage tank.

e) No service or supply pipe shall be connected directly to any hot water system or to any other apparatus used for heating other than through a feed cistern thereof.

4.10 Jointing of Pipes

4.10.1 *Cast Iron Pipes*

Jointing may be done by any of the following methods:

a) spigot and socket joints, or

b) flanged joints.

in accordance with good practice [E-1(10)]. Alternative jointing materials which are found to be equally effective, may be used in place of lead joints, with the approval of the Authority.

4.10.2 *Steel Pipes*

Plain-ended steel pipes may be joined by welding. Electrically welded steel pipes shall be jointed in accordance with good practice [E-1(11)].

4.10.3 *Wrought Iron and Steel Screwed Pipes*

Screwed wrought iron or steel piping may be jointed with screwed and socketed joints. Care shall be taken to remove any burr from the end of the pipes after screwing. A jointing compound approved by the Authority and containing no red lead composition shall be used. Screwed wrought iron or steel piping may also be jointed with screwed flanges.

4.10.4 *Asbestos Cement Pipes*

Asbestos cement pipes may be jointed in accordance with good practice [E-1(12)].

4.10.5 *Copper Pipes*

Copper pipes shall be jointed by internal solder ring joint, end-brazing joint or by use of compression fitting. The flux used shall be non-toxic and the solder used shall be lead free. The use of dezincification fittings shall be made in case of jointing of copper pipe and steel pipe. The jointing technology shall be used as per good engineering practice and as per manufacturers recommendations.

4.10.6 *Concrete Pipes*

Concrete pipes shall be jointed in accordance with good practice [E-1(13)].

4.10.7 *Polyethylene and Unplasticized PVC Pipes*

Polyethylene and unplasticized PVC pipes shall be jointed in accordance with good practice [E-1(14)].

4.11 Backflow Prevention

4.11.1 The installation shall be such that water delivered is not liable to become contaminated or that contamination of the public water supply does not occur.

4.11.2 The various types of piping and mechanical devices acceptable for backflow protection are:

a) Barometric loop,
b) Air gap,
c) Atmosphere vacuum breaker,
d) Pressure vacuum breaker,
e) Double check valve,
f) Reduced pressure backflow device.

4.11.3 The installation shall not adversely affect drinking water:

a) by materials in contact with the water being unsuitable for the purpose;
b) as a result of backflow of water from water fittings, or water using appliances into pipework connected to mains or to other fittings and appliances;
c) by cross-connection between pipes conveying water supplied by the water undertaker with pipes conveying water from some other source; and
d) by stagnation, particularly at high temperatures.

4.11.4 No pump or similar apparatus, the purpose of which is to increase the pressure in or rate of flow from a supply pipe or any fitting or appliance connected to a supply pipe, shall be connected unless the prior written permission of the water supplier has been obtained in each instance.

The use of such a pump or similar apparatus is likely to lead to pressure reduction in the upstream pipe work which, if significant, increase the risk of backflow from other fittings.

4.11.5 The water shall not come in contact with unsuitable materials of construction.

4.11.6 No pipe or fitting shall be laid in, on or through land fill, refuse, an ash pit, sewer, drain, cesspool or refuse chute or any manhole connected with them.

4.11.7 No pipe susceptible to deterioration by contact with any substance shall be laid or installed in a place where such deterioration is likely to occur. No pipe that is permeable to any contaminant shall be laid or installed in any position where permeation is likely to occur.

4.11.8 If a liquid (other than water) is used in any type of heating primary circuit, which transfers heat to water for domestic use, the liquid shall be non-toxic and non-corrosive.

4.11.9 A backflow prevention device shall be arranged or connected at or as near as practicable to each point of delivery and use of water. Appliances with built-in backflow prevention shall be capable of passing the test. All backflow prevention devices shall be installed so that they are accessible for examination, repair or replacement. Such devices shall be capable of being tested periodically by the Authority to ensure that the device is functioning efficiently and no backflow is occurring at any time.

4.12 Conveyance and Distribution of Water within the Premises

4.12.1 Basic *Principles*

Wholesome water supply provided for drinking and culinary purposes shall not be liable to contamination from any less satisfactory water. There shall, therefore, be no cross-connection whatsoever between the distribution system for wholesome water and any pipe or fitting containing unwholesome water, or water liable to contamination, or of uncertain quality, or water which has been used for any other purpose. The provision of reflux or non-return valves or closed and sealed stop valves shall not be construed as a permissible substitute for complete absence of cross-connection.

4.12.2 The design of the pipe work shall be such that there is no possibility of backflow towards the source of supply from any cistern or appliance, whether by siphonage or otherwise. Reflux non-return valves shall not be relied upon to prevent such backflow.

4.12.3 Where a supply of less satisfactory water than wholesome water becomes inevitable as an alternative or is required to be mixed with the latter, it shall be delivered only into a cistern and by a pipe or fitting discharging into the air gap at a height above the top edge of the cistern equal to twice its nominal bore and in no case less than 150 mm. It is necessary to maintain a definite air gap in all appliances or taps used in water-closets.

4.12.4 All pipe work shall be so designed, laid or fixed and maintained as to remain completely water-tight, thereby avoiding wastage, damage to property and the risk of contamination.

4.12.5 No water supply line shall be laid or fixed so as to pass into or through any sewer, scour outlet or drain or any manhole connected therewith, nor through any ash pit or manure pit or any material of such nature that is likely to cause undue deterioration of the pipe.

4.12.5.1 Where the laying of any pipe through corrosive soil or pervious material is unavoidable, the piping shall be properly protected from contact with such soil or material by being carried through an exterior pipe sleeves as approved by the Authority. Any existing piping or fitting laid or fixed, which does not comply with the above requirements, shall be removed immediately by the consumer and re-laid by him in conformity with the above requirements and to the satisfaction of the Authority.

4.12.5.2 Where lines have to be laid in close proximity to electric cables or in corrosive soils, adequate precautions/protection should be taken to avoid corrosion.

4.12.6 Underground piping shall be laid at such a depth that it is unlikely to be damaged by frost or traffic loads and vibrations. It shall not be laid in ground liable to subsidence, but where such ground cannot be avoided, special precautions shall be taken to avoid damage to the piping. Where piping has to be laid across recently disturbed ground, the ground shall be thoroughly consolidated so as to provide a continuous and even support. In the case of frost conditions, the pipes shall be laid below the frost line with suitable insulation to the pipes.

4.12.7 In designing and planning the layout of the pipe work, due attention shall be given to the maximum rate of discharge required, economy in labour and materials, protection against damage and corrosion, water hammer, protection from frost, if required, and avoidance of airlocks, noise transmission and unsightly arrangement.

4.12.8 To reduce frictional losses, piping shall be as smooth as possible inside. Methods of jointing shall be such as to avoid internal roughness and projection at the joints, whether of the jointing materials or otherwise.

4.12.9 Change in diameter and in direction shall preferably be gradual rather than abrupt to avoid undue loss of head. No bend or curve in piping shall be made which is likely to materially diminish or alter the cross-section.

4.12.10 No boiler for generating steam or closed boilers of any description or any machinery shall be supplied direct from a service or supply pipe. Every such boiler or machinery shall be supplied from a feed cistern.

4.13 Laying of Mains and Pipes on Site

4.13.1 The mains and pipes on site shall be laid in accordance with good practices [E-1(15)]. The pipes laid in buildings situated in seismic zone and across large building expansion joints should be installed with suitable expansion bellows and expansion loops to mitigate expansion of piping system for its intended function without failures.

4.13.2 *Excavation and Refilling*

The bottoms of the trench excavations shall be so prepared that the barrels of the pipes, when laid, are well bedded for their whole length on a firm surface and are true to line and gradient. In the refilling of trenches, the pipes shall be surrounded with fine selected material, well rammed so as to resist subsequent movement of the pipes. No stones shall be in contact with the pipes; when resting on rock, the pipes shall be bedded on fine-selected material or (especially where there is a steep gradient) on a layer of concrete.

4.13.2.1 The pipes shall be carefully cleared of all foreign matter before being laid.

4.13.3 *Laying Underground Mains*

Where there is a gradient, pipe laying shall proceed in ‘uphill’ direction to facilitate joint making.

4.13.3.1 Anchor blocks shall be provided to withstand the hydraulic thrust.

4.13.4 Iron surface boxes shall be provided to give access to valves and hydrants and shall be supported on concrete or brickwork which shall not be allowed to rest on pipes.

4.13.5 *Laying Service Pipes*

4.13.5.1 Service pipes shall be connected to the mains by means of right-hand screw down ferrule or T-branches. The ferrules shall conform to accepted standard [E-1(16)].

4.13.5.2 Precaution against contamination of the mains shall be taken when making a connection and, where risk exists, the main shall be subsequently disinfected. The underground water service pipe and the building sewer or drain shall be kept at a sufficient distance apart so as to prevent contamination of water. Water service pipes or any underground water pipes shall not be run or laid in the same trench as the drainage pipe. Where this is unavoidable, the following conditions shall be fulfilled:

a) the bottom of the water service pipe, at all points, shall be at least 300 mm above the top of the sewer line at its highest point;

b) the water service pipe shall be placed on a solid shelf excavated on one side of the common trench;

c) the number of joints in the service pipe shall be kept to a minimum; and

d) the materials and joints of sewer and water service pipe shall be installed in such a manner and shall possess such necessary strength and durability as to prevent the escape of solids, liquids and gases there from under all known adverse conditions, such as corrosion strains due to temperature changes, settlement, vibrations and superimposed loads.

4.13.5.3 The service pipe shall pass into or beneath the buildings at a depth of not less than 750 mm below the outside ground level and, at its point of entry through the structure, it shall be accommodated in a sleeve which shall have previously been solidly built into the wall of the structure. The space between the pipe and the sleeve shall be filled with bituminous or other suitable material for a minimum length of 150 mm at both ends.

4.13.6 *Pipes Laid through Ducts, Chases, Notches or Holes*

Ducts or chases in walls for piping shall be provided during the building of the walls. If they are cut into existing walls, they shall be finished sufficiently smooth and large enough for fixing the piping.

4.13.6.1 Piping laid in notches or holes shall not be subjected to external pressure.

4.13.7 *Lagging of Pipes*

Where lagged piping outside buildings is attached to walls, it shall be entirely covered all round with water-proof and fire insulating material and shall not be in direct contact with the wall. Where it passes through a wall, the lagging shall be continued throughout the thickness of the wall.

4.14 Hot Water Supply Installations

4.14.1 *Design Consideration*

4.14.1.1 *General*

In electric water heating practice for domestic purposes, the accepted method is to use storage heaters in which water is steadily heated up to a predetermined temperature and stored until required for use. The heating by electricity of a large quantity of water, such as water required for a hot bath, within the time normally taken to run the water into the bath, requires a heater of too high a rating to be practicable in normal domestic premises. It should be ensured that such vents and pipes are above reach/inaccessible during daily use to avoid accidents such as accidental contact and burning.

4.14.1.2 In modern hotels and apartment blocks and service apartments, centralized storage and distribution systems are adopted, where other energy sources such as oil, gas, solar panels, etc, may be used for the generation of hot water as these options prove more economical and convenient in heating large volumes of water for storage.

4.14.1.3 The implementation of a hybrid heating system, integrating solar-based heating with electrical geysers, has demonstrated effectiveness in extreme cold conditions where water freezing occurs, and prolonged use of electric geysers presents challenges. When selecting such hybrid systems, the design shall ensure operational safety during both the heating process and the extraction of hot water.

4.14.1.4 When water supplied to the buildings contain dissolved salts resulting in hardness of water, measures such as installation of water softening plants, etc, shall be taken to avoid formation of scales in the hot water installations.

4.14.2 *Storage Temperature*

4.14.2.1 The design of hot water supply system and its appliances shall be based on the temperatures at which water is normally required for the various uses, namely:

Scalding : 65 °C

Sink : 60 °C

Hot bath : 43 °C as run for use at 41 °C

Warm bath : 37 °C

Tepid bath : 29.5 °C

4.14.2.2 In order to minimize the danger of scalding, precipitation of scale from hard water, standing heat losses, risk of steam formation and the possibility of damage to porcelain or other fittings and to surface finishes, a storage temperature of 60 °C is recommended. If storage capacity is limited, a higher temperature up to 65 °C may be adopted when soft water is used.

4.14.3 *Storage Capacity*

The size of the storage vessel is governed by the maximum short time demand of the domestic premises. Depending on local conditions this shall be 50 litre to 75 litre at 60 °C in a dwelling with a bath tub and 25 litre at 60 °C for a shower or a tap (for bucket supply). The capacity of the storage vessel shall not be less than 20 percent in excess of the required maximum short time demand. In larger houses where a single hot water heater is intended to supply hot water to more than one bathroom or kitchen or both, the maximum short time demand shall be estimated and the capacity decided accordingly. Small electric or gas storage heaters of 15 litre to 25 litre capacity may be used to supply one or two points of draw off depending on the use of hot water.

4.14.4 *Rate of Flow*

With storage type installation, the recommended maximum rates of flow for different types of fixtures are given in Table 4.

Table 4 Rate of Hot Water Flow

(*Clause* 4.14.4)

Sl No. (1)	**Fixtures** (2)	**Rate of Flow** litre/min (3)
i)	Kitchen sink	5
ii)	Wash basin	5
iii)	Shower (spray type)	6.5

4.14.4.1 *Hot water supply systems*

Identification of water supply system is critical for safe functioning and protection of occupants. The first step is correct labelling of various water systems in the building. The requirements of identification/labelling shall be adhered on every installation where different water systems are provided.

While designing centralized hot water systems in major projects, the following points should be considered:

a) Fuel to be used,

b) Location and dimension of boiler house and calorifier chambers,

c) Location and dimension of fuel storage tank,

d) Means of ash disposal (in case of solid fuel),

e) Location and dimension of chimney,

f) Location of cold-water points,

g) Drainage facilities during emptying,

h) Quality of water supply,

j) Provision for air combustion and ventilation.

In laying hot water piping systems, the pressures of hot and cold water should be made equal at each fixture, especially where mixing faucets/thermostatic mixer are to be used. Otherwise, there would be imbalance of pressure where one pressure would be more than the other. These conditions should be avoided by proper design of the system.

Return circulation systems are recommended for energy conservation and user comfort.

In the inverted systems, hot water heaters and tanks are located at the highest point of water supply system and supply and return risers below the level of hot water source.

Environmental and consumer requirements should be considered when planning the installation of a solar hot water system. Factors affecting the performance of a system and decisions about how the system should be installed, include:

a) the climate zone of the site and possibility of:
    1) shading;
    2) frost and freezing;
    3) wind;
    4) dust;
    5) hail; and
    6) corrosion and scaling.
b) the ambient air temperature;
c) the cold-water temperature;
d) the availability of space and pitch of a suitable south-facing roof;
e) the presence and location of an existing hot water service;
f) the available energy sources (for example, gas or electricity);
g) the householder's hot water usage; and
h) the householder's budget.

4.14.5 *Design of Storage Vessel*

Storage tanks shall be oblong or cylindrical in shape and shall be installed, preferably with the long side vertical in order to assist the effective stratification or 'layering' of hot or cold water. The ratio of height to width or diameter shall not be less than 2 : 1. An inlet baffle should preferably be fitted near the cold inflow pipe in order to spread the incoming cold water.

4.14.6 *Materials for Storage Vessel and Pipes*

4.14.6.1 Under no circumstances shall ungalvanized (black) mild steel pipes and fittings, such as sockets, bushes, etc, be used in any part of domestic hot water installation, including the cold feed pipe and the vent pipe. Materials resistant to the chemical action of water supplied shall be used in construction of vessels and pipes. Each installation shall be restricted to one type of metal only, such as all copper or all galvanized mild steel. When water supplied is known to have appreciable salt content, galvanized iron vessels and pipes shall not be used. However, it is advisable to avoid use of lead pipes in making connection to wash basins. Where required it is also advisable to use vessels lined internally with glass, stainless steel, etc.

4.14.6.2 In general, tinned copper and other metals such as monel metal, etc, are suitable for most types of water. The suitability of galvanized mild steel for storage tanks depends upon the *p*H value of the water and the extent of its temporary hardness. For values of *p*H 7.2 or less, galvanized mild steel should not be used. For values of *p*H 7.3 and above, galvanized mild steel may be used provided the corresponding temporary hardness is not lower than those given below:

Sl No. (1)	*p*H *Value* (2)	*Minimum Temporary Hardness Required* mg/l (3)
i)	7.3	210
ii)	7.4	150
iii)	7.5	140
iv)	7.6	110
v)	7.7	90
vi)	7.8	80
vii)	7.9 to 8.5	70

4.14.7 *Location of Storage Vessel*

The loss of heat increases in proportion to the length of pipe between the storage vessel and the hot water outlet since each time the water is drawn, the pipe fills with hot water which then cools. The storage vessel shall therefore be so placed that the pipe runs to the most frequently used outlets are as short as possible.

4.14.8 *Immersion Heater Installation*

4.14.8.1 If a domestic storage vessel is to be adopted to electric heating by the provision of an immersion heater and thermostat, the following precautions shall be observed:

a) *Location of immersion heaters* — The immersion heater shall be mounted with its axis horizontal, except in the case of the circulation type which is normally mounted with its axis approximately vertical.

b) In a tank with a flat bottom, a space of not less than 75 mm below the immersion heater and 50 mm below the cold feed connection shall be provided to allow for accumulation of sludge and scale, where it will not affect the working of the immersion heater.

c) In a cylindrical storage vessel with inwardly dished bottom, the inlet pipe shall be so arranged that the incoming cold water is not deflected directly into the hot water zone. The lowest point of the immersion heater shall be 25 mm above the centre line of the cold feed inlet, which, in turn, is usually 100 mm above the cylinder rim.

d) *Location of thermostat* — Where the thermostat does not form an integral part of the immersion heater, it shall be mounted with its axis horizontal, at least 50 mm away from and not lower than the immersion heater.

e) *Dual heater installations* — If desired, the principle of the dual heater may be adopted. In this case, one heater and its thermostat shall be installed at a low level as indicated in (b) and (c). The second heater and its thermostat shall be similarly disposed in the upper half of the cylinder at a level depending on the reserve of hot water desired for ordinary domestic use. The bottom heater shall be under separate switch control.

f) *Clearance around storage vessel* — Adequate clearance shall be provided between the tank and the cupboard, door or walls to allow convenient insertion and adjustment of the immersion heater and thermostat and to give space for thermal insulation.

4.14.8.2 *Rating of immersion heaters*

The rating of an immersion heater shall be determined according to the following factors:

a) proposed hot water storage capacity (the maximum with cold water as indicated in **4.14.3** shall be taken into account);
b) rate of utilization (draw off frequency);
c) permissible recovery period; and
d) inlet water temperature.

For details regarding rated input of water, refer to good practice [E-1(17)].

4.14.9 *Thermal Insulation*

The hot water storage vessel and pipes shall be adequately insulated, wherever necessary to minimize heat loss.

The whole external surface of the storage vessel including the cover to the man hole shall also be duly insulated.

Insulation may be provided by wrapping storage vessel and pipes with fibre glass, mineral wool or closed cell flexible elastomeric foam based materials of desired thickness, covered with cladding for protection from damage or from weather in case of external use.

4.14.10 *Cold Water Supply to Heaters*

4.14.10.1 A storage water heater (pressure type) shall be fed from a cold water storage tank and under no circumstances connected directly to the water main, except the type which incorporates a feed tank with ball valves and overflow pipe arrangement (cistern type heaters) or non-pressure type heaters.

4.14.10.2 *Storage cisterns*

4.14.10.2.1 The storage capacity of a cold water tank shall be at least twice the capacity of the hot water heater. The capacity of the storage tank may, however, be 1.5 times when the number of heaters connected to one common tank exceeds 10.

4.14.10.2.2 The storage tank for supply of cold water to hot water heaters shall be separate, if practicable. In the case of a common tank which also supplies cold water to the fixtures, this cold water supply connection shall be so arranged that 50 percent of the net capacity, worked out as in **4.14.10.2.1**, shall be available for supply to the hot water heaters.

4.14.10.2.3 In the case of multi-storeyed buildings where a common overhead tank over the stair/lift well is generally installed, it is advisable to have one or more local tanks for supply to the hot water heaters or a compartment in the tank with required storage always available for hot water heater.

4.14.10.2.4 In tall multi-storeyed buildings where the static pressure increases with the height, the total static pressure on the hot water heaters on the lowest floor shall not exceed the rated working pressure of the hot water heater installed. Should the height of the building so require, additional tanks shall be provided on the intermediate floors to restrict the static head to permissible limits, or the pressure shall be reduced to working pressure by providing pressure reducing valves.

4.14.11 *Cold Water Feed*

4.14.11.1 The feed pipe connecting cold water tank with the hot water heater shall not be of less than 20 mm bore and it shall leave the cold water tank at a point not less than 50 mm above the bottom of the tank and shall connect into the hot water heater near its bottom. The feed pipe shall not deliver cold water to any other connection, but into the hot water cylinders only.

4.14.11.2 In the case of multi-storeyed buildings, a common cold water feed pipe may be installed, but each hot water heater shall be provided with a check valve (horizontal type check valve shall be preferred to vertical type for easy maintenance).

4.14.11.3 Care shall be taken in installing the piping to prevent air locks in the piping and negative pressure in the hot water heater. Cold water feed pipe shall not be cross-connected with any other source of supply under pressure.

4.14.12 *Hot Water Piping*

4.14.12.1 *Expansion pipe or vent pipe*

4.14.12.1.1 Each non-pressure type hot water heater or cylinder shall be provided with a vent pipe of not less than 20 mm bore. The vent pipe shall rise above the water line of the cold water tank by at least 150 mm plus 10 mm for every 300 mm height of the water line above the bottom of the heater. The vent shall discharge at a level higher than the cold water tank and preferably in the cold water tank supplying the hot water heaters. Care shall be taken to ensure that any accidental discharge from the vent does not hurt or scald any passer-by or persons in the vicinity.

It shall be ensured that such vents and pipes are so located so as not to encroach into the minimum maneuvering space and should be suitably insulated to avoid accidental contact and burns.

NOTE — Pressure type water heaters are very commonly used and non-pressure type is slowly phased out.

4.14.12.1.2 The vent pipe shall be connected to the highest point of the heater vessel and it shall not project downwards inside it, as otherwise air may be trapped inside, resulting in surging and consequent noises.

4.14.12.1.3 At no point, after leaving the vessel, shall the vent pipe dip below the level of its connection with the vessel.

4.14.12.1.4 A vent pipe may, however, be used for supply of hot water to any point between the cold water tank and the hot water heaters.

4.4.12.1.5 The vent pipe shall not be provided with any valve or check valves.

4.4.12.2 *Hot water heaters*

4.4.12.2.1 The common hot water delivery pipe shall leave the hot water heater near its top and shall be of not less than 20 mm bore generally, not less than 25 mm bore if hot water taps are installed on the same floor as that on which the hot water heater is situated.

4.14.12.2.2 Hot water taps shall be of such design as would cause the minimum friction. Alternatively, oversized tap may be provided, such as a 20 mm tap on a 15 mm pipe.

4.14.12.2.3 The hot water distributing system shall be so designed as to ensure that the time lag between opening of the draw-off taps and discharge of hot water is reduced to the minimum to avoid wastage of an undue amount of water which may have cooled while standing in the pipes when the taps are closed. With this end in view, a secondary circulation system with flow and return pipes from the hot water tank shall be used where justified. Whether such a system is used or not, the length of pipe to a hot water draw-off tap, measured along the pipe from the tap to the hot water tank or the secondary circulation pipe, shall not exceed the lengths given in Table 5.

Table 5 Maximum Permissible Lengths of Hot Water Draw-Off Pipes

(*Clause* 4.14.12.2.3)

Sl No. (1)	Largest Internal Diameter of Pipe (2)	Length m (3)
i)	Not exceeding 20 mm	12
ii)	Exceeding 20 mm but not exceeding 25 mm	7.5
iii)	Exceeding 25 mm	3.0

NOTE — In the case of a composite pipe of different diameters, the largest diameter is to be taken into consideration for the purpose of this table.

4.14.12.2.4 Wherever mixing of hot and cold water is done by a mixing fitting, that is, hot and cold stop-cocks deliver to a common outlet of mixed water (that is, showers, basin or bath supply fittings), the pressure in the cold and hot water systems shall be equal. This can be achieved by connecting the cold water supply from an overhead tank at the same static height as the overhead tank supplying cold water to the hot water heaters. In case this is not possible, hot and cold water should be supplied to the fixtures by separate supply taps.

The hot and cold water thermostatic mixers/diverters/faucets for public use should have ‘hot’ and ‘cold’ clearly marked in the form of colour coding and tactile information. The functioning of hot and cold water from the thermostatic mixer/diverter/faucet should be consistent, for example, a clockwise turn should result in discharge of hot water and counter clockwise for cold. It is recommended that a thermostat be installed to limit the temperature of the hot water to a maximum of 40 °C in order to prevent scalding. All faucets/mixers/diverts in public use shall be automatic (sensor operated) or lever type.

4.14.13 *Types of Hot Water Heaters*

The various types of water heaters used for preparation of hot water are as follows:

a) *Electric storage heaters*:

   1) Non–pressure or open outlet type,

    2) Pressure type,
    3) Cistern type,
    4) Dual heater type.

b) *Gas water heaters*:
    1) Instantaneous type {*see* accepted standard [E-1(18)]},
    2) Storage type.

c) *Solar heating systems*:
    1) Independent roof mounted heating units,
    2) Centrally banked heated system.

d) *Central hot water system*:
    1) Oil fired,
    2) Gas fired,
    3) Electrical coil type,
    4) Heat Pump.

4.14.13.1 The quality and construction of the different types of hot water heaters shall be in accordance with good practice [E-1(19)].

4.14.13.2 For solar water heating system and their installation reference shall be made to good practice [E-1(20)].

4.14.13.3 Requirements in regard to inspection and maintenance of hot water supply installations shall be in accordance with **4.15.1** to **4.15.4**.

4.15 Inspection and Testing

4.15.1 *Testing of Mains before Commencing Work*

All pipes, fittings and appliances shall be inspected, before delivery at the site to see whether they conform to accepted standards. All pipes and fittings shall be inspected and tested by the manufacturers at their factory and shall comply with the requirements of this Section. They shall be tested hydraulically under a pressure equal to twice this maximum permissible working pressure or under such greater pressure as may be specified. The pipes and fittings shall be inspected on site before laying and shall be sounded to disclose cracks. Any defective items shall be clearly marked as rejected and forthwith removed from the site.

4.15.2 *Testing of Mains after Laying*

After laying and jointing, the main shall be slowly and carefully charged with water by providing a 25 mm inlet with a stop-cock, so that all air is expelled from the main. The main is then allowed to stand full of water for a few days if time permits, and then tested under pressure. The test pressure shall be 0.5 N/mm^2 or double the maximum working pressure, whichever is greater. The pressure shall be applied by means of a manually operated test pump, or, in the case of long mains or mains of a large diameter, by a power-driven test pump, provided the pump is not left unattended. In either case, due precaution shall be taken to ensure that the required test pressure is not exceeded. Pressure gauges shall be accurate and shall preferably have been recalibrated before the test. The pump having been stopped, the test pressure shall maintain itself without measurable loss for at least 5 min. The mains shall be tested in sections as the work of laying proceeds; it is an advantage to have the joints exposed for inspection during the testing. The open end of the main may be temporarily closed for testing under moderate pressure by fitting a water-tight expanding plug of which several types are available. The end of the main and the plug shall be secured by struts or otherwise, to resist the end thrust of the water pressure in the mains.

4.15.2.1 If the section of the main tested terminates into a sluice valve, the wedge of the valve shall not be used to retain the water; instead the valve shall be temporarily fitted with a blank flange, or, in the case of a socketed valve, with a plug, and the wedge placed in the open position while testing. End support shall be given as in **4.15.2**.

4.15.3 *Testing of Service Pipes and Fittings*

When the service pipe is complete, it shall be slowly and carefully charged with water, allowing all air to escape, care being taken to avoid all shock or water hammer. The service pipe shall then be inspected under working conditions of pressure and flow. When all draw-offs taps are closed, the service pipe shall be absolutely water-tight. All piping, fittings and appliances shall be checked for satisfactory support, and protection from damage, corrosion and frost. Because of the possibility of damage in transit, cisterns shall be re-tested for water-tightness on arrival at the site, before fixing.

4.15.4 In addition to the provisions given in **4.15.1**, provisions given in **4.15.4.1** to **4.15.4.3** shall also apply to hot water supply installations in regard to inspection and testing.

4.15.4.1 *Testing of the system after installation*

After the hot water system, including the hot water heaters, has been installed, it shall be carefully charged with water, so that all air is expelled from the system. The entire system shall then be hydraulically tested to a pressure of 0.5 N/mm^2 or twice the working pressure, whichever is greater, for a period of at least 30 min after a steady state is reached. The entire installation shall then be inspected visually for leakages, and sweating. All defects found shall be rectified by removing and remaking the particular section. Caulking of threads, hammering and welding of leaking joints shall not be allowed.

4.15.4.2 *Hot water testing*

After the system has been proved water-tight, the hot water heaters shall be commissioned by connecting the same to the electrical supply. The system shall then be observed for leakage in pipes due to expansion or overheating. The temperature of water at outlets shall be recorded. The thermostats of the appliances shall be checked and adjusted to temperatures specified in **4.14.2.1**.

4.15.4.3 *Electrical connection*

For relevant provisions regarding general and safety requirements for household and similar electrical appliances, reference may be made to good practice [E-1(17)]. The metal work of the water heating appliances and installation other than current carrying parts shall be bonded and earthed in conformity with the good practice [E-1(17)]. It should be noted that screwing of an immersion heater into a tank or cylinder cannot be relied upon to effect a low resistance earth connection, a satisfactory separate earthing of heater should be effected.

4.16 Cleaning and Disinfection of the Supply System

4.16.1 All water mains communications pipes, service pipes and pipes used for distribution of water for domestic purposes shall be thoroughly and efficiently disinfected before being taken into use and also after every major repair. The method of disinfection shall be subject to the approval of the Authority. The pipes shall also be periodically cleaned at intervals, depending upon the quality of water, communication pipes and the storage cisterns shall be thoroughly cleaned at least once every year in order to remove any suspended impurities that may have settled in the pipes or the tanks.

4.16.2 *Disinfection of Storage Tanks and Down Take Distribution Pipes*

The storage tanks and pipes shall first be filled with water and thoroughly flushed out. The storage tank shall then be filled with water again and a disinfecting chemical containing chlorine added gradually while the tanks are being filled, to ensure thorough mixing. Sufficient quantities of chemicals shall be used to give the water a dose of 50 parts of chlorine to one million parts of water. If ordinary bleaching powder is used, the proportions will be 150 g of powder to 1 000 litre of water. The powder shall be mixed with water to a creamy consistency before being added to the water in the storage tank. When the storage tank is full, the supply shall be stopped and all the taps on the distributing pipes opened successively working progressively away from the storage tank. Each tap shall be closed when the water discharged begins to smell of chlorine. The storage tank shall then be topped up with water from the supply pipe and with more disinfecting chemical in the recommended proportions. The storage tank and pipes shall then remain charged for at least 3 h. Finally, the tank and pipes shall be thoroughly flushed out before any water is used for domestic purposes.

4.17 Water Supply Systems in High Altitudes and/or Sub-zero Temperature Regions

4.17.1 *Selection and Source*

In general, the site selected for a water source shall be such as to minimize the length of transmission line so as to reduce the inspection and upkeep. Attempt shall be made, where feasible, to locate the source near the discharge of waste heat, such as of power plants provided it does not affect the potability of water.

4.17.2 *Pumping Installation*

Pump and pumping machinery shall be housed inside well-insulated chambers. Where necessary, arrangements shall be made for heating the inside of pump houses. Pump houses, as far as possible, should be built directly above the water intake structures.

4.17.3 *Protection of Storage Water and Treatment*

Where ambient temperatures are so low as to cause danger of freezing, proper housing, insulation and protection shall be provided for all processes and equipment. If necessary, means shall be provided for proper heating of the enclosure.

4.17.4 *Transmission and Distribution*

Freezing of the buried pipe may be avoided primarily by laying the pipe below the level of the frost line; well consolidated bedding of clean earth or sand, under, around or over the pipe should be provided. For the efficient operation and design of transmission and distribution work, the available heat in the water shall be economically utilized and controlled. If the heat which is naturally present in water is made equate to satisfy heat losses from the system, the water shall be warmed. Where economically feasible, certain faucets on the distribution system may be kept in a slightly dripping condition so as to keep the fluid in motion and thus prevent is freezing. If found unsuitable for drinking purposes, such water may be used for heating purposes. Heat losses shall be reduced by insulation, if necessary. Any material that will catch, absorb or hold moisture shall not be used for insulation purposes. Adequate number of break pressure water tanks and air release valves shall be provided in the distribution system.

NOTE — The level of frost line is generally found to be between 0.9 m and 1.2 m below ground level in the northern regions of India, wherever freezing occurs.

4.17.4.1 *Materials for pipes*

Distribution pipes shall be made of any of the following materials conforming to Part B ‘Building Materials’ of this NBCS:

a) High density polyethylene pipes;
b) Asbestos cement pipes;
c) Galvanized iron pipes;
d) Cast iron pipes;
e) Copper pipes;
f) Chlorinated PVC pipes;
g) Unplasticized PVC pipes (where it is laid before frost line); and
h) Stainless steel pipes.

4.17.4.2 *Materials for insulation of pipes*

Insulation of pipes may be provided by wrapping the pipe with fibre glass, mineral wool or closed cell flexible elastomeric foam based insulation materials of desired thickness covered with cladding for protection from damage or from weather in case of external use/pipes laid in exposed conditions; other materials, like 85 percent magnesia, preformed pipe sections, etc, may also be used.

4.17.4.3 *Distribution methods*

Distribution by barrels or tank trucks shall be employed, where the water requirements are temporary and small. Utmost care shall be exercised for preventing the water from being contaminated by maintaining a residual of disinfecting agent at all times. Hoses, pails and the tank shall be kept free from dust and filth during all period of operation. Where winter temperatures are low, making frost penetration depths greater during the winter and where adequate facilities for heating the water in the distribution system do not exist, the use of tank trucks or barrels for delivery of water shall be considered only for cold weather; during the warm weather, piping system for seasonal use may be supplemented.

4.17.4.4 In the conventional distribution system involving the use of a network of pipelines requiring no auxiliary heat, it is essential that the pipelines are buried well below the frost line. Adequate facilities for draining the pipelines shall be provided where there is a danger of frost.

4.17.4.5 *House service connections*

House service connections shall be kept operative by the use of adequate insulation at exposed places extending below the frost line. Figure 7 shows a typical arrangement for providing insulation for house service connections.

4.17.5 For detailed information on planning and designing water supply system peculiar to high altitudes and/or sub-zero temperature regions of the country, reference may be made to good practice [E-1(2)].

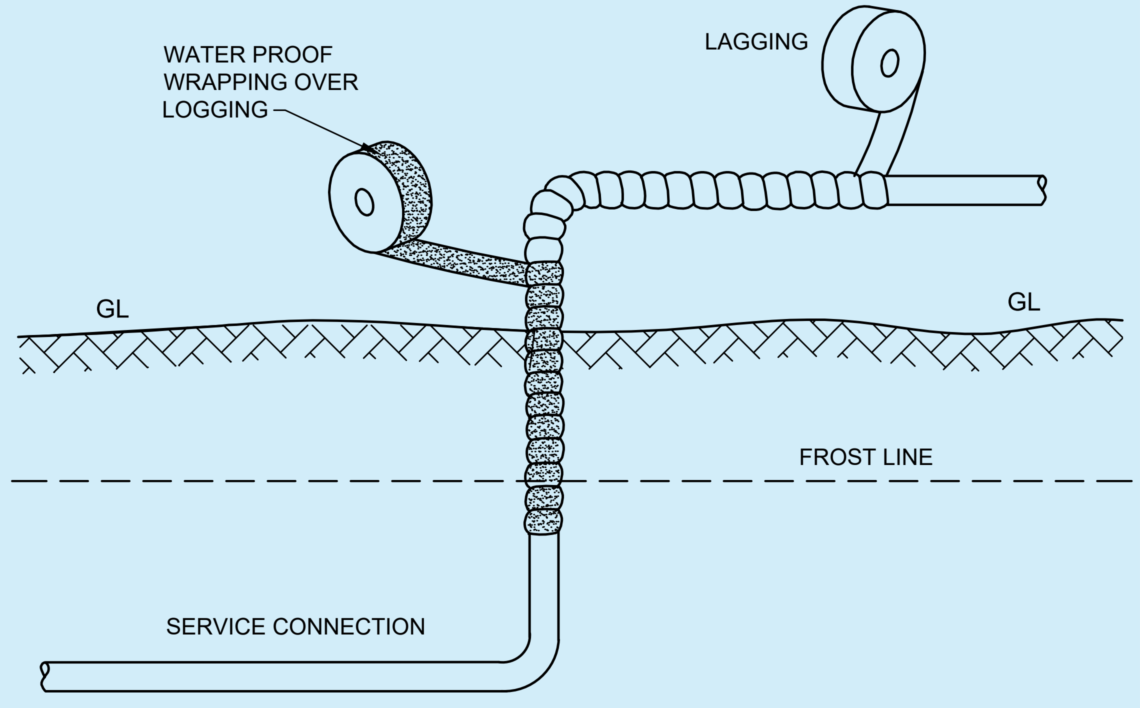


FIG. 7 INSULATION DETAILS AT SERVICE CONNECTION

4.18 Guidelines to Maintenance

4.18.1 Storage tanks shall be regularly inspected and shall be cleaned out periodically, if necessary. Tanks showing signs of corrosion shall be emptied, thoroughly wire brushed to remove loose material (but not scraped), cleaned and coated with suitable bituminous compositions or other suitable anti-corrosive material not liable to impart taste or odour or otherwise contaminate the water. Before cleaning the cistern, the outlets shall be plugged to prevent debris from entering the pipes. Tanks shall be examined for metal wastage and water tightness after cleaning.

4.18.2 Record drawings showing pipe layout and valve positions shall be kept up to date and inspection undertaken to ensure that any maintenance work has not introduced cross-connections or any other undesirable feature. Any addition or alterations to the systems shall be duly recorded from time to time.

4.18.3 Any temporary attachment fixed to a tap or outlet shall never be left in such a position that back-siphonage of polluted water may occur into the supply system.

4.18.4 All valves shall periodically be operated to maintain free movement of the working parts.

4.18.5 All taps and ball valves shall be watertight, glands shall be made good, washers shall be replaced and the mechanism of spring operated taps and ball valves shall be repaired where required.

4.18.6 All overflow pipes shall be examined and kept free from obstructions.

4.18.7 The electrical installation shall be checked for earth continuity and any defects or deficiencies corrected in the case of hot water supply installations.

4.19 Swimming Pools

4.19.1 *General*

A swimming pool is a container that is filled with water to enable swimming or such other leisure activities. Pools can be sunk into the ground or built above ground (as a freestanding construction or as part of a building or other larger structure), and are also a standard feature aboard ocean liners and cruise ships. In-ground pools are most commonly constructed from materials such as concrete, natural stone, metal, plastic or fiberglass, and can be of a custom size and shape or built to a standardized size.

All pools open to public shall take care of the barrier-free design for accessibility and use by persons with disabilities. Reference shall also be made to good practice [E-1(3)] for applicable requirements.

4.19.1.1 Swimming pools shall be of three types, namely:

Type	*Characteristic*
Fill and draw	Clear water of potable quality is retained till it becomes turbid or unfit for use. Thereafter, the pool is drained, cleaned and refilled with clear water. This type is not recommended considering water conservation
Flow through	Clear water of hygienic quality flows continuously. This type requires more water for replenishment and so cautious decision of usage of such pools should be made; it is not recommended considering water conservation
Recirculating	Recirculation system shall be provided to minimize water wastage and disinfection shall be done to ensure hygiene. The recirculation system shall be based on the nature of usage such as private, public, wading and competition pools. The entire pool water should be filtered based on the turnover period for various types of pools.

4.19.1.2 *Turnover rate*

It is the amount of time it would take for the volume of the pool to pass through the filtration system one time. Turnover rate is measured in hours and is expressed as:

Turnover rate, in hours = Pool volume (in litres)/Flow (in litre/h)

NOTE — Pool volume comprises volume of the pool water, balancing tank, overflow gutter and circulation pipe.

Typical turnover rates for the following pools are:

Sl No. (1)	*Type of Pool* (2)	*Turnover rate* h (3)
i)	Swimming pool:	
	a) Private (outdoor);	6
	b) Private (indoor);	10
	c) Public; and	6
	d) Competition.	6
ii)	Wading Pool	1
iii)	Spa (public)	½
	Spa (private)	1

4.19.1.3 *Swimming pool user load*

The maximum load for the pool shall be:

a) For pool depth up to 1m : 2.2 m^2 surface area per user
b) For pool depth up to 1.5m : 2.7 m^2 surface area per user
c) For pool depth more than 1.5m : 4.0 m^2 surface area per user

4.19.1.4 Recommended dimensions of the swimming pools shall be:

a) Half sized olympic pools : 25 m (length) × 12 to 13 m (width) ×1.8 m (depth)
b) Full size olympic pools : 50 m (length) × 25 m (wide) × 2 m (depth)
c) Diving depth : 3.5 m for 1 m spring board; and
5 m for a 10 m platform
d) Maximum depth : *See* **4.19.2.7**
e) Ladders : 2 treads for 1.2 m depth;
3 treads for 1.2 m to 1.5 m depth; and
4 treads for 1.5 m depth
f) Displacement : 60 litre per user for deeper pools; and
45 litre for shallow pools

4.19.2 *Design*

4.19.2.1 The pool should be so designed to withstand all anticipated hydraulic structural loadings for both full and empty conditions. All appurtenances to the pool, such as diving boards and slides, shall be designed to carry the anticipated load. Any obstruction creating a safety hazard shall not extend into or above the pool, or shall not protrude from the floor of the pool. Designers may refer good practice [E-1(21)] for providing the guidance on the procedures and the precautions to be taken during construction of swimming pool to ensure the water tightness of the structure.

4.19.2.2 *Material*

Any suitable material that is non-toxic and provides a rigid watertight shell with a smooth, impervious, light colour finish should be used to construct the pool. The floor of shallow areas shall have a slip-resistant finish. Sand or earth shall not be permitted to use as an interior finish in a swimming pool.

4.19.2.3 *Dimensions*

The shape and size of a pool largely depend on the usage. Shape should be considered from the standpoint of safety and circulation of the pool water.

NOTES

1 A long and rectangular pool may be ideal for sports and exercise as it gives length and breadth, but the shape of a pool for recreation largely depend on the choice of the owners, available space for making the pool and the design of the house.

2 In sports, normally the swimming pools are 50 m long, minimum 21 m wide and 1.8 m overall depth.

4.19.2.4 *Floor slopes*

Slope of the floor of the pool should be made downward toward the main drain. All slopes should be uniform. The slope in shallow areas should not exceed 300 mm vertical in 3.6 m horizontal except for a slope directed downward from a transition point, which shall not exceed 300 mm vertical in 1m horizontal. In portions of the pool with a depth greater than 1.5 m, the front slope of the deep area shall not be steeper than 300 mm in 1 m.

4.19.2.5 *Transition point*

Transition points should be marked with a stripe on the pool floor having a width of at least 100 mm and a colour that contrasts with that of the floor, and with a buoyed safety rope with colour buoys, installed at least 300 mm on the shallow side of the transition point. In other pools having adjoining shallow and deep areas, a safety rope with colour buoys shall be installed where the water depth reaches 1.5 m.

4.19.2.6 *Pool walls*

Where the pool depth is 1 m or less, pool walls shall be vertical to the floor and the junction of the wall with the floor shall consist of a cove with a radius not exceeding 150 mm. Where the pool depth exceeds 1 m, pool walls shall meet one of the following criteria:

a) The wall shall be vertical for a depth of at least 1.5 m below the water level, below which the wall may angle to the floor; or

b) The wall shall be vertical for a depth of at least 1 m below the water level, below which the wall shall form a curve to the floor. The curve shall be tangent to the pool wall.

4.19.2.7 *Water depth*

The depth of a swimming pool depends on the purpose of the pool, and whether it is open to the public or strictly for private use. If it is a private casual, relaxing pool, it may go from 1.0 m to 1.5 m deep. If it is a public pool designed for diving, it may slope from 3.5 m to 5.0 m in the deep end. A children's play pool may be from 0.3 m to 0.6 m deep. Public pools may have differing depths to accommodate different swimmer requirements. Water depths may be clearly marked on the pool walls.

The width between handrails of the pool stairs should be between 500 mm and 600 mm.

4.19.2.8 *Walkways and deck areas*

Pools shall be completely surrounded by a deck that is at least 1.2 m in width and extends completely around and adjacent to the pool. There shall be no obstructions or interruptions of the pool deck within the 1.2 m adjacent to the pool other than necessary structural supports, or appurtenances such as diving boards, slides, perimeter overflow systems, or handrails. A clear, unobstructed walkway at least 1.2 m in width shall be maintained at such obstructions or interruptions. A wheelchair turning space of minimum 1.5m × 1.5 m shall be provided at key places in the walkway.

Structural supports located within the minimum required deck width or within 1.2 m of the swimming pool shall be no closer than 3 m apart measured parallel to the adjacent perimeter of the pool, with the dimension of any single support in a plane parallel to the adjacent pool perimeter not greater than 1 m and the sum of all such support dimensions not greater than 10 percent of the pool perimeter.

The deck between two adjacent swimming pools shall be at least 2.5 m wide. All decks and walkways shall have an unobstructed overhead clearance of at least 2 m.
Synthetic material which meets the following criteria may be installed for deck coverings:

a) Non-fibrous and allows drainage such that it will not remain wet or retain moisture;

b) Inert and will not support bacterial or fungal growth;

c) Durable;

d) Cleanable; and

e) Provides a slip-resistant finish.

The decks and walkways shall have a paved surface. The surface of the pool deck and other surfaces used for foot contact, such as gratings of perimeter overflow systems, shall be slip-resistant.

The outer perimeter of the deck for outdoor pools shall be at least 10 cm higher than the surrounding ground surface except where access is provided to adjacent turf areas.

The pool shall have an accessible entry and exit that is accessible to persons with disabilities. Accessible entry/exit may require provision of a transfer wall or/and a sloped entry with an aquatic chair. Installing a pool lifts may be another option for accessible entry/exit.

The transfer wall should have a minimum clear deck space of 1.5 m × 1.5m, with a slope not steeper than 1 : 48 at the base of the transfer wall. The height of the transfer wall should be 400 mm to 480 mm from the deck floor. The transfer wall should be 300 mm to 400 mm wide. The length should be minimum 1.5 m centered on the clear deck space. Surfaces of transfer walls shall not be sharp and shall have rounded edges.

A grab bar should be provided on the transfer wall. Grab bars shall be perpendicular to the pool wall and shall extend the full depth of the transfer wall. The top of the gripping surface shall be 100 mm to 150 mm above transfer walls. Clearance of 610 mm should be available on both sides of the grab bar.

4.19.2.9 *Starting platforms*

Starting platforms may be from 0.50 m to 0.75 m above the surface of water. The maximum height of the platform above the water shall be 0.75 m where the water depth is 1.2 m or greater, and 0.50 m when the water depth is less than 1.2 m. The surface area of each platform shall be 0.5 m × 0.5 m with a maximum slope of not more than 10°. Surface of each block shall be covered with non-slip material and with back stroke hand grip facility.

4.19.3 *Electrical Installation*

4.19.3.1 *Lighting*

Artificial lighting shall be provided at all indoor pools and at all outdoor pools that are open for use after sunset in accordance with one of the following:

a) Underwater lighting of at least 8.35 lumens or 5.5 W per square metre of pool water surface area, located to provide illumination of the entire pool floor; plus area lighting of at least 10 lumens or 6.6 W per square metre of deck area; and

b) If underwater lights are not provided, at least 33.5 lumens or 2.2 W per square metre of pool water surface area and deck area.

Where portable electric vacuum cleaning equipment is used, electrical receptacles with ground-fault circuit interrupter protection shall be provided. Separation between receptacles shall be a maximum of 30 m. All receptacles installed in the swimming pool area shall have waterproof covers and ground-fault circuit interrupter protection. Lighting controls should not be accessible to the public.

4.19.3.2 *Ventilation*

Adequate ventilation shall be provided in facilities to prevent objectionable odor.

4.19.3.3 *Shower and bathroom*

Separate shower, dressing booth and sanitary facilities shall be provided for each gender. This may not be applicable for schools and other institutional use where a pool may be open to one gender at a time. The rooms should be well lit, drained, ventilated, and of good construction, using impervious materials. They should be developed and planned to ensure maintenance of good sanitation throughout the building at all times. Floors should have a slip-resistant surface and sufficiently smooth to ensure ease in cleaning.

Each shower and toilet block provided per pool, open for use by public, shall have a unisex accessible shower, dressing-cum-toilet facility for persons with disabilities. Design specifications of this accessible facility shall be as per good practice [E-1(3)].

4.19.4 *Water Treatment System*

4.19.4.1 *General*

A water treatment system shall be provided to filter, chemically balance and disinfect the swimming pool water.

4.19.4.2 *Hair and lint strainer*

A hair and lint strainer shall be installed on the suction side of the pump except on vacuum filter systems. The strainer basket shall be easily removable. Valves shall be installed to allow the flow to be shut off during cleaning, switching baskets or inspection.

4.19.4.3 *Inlets*

Inlets for filtered water shall be located and directed suitably to produce uniform circulation of water to facilitate the maintenance of a uniform disinfectant residual throughout the entire pool without the existence of dead spots, and to produce surface flow patterns that effectively assist skimming.

4.19.4.4 *Outlets*

Pools shall be provided with a minimum of two drains (outlets) at the deepest point. Centre-to-centre distance between drains shall not exceed 2.0 m. Drains shall not be more than 3.0 m away from the pool walls. The main drain may be connected to the recirculation system. Openings shall be covered by grating which cannot be removed without the use of tools. Openings of the grating shall be at least four times the area of the main drain pipe or have an open area. The maximum width of grate openings shall not exceed 8 mm. Main drains and all other suction outlets installed in the pool shall be designed to prevent bather entrapment and shall be of anti-vortex type. The velocity at outlet pipe shall not be more than 0.3 m/s.

4.19.4.5 *Velocities*

Maximum permissible velocities for various components of the pools are as follows:

a) Suction pipe: less than 1.5 m/s;

b) Return pipe: 1.5 to 2 m/s; and

c) Return/inlet fittings: 2.4 m/s to 2.75 m/s in private pools and 1.5 m/s to 2 m/s in public pools.

4.19.4.6 *Balancing* (*surge*) *tank*

Overflow system shall be designed for effective surge capacity. Balancing tank should be provided of capacity to accommodate surge storage and storage for makeup water. The volume of the balancing tank shall be the total of the above with equal proportions.

4.19.4.7 *Make-up water*

Make-up water shall be added through a fixed air gap of at least 150 mm to the pool, surge tank, vacuum filter tank, or other receptacle. When make-up water is added directly to the pool, the fill-spout should be located under a low diving board or immediately adjacent to a ladder rail, grab rail, or fixed lifeguard chair.

4.19.4.8 *Filtration*

The design filtration rate in the particular application in which the filter is utilized shall not exceed the maximum design filtration rate for which the filter was installed. Wash or backwash water from diatomaceous earth filters shall be passed through a separation tank designed for removal of suspended diatomaceous earth and solids, prior to disposal.

NOTE — Filtration rates for various type of filters:

a) Low rate filter — 10 $m^3/m^2/h$.
b) Medium rate filter — 11 to 30 $m^3/m^2/h$.
c) High rate filter — 31 to 50 $m^3/m^2/h$.
d) Minimum flow rate for filter backwash — 30 $m^3/m^2/h$.

4.19.4.9 *Disinfection*

The pool water shall be continuously disinfected by suitable disinfecting agent that imparts easily measured residual. Gaseous chlorine, chlorine compounds, bromine compounds or other bactericidal agents should be used to maintain the quality parameters of water.

4.19.5 *Water Quality*

4.19.5.1 *Disinfectant residual*

Where chlorine is used as a disinfectant, the chlorine residual shall be maintained between 1.0 ppm and 4.0 ppm as free chlorine residual. A free chlorine residual of at least 2.0 ppm shall be maintained when the pool water temperature exceeds 30 ºC.

Where bromine is used as a disinfectant, a bromine residual shall be maintained between 2.0 ppm and 8.0 ppm as total bromine. A bromine residual of at least 4.0 ppm shall be maintained when the pool water temperature exceeds 30 ºC.

Where chlorinated cyanurates are used, the cyanuric acid concentration shall not exceed 100 ppm.

Where silver/copper or copper ion generators are used, the concentration of copper shall not exceed 1.3 ppm and the concentration of silver shall not exceed 0.05 ppm.

Where ozone is used, the ambient air ozone concentration shall be less than 0.1 ppm at all times either in the vicinity of the ozonator or at the pool water surface.

For all other physical, chemical and bacteriological parameters, the quality of water used in swimming pools in continuous circulation type shall conform to good practice [E-1(22)]. For safety aspects related to public swimming pools, the good practice [E-1(23)] shall be referred.

4.20 Allowance for Expansion

4.20.1 The allowances for expansion of the water pipes are recommended as given below:

a) All pipes should be installed at ambient temperature;
b) Pipes carrying hot fluids such as water or steam operate at higher temperatures. It follows that they expand, especially in length, with an increase from ambient to working temperatures. This will create stress upon certain areas within the distribution system, such as pipe joints, which, in the extreme, could cause fracture;
c) The pipe work system shall be sufficiently flexible to accommodate the movements of the components as they expand. In many cases, the flexibility of the pipe work system, due to the length of the pipe and number of bends and supports, means that no undue stresses are imposed. In other installations, however, it will be necessary to incorporate some means of achieving this required flexibility;
d) The expansion fitting is one method of accommodating expansion. These fittings are placed within a line and are designed to accommodate the expansion without the total length of the line changing. They are commonly called expansion bellows, due to the bellows construction of the expansion sleeve; and

e) Other expansion fittings can be made from the pipe work itself. This can be a cheaper way to solve the problem, but more space is needed to accommodate the pipe.

4.20.2 *Full Loop*

a) This is simply one complete turn of the pipe and, on steam pipe work, should preferably be fitted in a horizontal rather than a vertical position to prevent condensate accumulating on the upstream side;

b) The downstream side passes below the upstream side and great care shall be taken that it is not fitted wrong way round, as condensate can accumulate in the bottom. When full loops are to be fitted in a confined space, care shall be taken to specify that wrong-handed loops are not supplied; and

c) The full loop does not produce a force in opposition to the expanding pipe work as in some other types, but with steam pressure inside the loop, there is a slight tendency to unwind, which puts an additional stress on the flanges.

4.21 Colour Codes for Different Types of Water Pipes

The following colour codes are recommended for pipes {*see also* good practice [E-1(24)]}:

Sl No. (1)	*Contents* (2)	*Ground Colour* (3)	*First Colour Band* (4)	*Second Colour Band* (5)
i)	Cooling water	Sea green	French blue	—
ii)	Boiler feed water	Sea green	Gulf red	—
iii)	Condensate	Sea green	Light brown	—
iv)	Drinking water	Sea green	French blue	Signal red
v)	Treated water	Sea green	Light orange	—
vi)	Fire water	Fire red	Crimson red	—
vii)	Central heating below 60 °C	Sea green	Canary yellow	—
viii)	Central heating 60 °C to 100 °C	Sea green	Dark violet	—
ix)	Central heating above 100 °C	Sea green	Dark violet	Signal red
x)	Cold water down service from storage tanks	Sea green	French blue	Canary yellow
xi)	Domestic, hot	Sea green	Light grey	—
xii)	Hydraulic power	Sea green	Black	—
xiii)	Sea, river, untreated	Sea green	White	—
xiv)	Filtered water	Sea green	Light brown	—
xv)	Soft water	Sea green	Light brown	Signal red
xvi)	Warm water	Sea green	Light grey	Canary yellow
xvii)	Chilled water	Sea green	Black	Canary yellow
xviii)	Sprinkle and hydrant water	Sea green	White	Signal red
xix)	Waste water	Sea green	Canary yellow	Signal red
xx)	Demineralized water	Sea green	Gulf red	—
xxi)	Process water	Sea green	Oxide red	—

Sl No. (1)	*Contents* (2)	*Ground Colour* (3)	*First Colour Band* (4)	*Second Colour Band* (5)
xxii)	Wash water	Sea green	Canary yellow	—
xxiii)	Quench water	Sea green	Dark grey	—

ANNEX A

(*Clause* 3.2.1)

APPLICATION FORM FOR TEMPORARY/PERMANENT SUPPLY OF WATER/FOR ADDITIONS AND/OR ALTERATIONS FOR SUPPLY OF WATER

I/We …………………………..hereby make application to the* …………………….. for the temporary/permanent supply of water for the following additions and/or alterations to the water supply requirements and water fittings at the premises…………. Ward No. ……..Street No. ………….Road/Street known as ……………….for the purpose described below and agreed to pay such charges as the Authority may from time to time be entitled to make and to conform to all their byelaws and regulations…………………………licensed/registered plumber, has been instructed by me/us to carry out the plumbing work.

Description of the premises:………………………………………………………………………
Address :…………………………………………………………………………………………………..
Purpose for which water is required……………………………………………………………………….

……

The connection/connections taken by me/us for temporary use, shall not be used by me/us for permanent supply unless such a permission is granted to me/us in writing by the Authority.

I/We hereby undertake to give the*…………………………………………………….. due notice of any additions or alterations to the above mentioned supply which I/we may desire to make.

My/Our requirements of water supply are as under:

a) I/We request that one connection be granted for the whole of the premises.

b) I/We request that separate connections may be granted for each floor and I/we undertake to pay the cost of the separate connections.

c) My/Our probable requirements for trade purpose are ……………litre per day and for domestic purposes are……………..litre per day.

d) Our existing supply is ………………..litre per day. Our additional requirement of supply is ………………..litre per day.

e) The details as regards proposed additions and alterations in fittings are as follows:
…………………………………………………………………………………………………..
…………………………………………………………………………………………………..

Signature of the licensed/registered plumber…….	Signature of the applicant………
Name and address of the licensed/registered Plumber…………………………….	Name and address of the Applicant …………………………
Date ……………………	Date ……………..

NOTES

1 Please strike out whatever is not applicable.

2 The application should be signed by the owner of the premises or his constituted attorney and shall be countersigned by the licensed/registered plumber.

---

* Insert here the name of the Authority.

ANNEX B

(*Clause* 3.2.3)

FORM FOR LICENSED/REGISTERED PLUMBER'S COMPLETION CERTIFICATE

Certified that I/we have completed the plumbing work of water connection No……. for the premises as detailed below. This may be inspected and connection given.

Ward No………………………….. Road/Street……………………………..

Locality…………………………….

Block No……………………… House No……………………………………..

Existing water connection No. (if any)………………….

Owned by………………………………………………….

Owner's address………………………………………….

Applicant's name………………………… son of…………………………….

Address……………………………………

Situation…………………………………...

Size of main………………on…………… street

Where main is situated……………………………

Size of service pipe……………………………….

Size of ferrule………………………………………

No. of taps…………………………… No. of closets……………………………………

No. of other fittings and appliances………………………………………………..

Road cutting and repairing fee …………………………………………………….

Paid Rs………………(Receipt No…………dated………..) (receipt enclosed)

Dated ………………...

Signature of licensed/registered plumber…………..
Name and address of the licensed/registered plumber
…………………………………………………

The Authority's Report

Certified that the communication and distribution pipes and all water fittings have been laid, applied and executed in accordance with the provisions of bye-laws, and satisfactory arrangements have been made for draining off waste water.

Connection will be made on……………………………………

Date……………………… The Authority………………………

ANNEX C

(*Clause* 4.7.4)

NOMOGRAM OF HAZEN AND WILLIAM'S EQUATION

C-1 Examples of the use of nomogram are given below:

Example 1

Find the total friction loss in 25 mm diameter G.I. Pipe discharging 0.25 l/s in a total length of 300 m.

Procedure

Discharge, Q = 0.25 l/s

Pipe diameter = 25 mm

Frictional loss (from nomogram) = 30 m per 1 000 m

Total friction loss in 300 m length

$$= \frac{30}{1\ 000} \times 300 = 9\ m$$

Example 2

Find suitable diameter pipe to carry 15 l/s from service line to overhead tank.
Total length of service main = 200 m
Residual pressure available at the take off point on supply line is 15 m.

Procedure

Available head = 15 m

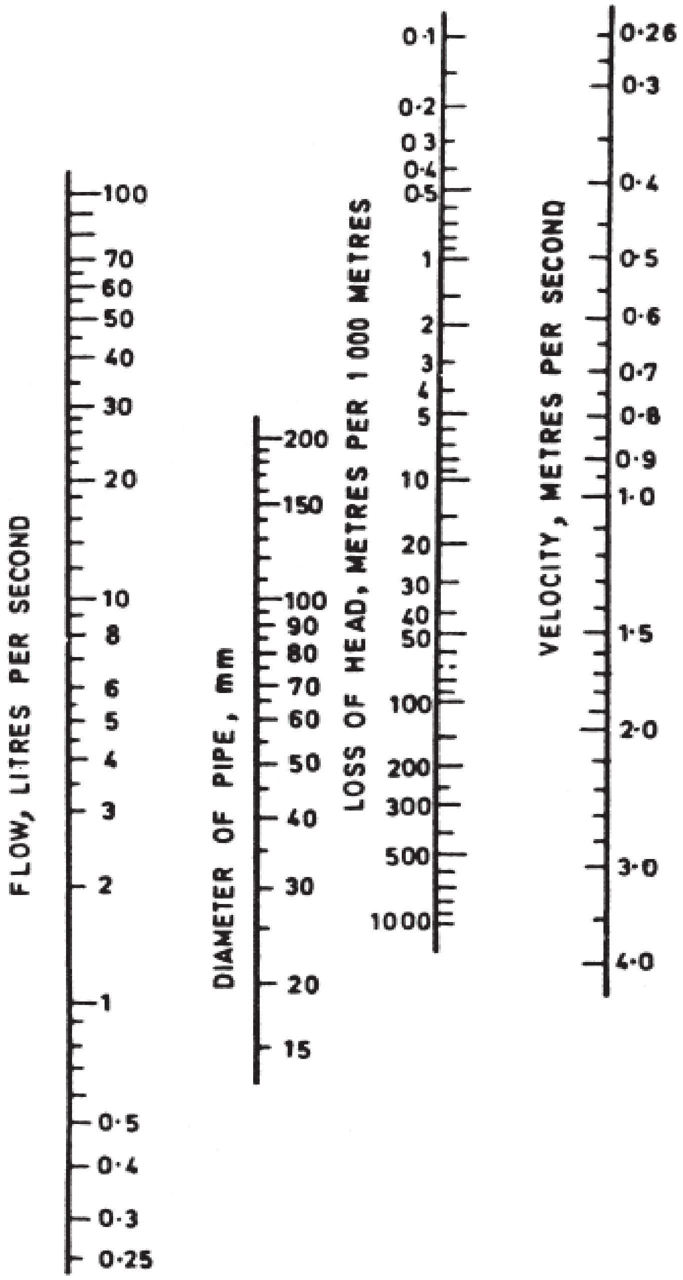
Deduct residual head = 2 m

Deduct 10 percent for losses in bends and specials = 1.3 m

Friction head available for loss in pipe of 1 000 m

$$= \frac{11.7}{200} \times 1\ 000 = 58.5\ m\ per\ 1\ 000\ m$$

From the follwing nomogram, for a discharge of 15 l/s and friction loss of 58.5 m per 1 000 m, nearest commercial size (diameter) of pipe is 100 mm.



Nomogram of Hazen & Williams Equation (c = 100)

LIST OF STANDARDS

The following list records those standards which are acceptable as 'good practice' and 'accepted standards' in the fulfilment of the requirements of this NBCS. The latest version of a standard shall be adopted at the time of enforcement of this NBCS. The standards listed may be used as a guide in conformance with the requirements of the referred clauses in this NBCS.

	IS No.	*Title*
(1)	IS 10446 : 1983	Glossary of terms relating to water supply and sanitation
(2)	IS 6295 : 1986	Code of practice for water supply and drainage in high altitudes and/or sub-zero temperature regions (*first revision*)
(3)	IS 4963 : 2025	Accessibility in built environment for older adults and persons with disabilities — Requirements (*second revision*)
(4)	IS 11208 :1985	Guidelines for registration of plumbers
(5)	IS 17650	Water efficient plumbing products — Requirements
	(Part 1) : 2021	Part 1 Sanitaryware
	(Part 2) : 2021	Part 2 Sanitary fittings
(6)	IS 10500 : 2012	Specification for drinking water (*second revision*)
(7)	IS 2041 : 2024	Steel plates and strips for pressure vessels used at moderate and low temperature — Specification (*fourth revision*)
	IS 804 : 1967	Specification for rectangular pressed steel tanks (*first revision*)
(8)	IS 4984 : 2016	Polyethylene pipes for water supply — Specification (*fifth revision*)
	IS 4985 : 2021	Unplasticized PVC pipes for water supplies — Specification (*fourth revision*)
	IS 15778 : 2007	Chlorinated polyvinyl chloride (CPVC) pipes for portable hot and cold water distribution supplies — Specification
(9)	IS 2065 : 1983	Code of practice for water supply in buildings (*second revision*)
(10)	IS 3114 : 1994	Code of practice for laying of cast iron pipes (*second revision*)
(11)	IS 5822 : 1994	Code of practice for laying of electrically welded steel pipes for water supply (*second revision*)
(12)	IS 6530 : 1972	Code of practice for laying of asbestos cement pressure pipes
(13)	IS 783 : 1985	Code of practice for laying of concrete pipes (*first revision*)
(14)	IS 7634	Code of practice for plastics pipe work for potable waters supplies
	(Part 1) : 1975	Choice of materials and general recommendations
	(Part 2) : 2012	Laying and jointing of polyethylene (PE) pipes (*first revision*)
	(Part 3) : 2003	Laying and jointing of UPVC pipes (*first revision*)
(15)	IS 783 : 1985	Code of practice for laying of concrete pipes (*first revision*)
	IS 3114 : 1994	Code of practice for laying of cast iron pipes (*second revision*)
	IS 5822 : 1994	Code of practice for laying of welded steel pipes for water supply (*second revision*)
	IS 6530 : 1972	Code of practice for laying of asbestos cement pressure pipes
	IS 7634	Code of practice for plastics pipe work for potable water supplies
	(Part 1) : 1975	Choice of materials and general recommendations
	(Part 2) : 2012	Laying and jointing of polyethylene (PE) pipes (*first revision*)
	(Part 3) : 2003	Laying and jointing of UPVC pipes (*first revision*)

	IS No.	*Title*
(16)	IS 2692 : 1989	Ferrules for water services — Specification (*second revision*)
(17)	IS 302 (Part 1) : 2024 /IEC 60335-1 : 2020	Household and similar electrical appliances — Safety: Part 1 General requirements (*seventh revision*)
	IS 2082 : 2018	Stationary storage type electric water heaters — Specification (*fifth revision*)
(18)	IS 17150 : 2025	Mini domestic water heater for use with piped natural gas (PNG) — Specification (*first revision*)
(19)	IS 7558 : 1974	Code of practice for domestic hot water installations
	IS 16093 : 2013	Installation of gas based instantaneous water heater — Code of practice
(20)	IS 12976 : 2023	Solar water heating systems — Code of practice (*first revision*)
(21)	IS 6494 : 1988	Code of practice for water-proofing of underground water reservoirs and swimming pools (*first revision*)
(22)	IS 3328 : 2026	Quality requirements of water for swimming pools (*second revision*)
(23)	IS 16508 : 2017	Swimming pool for public — Code of safety
(24)	IS 2379 : 2024	Colour code for pipeline identification — Code of practice (*second revision*)

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART E PLUMBING SERVICES (INCLUDING SOLID WASTE MANAGEMENT)

SECTION 2 DRAINAGE AND SANITATION

BUREAU OF INDIAN STANDARDS

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National Building Code Sectional Committee, CED 46

FOREWORD

This NBCS (Part E/Section 2) covers the drainage and sanitation requirements of buildings, design, layout, construction and maintenance of drains inside buildings and from the buildings up to the connection to public sewer, private sewer, individual sewage disposal system, cesspool, or to other approved point of disposal/treatment work. It also covers drainage systems peculiar to high altitudes and/or sub-zero temperature regions of the country.

In the first version of the Code formulated in 1970, as part of the National Building Code of India, three separate sections of this Part on 'Plumbing Services', were brought out, namely, Section 1 'Water Supply', Section 2 'Drainage and Sanitation', and Section 3 'Gas Supply'. These sections were subsequently revised in 1983.

The major changes incorporated in the first revision in Section 2 'Drainage and Sanitation' were rationalization of definitions; modification of the requirements for fitments for drainage and sanitation in the case of buildings other than residences; addition of table for sanitation facilities in fruit and vegetable markets; introduction of table giving detailed guidance regarding the selection of plumbing system, depending on the nature of drainage load in buildings and height of buildings; amplification of provision relating to safeguards to be adopted in single stack system; modification of the values of gradients, pipe sizes and the corresponding discharges; rationalization of sizes of manholes/inspection chambers; modification of the sizing of rainwater pipe for roof drainage, to take into account rainfall intensities and recommend sizes on a more rational basis; addition of provisions for drainage and sanitation system peculiar to high altitudes and/or sub-zero temperature regions of the country; and inclusion of requirements of the refuse chute system.

As a result of experience gained in implementation of 1983 version of the Code and feedback received as well as revision of some of the standards based on which this Section was prepared, a need to revise this Section was felt. The second revision of 2005 was therefore prepared to take care of these. In the revision, the erstwhile two Sections were merged and a combined and comprehensive section, namely Section 1 Water Supply, Drainage and Sanitation (including solid waste management), was brought out. Gas supply was brought out as Section 2. Following significant changes were incorporated in the second revision of Section 1 on Water Supply, Drainage and Sanitation, in respect to drainage and sanitation: rationalization and addition of new definitions under terminology; enunciation of certain basic principles for water supply and drainage; addition of a new clause on sanitary appliances; updation of Table 1 to Table 14 of the existing version, regarding drainage and sanitation requirement; addition of additional requirements under layout clause of design considerations; modification and rationalization of provisions regarding choice of plumbing systems; addition of new clause on drain appurtenances having details on trap, floor drain and cleanout; incorporation of provisions on indirect wastes, special wastes (covering laboratory wastes, infected wastes, research laboratory wastes, etc), grease traps, oil interceptors, radio-active wastes, etc; revision of manhole details on size and enhancement of construction clause; inclusion of provisions on rainwater harvesting; revision of the minimum rainfall intensity which is drain design basis for discharge of storm water drain into a public storm water drain, to 50 mm/h; modification of the table for sizing of rainwater pipes for roof drainage, with inclusion of rainfall data which were not available in the earlier version; inclusion of figure on detail of subsoil drainage; and addition of details on support/protection of pipes. This revision also incorporated for the first time the provisions on solid waste management.

In the third revision in 2016, to comprehensively address the various and distinct features related to the plumbing aspects, this Part on 'Plumbing Services' was rearranged as follows:

Section 1	Water supply
Section 2	Drainage and sanitation
Section 3	Solid waste management
Section 4	Gas supply

In the 2016 version of this Section 2 on Drainage and Sanitation, several significant updates were incorporated to address contemporary needs and enhance the comprehensiveness of the provisions. Various tables on the requirements for fitments for drainage and sanitation across different occupancies were updated, including a new table specifically for shopping malls and retail buildings. Enabling provisions were introduced for the use of corrugated pipes, low-noise pipes and under-slung pipes, alongside information on bio-toilets. Typical mounting arrangements for plumbing fixtures and drainage systems were illustrated and a new table for single-stack sizing was included. Key updates also focused on drainage and sanitation system layouts, venting systems for high-rise buildings with detailed tables**,** and the gradients of drainage pipes. Fixture unit tables and maximum connections to branches, stacks, and sewers were revised, and new provisions for high-rise building drainage systems were added. Provisions for manhole covers, stormwater runoff estimation, rainwater pipe sizing, siphonic drainage, rainwater harvesting and artificial groundwater recharge were included, along with recommendations for septic tanks.

In this revision, this publication has been renamed as National Building Construction Standards (NBCS).

In this revision, following significant changes have been incorporated:

a) Key terms along with their definition, such as emergency floor drain, flood level rim and yoke vent, have been included to enhance clarity and technical precisions in plumbing systems;

b) Tables on requirements for fitments in drainage and sanitation in various building occupancies, have been updated;

c) Provisions have been added for managing the horizontal and vertical distances of sanitary fixtures and connections to drainage stacks to ensure efficiency and prevent blockages;

d) Guidelines for packaged sewage treatment plant (PSTP) have been included to facilitate on-site treatment of grey and black water, particularly in areas without centralized sewer systems; and

e) Biodigesters have been included as a sustainable, non-sewer on-site waste treatment solution.

This Section is largely based on the following Indian Standards:

IS 1742 : 1983	Code of practice for building drainage (*second revision*)
IS 4111 (Part 1) : 1986	Code of practice for ancillary structures in sewage system: Part 1 Manholes (*first revision*)
IS 5329 : 1983	Code of practice for sanitary pipe work above ground for buildings (*first revision*)
IS 6295 : 1986	Code of practice for water supply and drainage in high altitudes and/or sub-zero temperature regions (*first revision*)

A reference to SP 35 : 1987 'Handbook on Water Supply and Drainage' may be useful, from where also, assistance has been derived.

All standards, whether given herein above or cross-referred to in the main text of this Section, are subject to revision. The parties to agreement based on this section are encouraged to investigate the possibility of applying the most recent editions of the standards.

In the formulation of this Section, reference has also been made to the following:

International Plumbing Code 2024, International Code Council, and

Uniform Illustrated Plumbing Code – India (Volume I and Volume II) 2022, IAPMO India Private Limited

As the regulation of land development and buildings is a State subject and is dealt by the States and local bodies such as urban local bodies within their jurisdiction through building regulatory documents like building regulations, building byelaws, and fire regulations, this document is voluntary in nature and is non-binding. The implementation depends on adoption by concerned parties or stipulations in a contract or by appropriate adoption by the concerned authorities.

For the purpose of deciding whether a particular requirement of this Section is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 'Rules for rounding off numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this Section.

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Important Explanatory Note for Users of this NBCS

In any Part/Section of this NBCS, where reference is made to **'good practice'** in relation to design, constructional procedures or other related information, and where reference is made to **"accepted standard"** in relation to material specification, testing, or other related information, the Indian Standards listed at the end of the Part/Section shall be used as a guide to the interpretation.

At the time of publication, the editions indicated in the standards were valid. All standards are subject to revision and parties to agreements based on any Part/Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

In the list of standards given at the end of a Part/Section, the number appearing within parentheses in the first column indicates the number of the reference of the standard in the Part/Section. For example:

a) Good practice [E-2(1)] refers to the Indian Standard(s) given at serial number (1) of the list of standards given at the end of this Part E/Section 2, that is, IS 10446 : 1983 'Glossary of terms relating to water supply and sanitation'.

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART E PLUMBING SERVICES (INCLUDING SOLID WASTE MANAGEMENT)

SECTION 2 DRAINAGE AND SANITATION

1 SCOPE

1.1 This NBCS (Part E/Section 2) covers the design, layout, construction and maintenance of drains for foul water, surface water, subsoil water and sewage together with all ancillary works, such as connections, manholes and inspection chambers used within the building and from building to the connection to a public sewer, private sewer, individual sewage-disposal system, cess-pool, soakaway or to other approved point of disposal/treatment work.

NOTE — A sanitary drainage system consists of a building sewer, a building drain, a soil and/or waste stack, horizontal branches or fixture drain and vents. The sanitary drainage of a large building may have a number of primary and secondary branches and several soil and/or waste stacks, each of them in turn may have a number of horizontal branches.

2 TERMINOLOGY

For the purpose of this Section, the following definitions shall apply in addition to the definitions given in accepted standards [E-2(1)].

2.1 Air Admittance Valve — One way valves designed to allow air to enter drainage system when negative pressure develops in the system. The purpose is to provide a method of allowing air to enter the drainage system for prevention of siphonage of traps.

2.2 Air Break — Physical separation which may be a low inlet into the indirect waste receptor from the fixture or device indirectly connected.

2.3 Air Gap, Drainage — Unobstructed vertical distance through the free atmosphere between the lowest opening from any pipe, plumbing fixture or appurtenance conveying waste to flood level of the receptor.

2.4 Back Up — A condition where the waste water may flow back into another fixture or compartment but not back into the potable water system.

2.5 Back Water Valve — Device installed in a drainage system to prevent reverse flow.

2.6 Bath Room Group — Group of fixtures consisting of water closet, lavatories bath tub or shower and other fittings with a floor drain located together.

2.7 Battery of Fixtures — Any group of two or more similar adjacent fixtures which discharge into a common horizontal waste or soil pipe.

2.8 Bed Pan Washer — A washer which is to be used for disposing human waste and sterilizing the bed pan for reuse. Bed pan washer requires water connection and electrical heating arrangement. This is to be considered as soil appliance.

2.9 Benching — Sloping surfaces constructed on either side of channels at the base of a manhole or inspection chamber for the purpose of confining the flow of sewage, avoiding the accumulation of deposits and providing a safe working platform.

2.10 Black Water — Waste water from water closet, bidet, urinals, kitchen sink and bed pan sink or similar contaminated sources.

2.11 Branch

a) Special form of sewer pipe used for making connections to a sewer or water main. The various types are called ‘T’, ‘Y’, ‘T-Y’, double Y and V branches, according to their respective shapes; and

b) Any part of a piping system other than a main or stack.

2.12 Branch Soil Pipe (BSP) — A pipe connecting one or more soil appliances to the main soil pipe.

2.13 Branch Soil Waste Pipe (BSWP) — A pipe connecting one or more soil and/or waste appliances to the main soil waste pipe (one pipe system).

2.14 Branch Vent Pipe (BVP) — A pipe, one end of which is connected to the system adjacent to the trap of an appliance and the other to a main vent pipe or a drain-vent pipe. It is fitted to prevent loss of water seal from a trap owing to partial vacuum, back-pressure, or surging caused by air movement within the pipe system. It also provides ventilation for the branch waste pipe.

2.15 Branch Waste Pipe (BWP) — A pipe connecting one or more waste appliances to the main waste pipe.

2.16 Building Drain-Combined — A building drain which conveys both sewage and storm water or other drainage.

2.17 Building Drain-Sanitary — A building drain which conveys sewage and sullage only.

2.18 Building Drain-Storm — A building drain which conveys storm water or other drainage but no sewage or sullage.

2.19 Building Sewer — That part of the horizontal piping of a drainage system which extends from the end of the building drain and which receives the discharge of the building drain and conveys it to a public sewer, private sewer, individual sewage-disposal system or approved point of disposal.

2.20 Building Sub-Drain — That portion of a drainage system which cannot drain by gravity in the building sewer.

2.21 Building Trap — A device, fitting or assembly of fittings installed in the building drain to prevent circulation of air between the drainage of the building and the building sewer. It is usually installed as running trap.

2.22 Cesspool

a) An underground chamber for the reception and storage of foul water, the contents of which are periodically removed for disposal; and

b) A box-shaped receiver constructed in a roof or gutter for collecting rainwater which then passes into a rainwater pipe connected thereto.

2.23 Cleaning Eye — An access opening in a pipe or pipe fitting arranged to facilitate the cleaning of obstructions and fitted with removable cover.

2.24 Clear Waste Water — Cooling water and condensate drainage from refrigeration and air conditioning equipment, cooled condensate from steam heating systems, cooled boiler blow-down water, waste water drainage from equipment rooms and other areas where water is used without an appreciable addition of oil, gasoline, solvent, acid, etc, and treated effluent in which impurities have been reduced below a minimum concentration considered harmful.

2.25 Collection Chamber — A compartment situated at the lower end of the chute for collecting and housing the refuse during the period between two successive cleanings.

2.26 Connection — The junction of a foul water drain, surface water drain or sewer from building or building with public sewer treatment works, public sewer, private sewer, individual sewage-disposal system, cess-pool, soakaway or to other approved point of disposal/treatment work.

2.27 Consumer — Any person who discharges waste or sewage to the public sewer installed by the Authority.

2.28 Crown of Trap — The topmost point of the inside of a trap outlet.

2.29 Deep Manhole — A manhole of such depth that an access shaft is required in addition to the working chamber.

2.30 Depth of Manhole — The vertical distance from the top of the manhole cover to the outgoing invert of the main drain channel.

2.31 Developed Length — The length measured along the centre line of a pipe and fittings.

2.32 Diameter — The nominal internal diameter of pipes and fittings.

2.33 Drain — A conduit, channel or pipe for the carriage of storm water, sewage, waste water or other water-borne wastes in a building drainage system.

2.34 Drain Vent Pipe (DVP) — A pipe installed to provide flow of air to or from a drain to prevent undue concentration of foul air in the drain. The main soil pipe or main waste pipe may serve as drain vent pipe wherever their upper portions, which do not receive discharges, are extended to the roof level and let open to air.

2.35 Drainage — The removal of any liquid by a system constructed for the purpose.

2.36 Drainage Fixture Unit (DFU) — A measure of probable discharge into the drainage system by various types of plumbing fixtures. The drainage fixture unit value for a particular fixture depends on its volume rate of drainage discharge, on the time duration of a single drainage operation and on the average time between successive operations.

2.37 Drainage Work — The design and construction of a system of drainage.

2.38 Drop Connection — A length of conduit installed vertically immediately before its connection to a sewer or to another drain.

2.39 Drop Manhole — A manhole installed in a sewer where the elevation of the incoming sewer considerably exceeds that of the outgoing sewer; a vertical waterway outside the manhole is provided to divert the waste from the upper to the lower level so that it does not fall freely into the manhole except at peak rate of flow.

2.40 Eco-Toilet (or Bio-toilet) — The dry toilet that uses a predominantly aerobic processing system to treat human excreta, by composting or managed-aerobic decomposition. It generally uses little to no water and may be used as an alternative to flush toilets.

2.41 Emergency Floor Drain — A floor drain that does not receive the discharge of any drain or indirect waste pipe, and that protects against damage from accidental spills, fixture overflows and leakage.

2.42 Fittings — The appurtenances such as coupling, flange, branch, bend, tees, elbows, unions, waste (with or without plug), P or S trap (with or without vent), stop ferrule, bib tap, pillar tap, bath faucet, water meter, garden hydrant, valves and any other article used in connection with water supply, drainage and sanitation.

2.43 Fixture Unit — A quantity in terms of which the load producing effects on the plumbing system of different kinds of plumbing fixtures is expressed on some arbitrarily chosen scale.

2.44 Formation — The finished level of the excavation at the bottom of a trench or heading prepared to receive the permanent work.

2.45 French Drain or Rubble Drain — A shallow trench filled with coarse rubble, clinker, or similar material with or without field drain pipes.

2.46 Frost Line — The line joining the points of greatest depths below ground level up to which the moisture in the soil freezes.

2.47 Flood Level Rim — The edge of the receptacle from which water overflows.

2.48 Grease Interceptor (or Grease Trap) — A chamber, on the line of a drain or waste pipe, for preventing grease from passing into the drainage system. It reduces non-petroleum fats, oils and grease in effluent by separation and volume reduction to improve sewage treatment efficiency.

As it is used to intercept fats, oils and grease (FOG) from a waste water discharge, it is also known as FOG interceptor.

2.49 Grey Water — Waste water that has not encountered water closet, kitchen sink waste, or similar contaminated sources. Grey water includes waste water from bathtubs, showers, lavatories, clothes washers, dishwashers and domestic reverse osmosis (RO) reject water.

2.50 Gully Chamber — The chamber built of masonry round a gully trap for housing the same.

2.51 Gully Trap — A trap provided in a drainage system with a water seal fixed in a suitable position to collect wastewater from the scullery, kitchen sink, wash basins, baths and rainwater pipes.

2.52 High Altitudes — Elevations higher than 1 500 m above mean sea level (MSL).

2.53 Highway Authority — The public body in which is vested, or which is the owner of, a highway repairable by the inhabitants collectively; otherwise the body or persons responsible for the upkeep of the highway.

2.54 Horizontal Pipe — Any pipe of fitting which makes an angle of more than 45° with the vertical.

2.55 Indirect Waste Pipe — The pipe that does not connect directly with the drainage system but conveys liquid wastes by discharging into a plumbing fixture/interceptor that is directly connected to the drainage system.

2.56 Inlet Fittings — An arrangement of connecting the internal waste branch pipe from wash basin, sinks and shower drains to the main deep seal trap with the help of hopper extension.

2.57 Inlet Hopper — A receptacle fitting for receiving refuse from each floor and dropping it into the chute.

2.58 Insanitary — Condition that is contrary to sanitary principles or is injurious to health.

2.59 Inspection Chamber — A water-tight chamber constructed in any house-drainage system which takes wastes from gully traps and disposes to manhole with access for inspection and maintenance.

2.60 Interceptor — A device designed and installed so as to separate and retain deleterious, hazardous or undesirable matter from normal wastes and permit normal sewage or liquid wastes to discharge into the disposal terminal by gravity.

2.61 Interceptor Manhole or Interceptor Chamber — A manhole incorporating an intercepting trap and providing means of access thereto.

2.62 Invert — The lowest point of the internal surface of a pipe or channel at any cross section.

2.63 Junction Pipe — A pipe incorporating one or more branches.

2.64 Lagging — Thermal insulation or pipes.

2.65 Licensed (or Registered) Plumber — A person licensed (or registered) under the provisions of this NBCS.

2.66 Main Soil Pipe (MSP) — A pipe connecting one or more branch soil pipes to the drain.

2.67 Main Soil and Waste Pipe (MSWP) — A pipe connecting one or more branch soil and waste pipes to the drain.

2.68 Main Vent Pipe (MVP) — A pipe which receives a number of branch vent pipes.

2.69 Main Waste Pipe (MWP) — A pipe connecting one or more branch waste pipes to the drain.

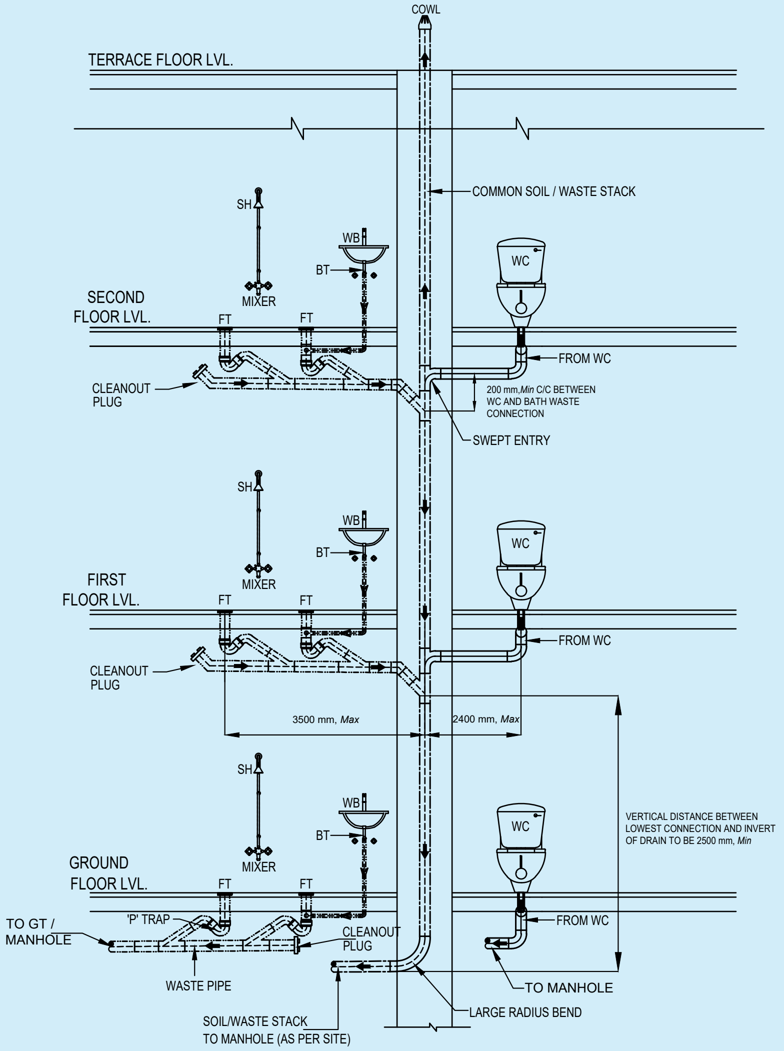
2.70 Manhole — An opening by which a man may enter or leave a drain, a sewer or other closed structure for inspection, cleaning and other maintenance operations, fitted with suitable cover.

2.71 Manhole Chamber — A Chamber constructed on a drain or sewer so as to provide access thereto for inspection, testing or clearance of obstruction.

2.72 Offset — A pipe fitting used to connect two pipes whose axes are parallel but not in line.

2.73 Pipe System — The system to be adopted will depend on the type and planning of the building in which it is to be installed and will be one of the following:

a) *Single stack system* (*see* Fig. 1) — The piping system in which there is no trap ventilation and the stack itself acts as vent through roof. In this system care shall be taken for proper sizing of the pipes and the trap arm distance, specially the horizontal distance of sanitary fixtures from the drainage stack and vertical distance between connection of branches from fixtures to drainage stack;


COWL
TERRACE FLOOR LVL.
COMMON SOIL / WASTE STACK
SH
WB
BT
WC
MIXER
SECOND FLOOR LVL.
FT
FT
FROM WC
CLEANOUT PLUG
200 mm,*Min* C/C BETWEEN WC AND BATH WASTE CONNECTION
SWEPT ENTRY
SH
WB
BT
WC
MIXER
FIRST FLOOR LVL.
FT
FT
FROM WC
CLEANOUT PLUG
3500 mm, *Max*
2400 mm, *Max*
SH
WB
BT
WC
VERTICAL DISTANCE BETWEEN LOWEST CONNECTION AND INVERT OF DRAIN TO BE 2500 mm, *Min*
GROUND FLOOR LVL.
MIXER
FT
FT
'P' TRAP
TO GT / MANHOLE
CLEANOUT PLUG
FROM WC
WASTE PIPE
TO MANHOLE
LARGE RADIUS BEND
SOIL/WASTE STACK TO MANHOLE (AS PER SITE)

LEGEND

SH	SHOWER
WC	WATER CLOSET
WB	WASH BASIN
FT	FLOOR TRAP
BT	BOTTLE TRAP
GT	GULLY TRAP

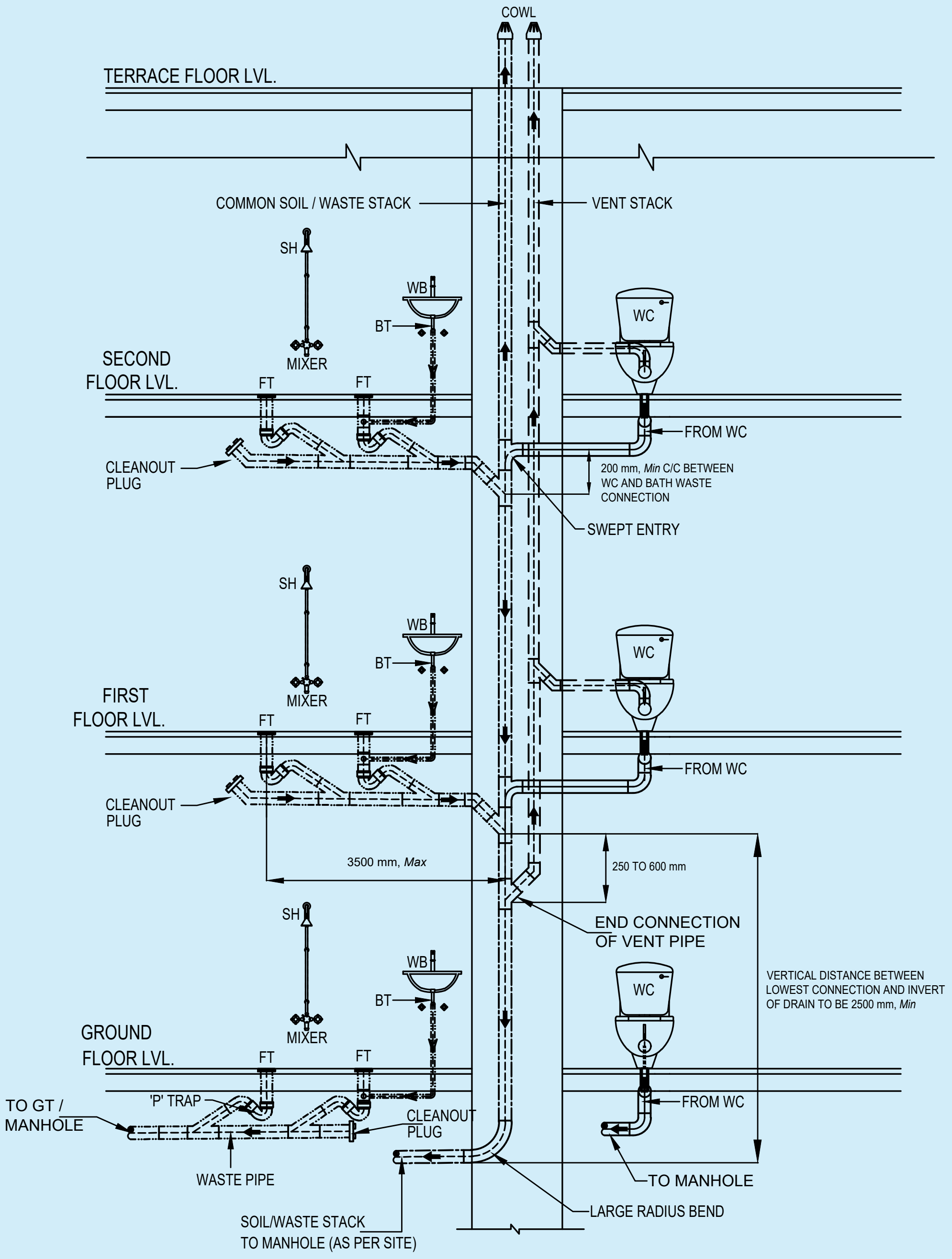
NOTES

1 Presentation of type of fixtures/drains, and pipe route/layout is typical in nature.

2 Kitchen waste piping shall also be planned in a similar manner as for other waste appliances.

FIG. 1 SINGLE STACK SYSTEM

b) *One pipe — Partially ventilated system* (*see* Fig. 2) — The piping system in which soil and waste pipes are connected to a single vertical stack [as explained in **2.73(a)**] with additional vent pipe for ventilation of traps of water closets;



COWL
TERRACE FLOOR LVL.
COMMON SOIL / WASTE STACK
VENT STACK
SH
WB
BT
WC
MIXER
SECOND
FLOOR LVL.
FT
FT
FROM WC
CLEANOUT
PLUG
200 mm, *Min* C/C BETWEEN
WC AND BATH WASTE
CONNECTION
SWEPT ENTRY
SH
WB
BT
WC
MIXER
FIRST
FLOOR LVL.
FT
FT
FROM WC
CLEANOUT
PLUG
3500 mm, *Max*
250 TO 600 mm
END CONNECTION
OF VENT PIPE
VERTICAL DISTANCE BETWEEN
LOWEST CONNECTION AND INVERT
OF DRAIN TO BE 2500 mm, *Min*
SH
WB
BT
WC
MIXER
GROUND
FLOOR LVL.
FT
FT
TO GT /
MANHOLE
'P' TRAP
CLEANOUT
PLUG
FROM WC
WASTE PIPE
TO MANHOLE
LARGE RADIUS BEND
SOIL/WASTE STACK
TO MANHOLE (AS PER SITE)

LEGEND

SH	SHOWER
WC	WATER CLOSET
WB	WASH BASIN
FT	FLOOR TRAP
BT	BOTTLE TRAP
GT	GULLY TRAP

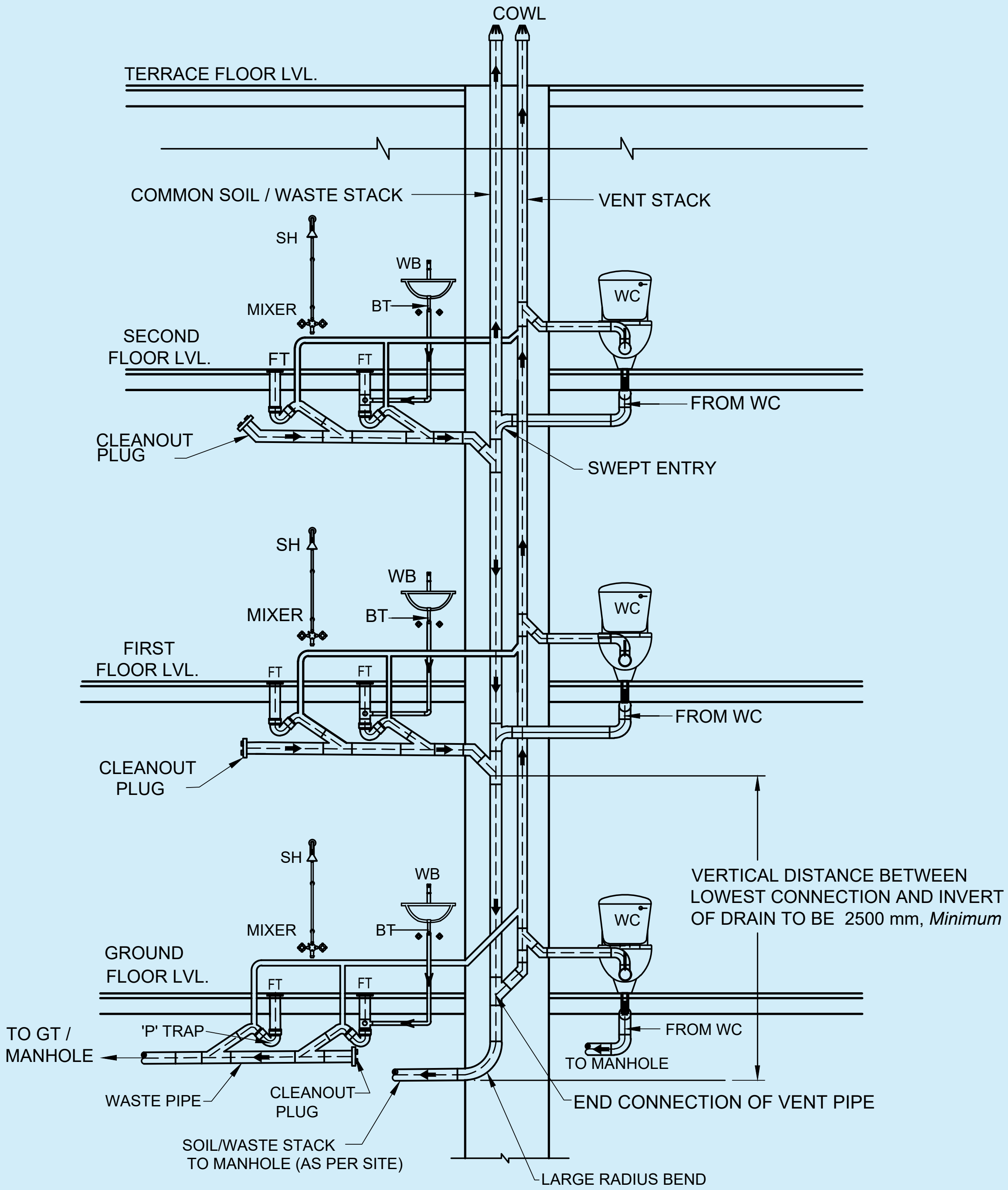
NOTES

1 Presentation of type of fixtures/drains, and pipe route/layout is typical in nature.

2 Kitchen waste/vent piping shall also be planned in a similar manner as for other waste appliances.

FIG. 2 ONE PIPE — PARTIALLY VENTILATED SYSTEM

c) *One pipe — Fully ventilated system* (*see* Fig. 3) — The piping system in which the waste pipes from the sinks, baths and wash basins, and the soil pipe from water closet are connected to a single vertical stack. The traps of the water closets, waste appliances, etc, are individually ventilated and connected with a separate stack to preserve the water seal;


COWL
TERRACE FLOOR LVL.
COMMON SOIL / WASTE STACK
VENT STACK
SH
WB
MIXER
BT
WC
SECOND FLOOR LVL.
FT
FT
FROM WC
CLEANOUT PLUG
SWEPT ENTRY
SH
WB
MIXER
BT
WC
FIRST FLOOR LVL.
FT
FT
FROM WC
CLEANOUT PLUG
SH
WB
MIXER
BT
WC
VERTICAL DISTANCE BETWEEN LOWEST CONNECTION AND INVERT OF DRAIN TO BE 2500 mm, *Minimum*
GROUND FLOOR LVL.
FT
FT
TO GT / MANHOLE
'P' TRAP
FROM WC
TO MANHOLE
WASTE PIPE
CLEANOUT PLUG
END CONNECTION OF VENT PIPE
SOIL/WASTE STACK TO MANHOLE (AS PER SITE)
LARGE RADIUS BEND

LEGEND

SH	SHOWER
WC	WATER CLOSET
WB	WASH BASIN
FT	FLOOR TRAP
BT	BOTTLE TRAP
GT	GULLY TRAP

NOTES

1 Presentation of type of fixtures/drains, and pipe route/layout is typical in nature.

2 Kitchen waste/vent piping shall also be planned in a similar manner as for other waste appliances.

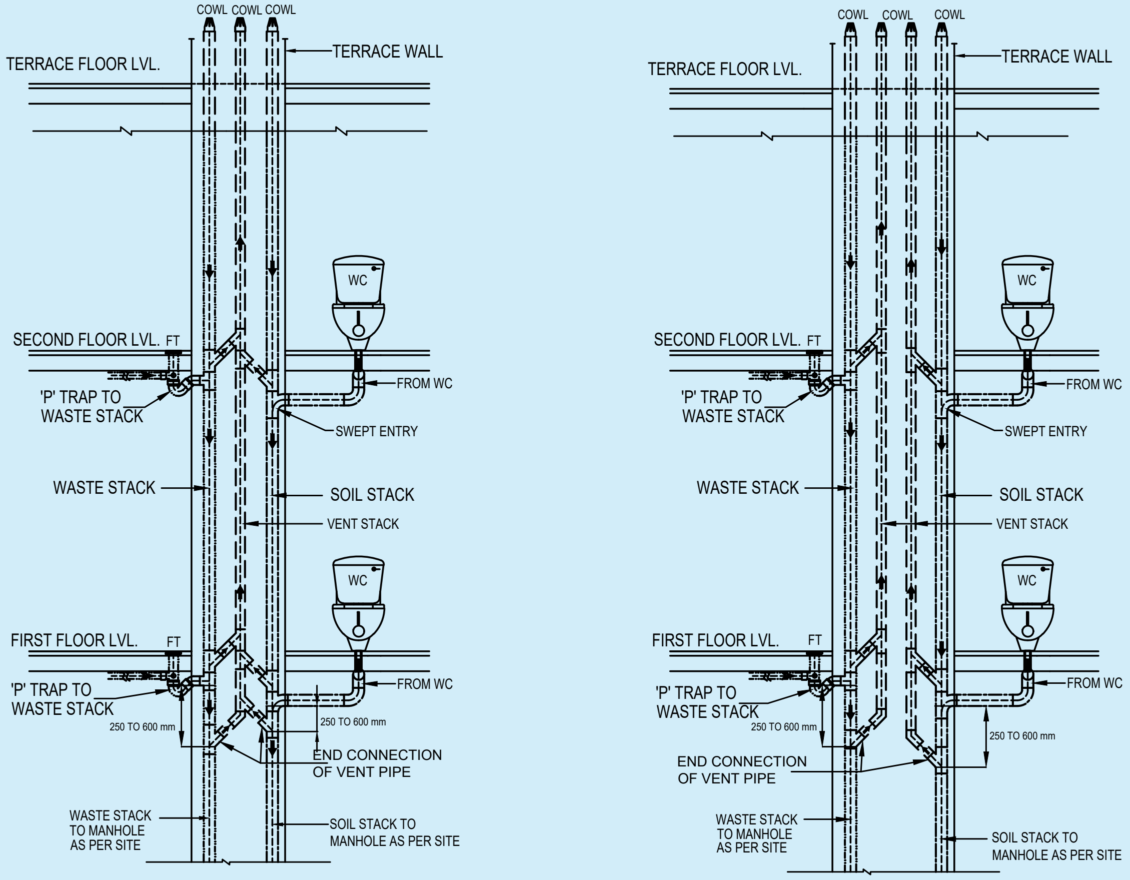
3 The vent pipe shall be installed in the wall above or in suspended ceiling depending on project pipe routing, but vent should be above water level.

FIG. 3 ONE PIPE – FULLY VENTILATED SYSTEM

d) *Two pipe system*:

1) *Two pipe system with common vent pipe* (*see* Fig. 4A) — The piping system in which all soil appliances such as water closets, urinals, bidet and bedpan sinks are connected to soil stack and all other plumbing fixtures such as baths, sinks, and basins are connected to waste stack through deep seal trap. In addition, a common vent stack is provided for ventilation of soil and waste stacks; and

2) *Two pipe system with independent vent pipes* (*see* Fig. 4B) — The piping system in which all soil appliances such as water closets, urinals, bidet and bedpan sinks are connected to soil stack, and all other plumbing fixtures such as baths, sinks, and basins are connected to waste stack through deep seal trap. In addition, there are independent a vent stacks provided for respective ventilation of soil and waste stacks.


COWL
COWL
COWL
TERRACE FLOOR LVL.
TERRACE WALL
WC
SECOND FLOOR LVL.
FT
FROM WC
'P' TRAP TO WASTE STACK
SWEPT ENTRY
WASTE STACK
SOIL STACK
VENT STACK
WC
FIRST FLOOR LVL.
FT
FROM WC
'P' TRAP TO WASTE STACK
250 TO 600 mm
250 TO 600 mm
END CONNECTION OF VENT PIPE
WASTE STACK TO MANHOLE AS PER SITE
SOIL STACK TO MANHOLE AS PER SITE
COWL
COWL
COWL
TERRACE FLOOR LVL.
TERRACE WALL
WC
SECOND FLOOR LVL.
FT
FROM WC
'P' TRAP TO WASTE STACK
SWEPT ENTRY
WASTE STACK
SOIL STACK
VENT STACK
WC
FIRST FLOOR LVL.
FT
FROM WC
'P' TRAP TO WASTE STACK
250 TO 600 mm
250 TO 600 mm
END CONNECTION OF VENT PIPE
WASTE STACK TO MANHOLE AS PER SITE
SOIL STACK TO MANHOLE AS PER SITE

4A TWO PIPE SYSTEM WITH COMMON VENT PIPE

4B TWO PIPE SYSTEM WITH INDEPENDENT VENT PIPES

LEGEND

SH	SHOWER
WC	WATER CLOSET
WB	WASH BASIN
FT	FLOOR TRAP
BT	BOTTLE TRAP
GT	GULLY TRAP

NOTES

1 Presentation of type of fixtures/drains, and pipe route/layout is typical in nature.

2 Kitchen waste/vent piping shall also be planned in a similar manner as for other waste appliances.

FIG. 4 TWO PIPE SYSTEM

2.74 Plumbing

a) The pipes, fixtures and other apparatus inside a building for bringing in the water supply and removing the liquid and water borne wastes; and

b) The installation of the foregoing pipes, fixtures and other apparatus.

2.75 Plumbing System ð The plumbing system shall include the water supply and distribution pipes; plumbing fittings and traps; soil, waste, ventilating pipes and anti-siphonage pipes; building drains and building sewers including their respective connections, devices and appurtenances within the property lines of the premises; and water-treating or water-using equipment.

2.76 Premises ð Premises shall include passages, buildings and lands of any tenure, whether open or enclosed, whether built on or not, and whether public or private in respect of which a water rate or charge is payable to the authority or for which an application is made for supply of water and disposal of waste to the public sewer.

2.77 Puff Ventilation ð The ventilation provided for waste traps in two-pipe system, in order to preserve the water seal.

2.78 Relief Vent ð An additional ventilating pipe connected to a discharge pipe at any point where excessive pressure fluctuation is likely to occur.

2.79 Saddle ð A purpose made fitting, so shaped as to fit over a hole cut in a sewer or drain used to form connections.

2.80 Sanitary Appliances ð The appliances for the collection and discharge of soil or waste matter.

2.81 Sewer ð A pipe or conduit, generally closed, but normally not flowing full for carrying sewage and/or other waste liquids.

2.82 Slop Hopper (Slop Sink) ð A hopper shaped sink, with a flushing run and outlet similar to those of a WC pan, for the reception and discharge of human excreta.

2.83 Soakaway ð A pit, dug into permeable ground lined to form a covered perforated chamber or filled with hard-core, to which liquid is led, and from which it may soak away into the ground.

2.84 Soffit (Crown) ð The highest point of the internal surface of a sewer or culvert at any cross section.

2.85 Soil Appliances ð A sanitary appliance for the collection and discharge of excretory matter.

2.86 Soil Pipe ð A pipe that conveys the discharge of water closets or fixtures having similar functions, with or without the discharges from other fixtures.

2.87 Soil Waste ð The discharge from water closets, urinals, slop hopper, stable yard or cowshed gullies and similar appliances.

2.88 Stack Vent ð The extension of a soil or waste stack above the highest horizontal drain connected to the stack.

2.89 Sub Soil Water ð Water occurring naturally in the subsoil.

2.90 Sub Soil Water Drain

a) A drain intended to collect and carry away subsoil water; and

b) A drain intended to disperse into the subsoil from a septic tank.

2.91 Sullage ð *See* 2.104.

2.92 Supply Pipe ð So much of any service pipe as is not a communication pipe.

2.93 Supports — Hangers and anchors or devices for supporting and securing pipe and fittings to walls, ceilings, floors or structural members.

2.94 Surface Water — Natural water from the ground surface, paved areas and roofs.

2.95 Surface Water Drain — A drain conveying surface water including storm water.

2.96 Systems of Drainage

a) *Combined system* — A system in which foul water (sewage) (black and grey water) and surface water are conveyed by the same sewers and drains;
b) *Separate system* — A system in which foul water (sewage) (black and grey water) and surface water are conveyed by the separate sewers and drains; and
c) *Partially separate system* — A modification of the separate system in which part of the surface water is conveyed by the foul (sanitary) sewers and drains.

2.97 Trade Effluent — Any liquid either with or without particles of matter in suspension which is wholly or in part produced in the course of any trade or industry, at trade premise. It includes farm wastes but does not include domestic sewage.

2.98 Trap — A fittings or device so designed and constructed as to provide, when properly vented, a liquid seal which will prevent the back passage of air without materially affecting the flow of sewage or waste water through it.

2.99 Vertical Pipe — Any pipe or fitting which is installed in a vertical position or which makes an angle or not more than 45° with the vertical.

2.100 Vent Stack/Vent Pipe — A vertical vent-pipe installed primarily for the purpose of proving circulation of air to and from any part of the drainage system. It also protects trap seals from excessive pressure fluctuation.

2.101 Vent System — A pipe or pipes installed to provide a flow of air to or from a drainage system or to provide a circulation of air with in such system to protect traps seals from siphonage and back-pressure.

2.102 Waste Appliance — A sanitary appliance for the collection and discharge of water after use for ablutionary, culinary and other domestic purpose.

2.103 Waste Pipe — In plumbing, any pipe that receives the discharge of any fixtures, except water closets or similar fixtures and conveys the same to the house drain or soil or waste stack. When such pipe does not connect directly with a house drain or soil stack, it is called an indirect waste pipe.

2.104 Waste Water (Sullage) — The discharge from wash basins, sinks and similar appliances, which does not contain human or animal excreta.

2.105 Water Closet — A water flushed plumbing fixture designed to receive human excrement directly from the user of the fixture. The term is used sometimes to designate the room or compartment in which the fixture is placed.

2.106 Water Seal — The water in a trap, which acts as a barrier to the passage of air through the trap.

2.107 Yoke Vent (**Cross-Vent**) — A short relief vent between the main soil or waste pipe and a main ventilating pipe.

3 GENERAL

3.1 Basic Principles

The basic principles of water supply, drainage and sanitation are given below and the design of drainage and sanitation should in general be guided by the applicable principles.

3.1.1 *Potable Water*

All premises intended for human habitation, occupancy, or use shall be provided with supply of potable water. This water supply shall not be connected with unsafe water resources, nor shall it be subject to the hazards of backflow.

3.1.2 *Water Provision*

Plumbing fixtures, devices and appurtenances shall be provided with water in sufficient volume and at pressures adequate to enable them to function properly and without undue noise under normal conditions of use.

There should be at least a residual head of 0.018 N/mm^2 at the consumer's tap. There may be certain fixtures or appliances in the installation that may require a higher pressure, such as 0.05 N/mm^2 or even higher, in which case the system shall be designed using pumps, tanks or both to achieve the required minimum pressure.

NOTE — The residual head shall be taken at the highest/farthest outlets in the building.

3.1.3 *Water Efficiency*

Plumbing system shall be designed, installed and adjusted to use the optimum quantity of water consistent with proper performance and cleaning.

3.1.4 *Safety Devices*

Plumbing system shall be designed and installed with safety devices to safeguard against dangers from contamination, explosion, overheating, etc.

3.1.5 *Minimum Amenities*

Each dwelling unit on premises (abutting on a sewer or with a private sewage disposal system) shall have at least one water closet, one kitchen wash place or a sink and one bathing place or shower to meet the basic requirements of sanitation and personal hygiene.

In case of a group housing, the requirements relating to toilet or sanitary room and kitchen as given in good practice [E-2(2)] shall also be complied with.

3.1.6 *Drainage System*

The drainage system shall be designed, installed and maintained to guard against fouling, deposit of solids and clogging and with adequate cleanouts so arranged that the pipes may be readily cleaned.

3.1.7 *Materials and Workmanship*

The plumbing system shall have durable material, free from defective workmanship and so designed and installed as to give satisfactory service for its reasonable expected life. The accessories of the plumbing system should be of such specifications as to meet the functional requirements of the installation, so as to also avoid any inconsistency leading to leakage and resultant seepage.

3.1.8 *Fixture Traps and Vent Pipes*

Each fixture directly connected to the drainage system shall be equipped with a liquid seal trap. Trap seals shall be maintained to prevent sewer gas, other potentially dangerous or noxious fumes, or vermin from entering the building. Further, the drainage system shall be designed to provide an adequate circulation of air in all pipes with no danger of siphonage, aspiration, or forcing of trap seals under conditions of ordinary use by providing vent pipes throughout the system.

3.1.9 *Foul Air Exhaust*

Each vent terminal shall extend to the outer air and be so installed as to minimize the possibilities of clogging and the return of foul air to the building, as it conveys potentially noxious or explosive gases to the outside atmosphere. All vent pipes shall be provided with a cowl.

3.1.10 *Testing*

The plumbing system shall be subjected to required tests to effectively disclose all leaks and defects in the work or the material.

3.1.11 *Exclusion from Plumbing System*

No substance that will clog or accentuate clogging of pipes, produce explosive mixtures, destroy the pipes or their joints, or interfere unduly with the sewage-disposal process shall be allowed to enter the drainage system.

3.1.12 *Light and Ventilation*

Wherever water closet or similar fixture is located in a room or compartment, it should be properly lighted and ventilated.

3.1.13 *Individual Sewage Disposal Systems*

If water closets or other plumbing fixtures are installed in buildings where connection to public sewer is not possible, suitable provision shall be made for acceptable treatment and disposal.

3.1.14 *Maintenance*

Plumbing systems shall be maintained in a safe and serviceable condition.

3.1.15 *Approach for Use and Cleaning*

All plumbing fixtures shall be so installed with regard to spacing as to be approachable for their intended use and for cleaning. All doors, windows and any other device needing access within the toilet shall be so located that they have proper approach.

3.1.16 *Accessibility for Persons with Disabilities*

All doors, windows and fixtures, including WC, urinals, grab bars, washbasin, mirror and all other accessories for use by persons with disabilities shall be so installed/located that they have proper access with appropriate width, height, space, centerlines and ease of operation {*see* good practice [E-2(2)]}.

3.1.17 *Structural Safety*

Plumbing system shall be installed with due regard to preservation of the structural members and prevention of damage to walls and other surfaces.

3.1.18 *Protection of Ground and Surface Water*

Sewage or other waste shall not be discharged into surface or sub-surface water without acceptable form of treatment.

3.2 Drainage and Sanitation

3.2.1 *Preparation and Submission of Plan*

No person shall install or carry out any water-borne sanitary installation or drainage installation or any works in connection with anything existing or new buildings or any other premises without obtaining the prior sanction of the Authority.

The owner shall make an application in the prescribed form (*see* Annex A) to the Authority to carry out such a work.

3.2.2 *Site Plan*

A site plan of the premises on which the building is to be situated or any such work is to be carried out shall be prepared drawn to a scale not smaller than 1 in 500. The site plan of the building premises shall show:

a) The adjoining plots and streets with their names;

b) The position of the municipal sewer and the direction of flow in it;

c) The invert level of the municipal sewer, the road level, and the connection level of the proposed drain connecting the building in relation to the sewer,

d) The angle at which the drain from the building joints the sewer; and

e) The alignment, sizes and gradients of all drains and also of surface drains, if any.

A separate site plan is not necessary if the necessary particulars to be shown in such a site plan are already shown in the drainage plan.

3.2.3 *Drainage Plan*

The application (*see* 3.3.1) shall be accompanied by a drainage plan drawn to a scale of not smaller than 1 in 100 and furnished along with the building plan. The plans shall show the following:

a) Every floor of the building in which the pipes or drains are to be used;

b) The position, forms, level and arrangement of the various parts of such building, including the roof thereof;

c) All new drains as proposed with their sizes and gradients;

d) Invert levels of the proposed drains with corresponding ground levels;

e) The position of every manhole, gully, soil and waste pipe, ventilating pipe, rainwater pipe, water closet, urinal, latrine, bath, lavatory, sink, trap or other appliances in the premises proposed to be connected to any drain and the following colours are recommended for indicating sewers, waste water pipes, rainwater pipes an existing work:

Sl No. (1)	*Description of Work* (2)	*Colour* (3)
i)	Sewers	Red
ii)	Waste water pipes and rainwater pipes	Blue
iii)	Existing work	Black

f) The position of refuse chute, inlet hopper and collection chamber.

3.2.3.1 In the case of an alteration or addition to an existing building, this clause shall be deemed to be satisfied if the plans as furnished convey sufficient information for the proposals to be readily identified with previous sanctioned plans and provided the locations of tanks and other fittings are consistent with the structural safety of the building.

3.2.3.2 The plans for the building drainage shall in every case be accompanied by specifications for the various items of work involved. This information shall be supplied in the prescribed from given in Annex B.

3.2.4 In respect of open drains, cross-sectional details shall be prepared to a scale not smaller than 1 in 50 showing the ground and invert levels and any arrangement already existing or proposed for the inclusion of any or exclusion of all storm water from the sewers.

3.2.5 *Completion Certificate*

At the completion of the plumbing installation work, the licensed/registered plumber shall give a completion certificate in the prescribed form, which is given in Annex C.

3.3 Licensing/Registration of Plumbers

3.3.1 *Execution of Work*

The work which is required to be carried out under the provisions of this Section, shall be executed only by a licensed/registered plumber under the control of the Authority and shall be responsible to carry out all lawful directions given by the Authority. No individual shall engage in the business of plumbing unless so licensed/registered under the provisions of this Section.

3.3.1.1 No individual, firm, partnership or corporation shall engage in the business of installing, repairing or altering plumbing unless the plumbing work performed in the course of such business is under the direct supervision of a licensed/registered plumber from approved Authority**.**

3.3.2 *Examination and Certification*

The Authority shall establish standards and procedure for the qualification, examination and licensing/registration of plumbers and shall issue licences to such persons who meet the qualifications thereof and successfully pass the examination.

3.3.3 For guidelines for registration of plumbers including the minimum standards for qualifications for the grant of licences, reference may be made to good practice [E-2(3)]. The Authority may also utilize the services of the certified plumbers who are certified for the required skill level under the appropriate scheme of the Government.

4 DRAINAGE AND SANITATION

4.1 Types of Sanitary Appliances

4.1.1 *Soil Appliances*

4.1.1.1 *Water closet*

It shall essentially consist of a closet consisting of a bowl to receive excretory matter, trap and a flushing apparatus. It is recommended to provide ablution tap adjacent to the water closet, preferably on right hand side wall. The various types/style of water closets may be:

a) Squatting Indian type water closet;

b) Washdown type water closet;

c) Siphonic washdown type water closet; and

d) Universal or Anglo-Indian water closet.

4.1.1.2 *Bidet*

Bidet is an ablution appliance for cleansing excretory organs with water for personnel hygiene. It may be pedestal type or wall hung with a shallow bowl. Hot and cold water supplied through a mixer is discharged from a spray installed over the rim of the appliance. The bidet outlet should essentially connect to soil pipe in a system.

4.1.1.3 *Urinal*

It is a soil appliance for urination and is connected to soil pipe after a suitable trap. Urinal should have adequate provision of flushing apparatus. The various types/style of urinal may be:

a) bowl type urinal: flat back or angle back;

b) slab (single) type urinal;

c) stall (single) type urinal;

d) squatting plate type urinal;

e) syphon jet urinal with integral trap; and

f) water less (non-water) urinal

4.1.1.4 *Slop sink*

Slop sink is a large sink, generally of square shape. The appliance is used in hospitals and is installed in the dirty utility room, sluice room and similar locations for disposal of excreta and other foul waste and for washing bed pans and urine bottles/pans. It is provided with a flushing mechanism. It is also provided in Janitor's closet where it is used for cleaning the housekeeping mops, etc.

4.1.1.5 *Bed pan sink*

Bed pan sink, also known as bedpan washer and disinfector, is a part of medical equipment inventory which is used to clean manually or automatically, the hospital bedpans, urine bottles and other containers used for collecting body fluids. It is provided in dirty utility room, sluice room, similar locations for disposal of excreta and other foul waste and for washing bed pans, urine bottles/pans. It is a soil appliance and is connected to soil pipe after a suitable trap. In manual models, it has a flushing arrangement.

Provision for installing a bedpan washer and disinfector should be made in all intensive care units in hospitals.

4.1.2 *Waste Appliances*

4.1.2.1 *Wash basin*

It is of one-piece construction having a combined overflow and preferably should have soap holding recess or recesses that should properly drain into the bowl. Each basin shall have circular waste hole through which the liquid content of the basin shall drain.

4.1.2.2 *Wash-trough*

It is a linear trough for simultaneous use by number of persons.

4.1.2.3 *Sink*

It is used in kitchen and laboratory for the purpose of cleaning utensils/ apparatus and also serve the purpose of providing water for general usage. The sink may be made with or without overflow arrangement. The sink shall be of one-piece construction including combined over flow, where provided. The sink shall have a circular waste hole into which the interiors of the sink shall drain.

4.1.2.4 *Bath tub*

Bath tub may be of enameled steel, cast iron, gel-coated, glass fibre reinforced plastic or may be cast in-situ. It shall be stable, comfortable, easy to get in and out, water tight, with anti-skid base, and easy to install and maintain. The bath tub shall be fitted with overflow and waste pipe of nominal diameter of not less than 32 mm and 40 mm, respectively.

4.1.2.5 *Drinking fountain*

It is a bowl fitted with a push button tap and a water bubbler or a tap with a swan neck outlet fitting. It has a waste fitting, a trap and is connected to the waste pipe.

4.1.3 The requirements of various soil appliances and waste appliances shall be in accordance with accepted standards [E-2(4)].

4.2 Drainage and Sanitation Requirements

4.2.1 *General*

There should be at least one water tap and arrangement for drainage in the vicinity of each water closet or group of water closet in all the buildings.

4.2.2 Each dwelling unit on premises (abutting on a sewer or with a private sewage disposal system) shall have at least one water closet, one kitchen wash place or a sink, and one bathing place or shower to meet the basic requirements of sanitation and personal hygiene.

In case of a group housing, the requirements relating to toilet or sanitary room and kitchen as given in good practice [E-2(2)] shall also be complied with.

4.2.3 All other structures for human occupancy or use on premises (abutting on a sewer or with a private sewage disposal system) shall have adequate sanitary facilities, but in no case less than one water closet and one other fixture for cleaning purposes.

4.2.4 *For Residences*

4.2.4.1 Dwelling with individual convenience shall have at least the following fitments:

a) One bathroom provided with a tap and a floor trap;

b) One water closet with flushing apparatus with an ablution tap; and

c) One tap with a floor trap or a sink in kitchen or wash place.

4.2.4.1.1 Where only one water closet is provided in a dwelling, it is desirable to have the bath and water closet separately accommodated.

4.2.4.2 Dwellings without individual conveniences shall have the following fitments:

a) One water tap with floor trap in each tenement;

b) One water closet with flushing apparatus and one ablution tap bath for every two tenements; and

c) One bath with water tap and floor trap for every two tenements

4.2.5 *For Buildings other than Residences*

4.2.5.1 The requirements for fitments for drainage and sanitation in the case of buildings other than residences shall be in accordance with Table 1 to Table 17.

The accessibility requirements for provision of these facilities for persons with disabilities shall be in accordance with good practice [E-2(2)].

The following shall be, in addition, taken into consideration:

a) The figures shown are based upon one (1) fixture being the minimum required for the number of persons indicated or part thereof;

b) Building categories not included in the tables shall be considered separately by the Authority;

c) Drinking fountains shall not be installed in the toilets;

d) Where there is the danger of exposure to skin contamination with poisonous, infectious or irritating material, washbasin with eye wash jet and an emergency shower (safety shower with eye wash unit) located in an area accessible at all times with the passage/right of way suitable for access to a wheel chair, shall be provided;

e) When applying the provision of these tables for providing the number of fixtures, consideration shall be given to the accessibility of the fixtures. Using purely numerical basis may not result in an installation suited to the need of a specific building. For example, schools should be provided with toilet facilities on each floor. Similarly, toilet facilities shall be provided for temporary workmen employed in any establishment according to the needs; and in any case one WC and one washbasin shall be provided;

f) All buildings used for human habitation for dwelling, work, occupation, medical care or any purpose detailed in the various tables, abutting a public sewer or a private sewage disposal system, shall be provided with minimum sanitary facilities as per the schedule in the tables. In case the disposal facilities are not available, they shall be provided as a part of the building design for ensuring high standards of sanitary conditions in accordance with this Section;

g) Workplaces where crèches are provided, they shall be provided with one WC for 10 persons or part thereof, one wash basin for 15 persons or part thereof, one kitchen sink with floor trap for preparing food/milk preparations. The sink provided shall with a drinking water tap;

h) In all types of buildings, individual toilets and pantry should be provided for executives, and for meeting/seminar/conference rooms, etc as per the user requirement;

j) Where food is consumed indoors, water stations and handwashing points may be provided in place of drinking water fountains; and

k) All public areas where floating population is expected need to provide low-mounted urinals and washbasins for children/dwarfs, at least 1 percent or 10 percent of the total.

Table 1 Office Buildings

(*Clause* 4.2.5.1)

Sl No.	Fixtures	Public Toilets		Staff Toilets	
		Males	Females	Males	Females
(1)	(2)	(3)	(4)	(5)	(6)
	Executive rooms and conference halls in office buildings				
i)	Toilet suite comprising one WC, one washbasin (with optional shower stall if building is used round the clock at user's option) Pantry optional as per user requirement	Unit could be common for male/female or separate depending on the number of user of each facility		For individual officer rooms	
	Main office toilets for staff and visitors				
ii)	Water closets	*See* Note		1 per 25	1 per 15
iii)	Ablution tap with each water closet	← 1 in each water closet →			
iv)	Urinals	*See* Note	–	Nil up to 6 1 for 7 to 20 2 for 21 to 45 3 for 46 to 70 4 for 71 to 100 From 101 to 200, add @ 3 percent For over 200, add @ 2.5 percent	–
v)	Wash basins	*See* Note		1 per 25	1 per 25
vi)	Drinking water fountain	*See* Note		1 per 100	1 per 100
vii)	Cleaner's sink	← 1 per floor →			

NOTES

1 Staff and public toilet utilities are generally common in office buildings. Where public toilets are to be provided independently, similar requirements as that of staff toilet may be provided.

2 Space for one janitor per toilet core shall to be planned.

3 The male population may be assumed as half and the female population as half.

Table 2 Factories

(*Clause* 4.2.5.1)

Sl No.	Fixtures	Offices/Visitors		Workers	
		Males	Females	Males	Females
(1)	(2)	(3)	(4)	(5)	(6)
i)	Water closets (workers and staff)	1 for up to 25	1 for up to 15	1 for up to 15	1 for up to 12
		2 for 26 to 35	2 for 16 to 25	2 for 16 to 35	2 for 13 to 25
		3 for 36 to 65	3 for 26 to 40	3 for 36 to 65	3 for 26 to 40
		4 for 66 to 100	4 for 41 to 57	4 for 66 to 100	4 for 41 to 57
			5 for 58 to 77		5 for 58 to 77
			6 for 78 to 100		6 for 78 to 100
	For persons 101 to 200 add	3 percent	5 percent	3 percent	5 percent
	For persons over 200 add	2.5 percent	4 percent	2.50 percent	4 percent
ii)	Ablution tap	1 in each water closet	1 in each water closet	1 in each water closet	1 in each water closet
iii)	Urinals	Nil up to 6	–	Nil up to 6	–
		1 for 7 to 20		1 for 7 to 20	
		2 for 21 to 45		2 for 21 to 45	
		3 for 46 to 70		3 for 46 to 70	
		4 for 71 to 100		4 for 71 to 100	
		From 101 to 200, add @ 3 percent		From 101 to 200, add @ 3 percent	
		For over 200, add @ 2.5percent		For over 200, add @ 2.5 percent	
iv)	Wash basins	1 per 25 or part thereof	1 per 25 or part thereof	1 per 25 or part thereof	1 per 25 or part thereof
	Wash basins in rows or troughs and taps spaced 750 mm c/c				
v)	Drinking water fountain	1 per every 100 or part thereof with minimum one on each floor		1 per every 100 or part thereof with minimum one on each floor	
vi)	Cleaner's sink	1 on each floor	1 on each floor	1 on each floor	1 on each floor
vii)	Showers/bathing rooms	◄ As per trade requirements ►			
viii)	Emergency shower and eye wash fountain	–	–	1 per every shop floor per 500 persons	

NOTES

1 For factories requiring workers to be engaged in dirty and dangerous operations or requiring them to being extremely clean and sanitized conditions additional and separate (if required so) toilet facilities and if required by applicable Industrial and Safety Laws and the *Factories Act* shall be provided in consultation with the user.

2 Depending on the type of disability of a person and the hazard posed by the type of activities in the factory for a person with disabilities, if a person with disabilities is decided to be engaged for a particular activity, the requirements of accessibility shall be guided by the provisions given in good practice [E-2(2)].

Table 3 Warehouse and Storage Area

(*Clause* 4.2.5.1)

Sl No.	Fixtures	Offices/Visitors		Workers	
		Males	Females	Males	Females
(1)	(2)	(3)	(4)	(5)	(6)
i)	Water closets (workers and staff)	1 for up to 25	1 for up to 15	1 for up to 15	1 for up to 12
	For persons 101 to 200 add	3 percent	5 percent	4 percent	5 percent
	For persons over 200 add	2.5 percent	4 percent	2.50 percent	4 percent
ii)	Ablution tap	1 in each water closet	1 in each water closet	1 in each water closet	1 in each water closet
iii)	Urinals	Nil up to 6	–	Nil up to 6	–
		1 for 7 to 20	–	1 for 7 to 20	–
		2 for 21 to 45	–	2 for 21 to 45	–
		3 for 46 to 70	–	3 for 46 to 70	–
		4 for 71 to 100	–	4 for 71 to 100	–
		From 101 to 200, add @ 3 percent	–	From 101 to 200, add @ 3 percent	–
		For over 200, add @ 2.5 percent	–	For over 200, add @ 2.5 percent	–
iv)	Wash basins	1 per 25 or part thereof	1 per 15 or part thereof	1 per 25 or part thereof	1 per 25 or part thereof
	Wash basins in rows or troughs and taps spaced 750 mm c/c				
v)	Drinking water fountain	1 per every 100 or part thereof with minimum one on each floor		1 per every 100 or part thereof with minimum one on each floor	
vi)	Cleaner’s sink	1 on each floor	1 on each floor	1 on each floor	1 on each floor
vii)	Showers/bathing rooms	← As per trade requirements →			
viii)	Emergency shower and eye wash fountain	–	–	1 per every shop floor per 500 persons	

NOTE — Emergency shower and eye wash as per trade requirement to be provided.

Table 4 Cinema, Multiplex Cinema, Concerts and Convention Halls, Theatres and Stadia

(*Clause* 4.2.5.1)

Sl No.	Fixtures	Public		Staff	
		Males	Females	Males	Females
(1)	(2)	(3)	(4)	(5)	(6)
i)	Water closets	1 per 100 up to 400 Over 400 add at 1 per 250 or part thereof	4 per 100 up to 200 Over 200 add at 2 per 100 or part thereof	1 for up to 15 2 for 16 to 35	1 for up to 12 2 for 13 to 25
ii)	Ablution tap	1 in each water closet	1 in each water closet	1 in each water closet	1 in each water closet
		1 water tap with draining arrangements shall be provided for every 50 persons or part thereof in the vicinity of water closets and urinals			
iii)	Urinals	1 per 25 or part thereof	–	Nil up to 6 1 for 7 to 20 2 for 21 to 45	–
iv)	Wash basins	1 per 200 or part thereof		1 for up to 15 2 for 16 to 35	1 for up to 12 2 for 13 to 25
v)	Drinking water fountain	← 1 per 100 persons or part thereof →			
vi)	Cleaner's sink	← 1 per floor →			
vii)	Showers/bathing rooms	← As per trade requirements →			

NOTES

1 Some WCs may be Indian style if desired.

2 Male population may be assumed as half and female population as half.

Table 5 Art Galleries, Libraries, Indoor Activity/Sports Rooms and Museums

(*Clause* 4.2.5.1)

Sl No.	Fixtures	Public		Staff	
		Males	Females	Males	Females
(1)	(2)	(3)	(4)	(5)	(6)
i)	Water closets	1 per 200 up to 400 Over 400 add at 1 per 250 or part thereof	1 per 100 up to 200 Over 200 add at 1 per 150 or part thereof	1 for up to 15 2 for 16 to 35	1 for up to 12 2 for 13 to 25
ii)	Ablution tap	One in each water closet	One in each water closet	One in each water closet	One in each water closet
		1 water tap with draining arrangements shall be provided for every 50 persons or part thereof in the vicinity of water closets and urinals			
iii)	Urinals	1 per 50	–	Nil up to 6 1 per 7 to 20 2 per 21 to 45	–
iv)	Wash basins	1 for every 200 or part thereof. For over 400, add at 1 per 250 persons or part thereof	1 for every 200 or part thereof. For over 200, add at 1 per 150 persons or part thereof	1 for up to 15 2 for 16 to 35	1 for up to 12 2 for 13 to 25
v)	Drinking water fountain	← 1 per 100 persons or part thereof →			
vi)	Cleaner's sink	← 1 per floor (Minimum) →			
vii)	Showers/bathing rooms	← As per requirements →			

NOTES

1 Some WCs may be Indian style if desired.

2 Male population may be assumed as half and female population as half.

3 Board game rooms, indoor sports and club house for community in residential premises can be considered as indoor activity areas.

Table 6 Hospitals with Indoor Patient Wards

(*Clause* 4.2.5.1)

Sl No.	Fixtures	Patient Toilets		Staff Toilets	
		Males	Females	Males	Females
(1)	(2)	(3)	(4)	(5)	(6)
i)	Toilet suite comprising one WC and one washbasin and shower stall	Private room with up to 4 patients		For individual doctor's/officer's rooms	
	For General Wards, Hospital Staff and Visitors				
ii)	Water closets	1 per 5 beds or part thereof	1 per 5 beds or part thereof	1 for up to 15 2 for 16 to 35	1 for up to 12 2 for 13 to 25
iii)	Ablution tap	One in each water closet	One in each water closet	One in each water closet	One in each water closet
		1 water tap with draining arrangements shall be provided for every 50 persons or part thereof in the vicinity of water closets and urinals			
iv)	Urinals	1 per 15 beds	–	Nil up to 6 1 for 7 to 20 2 for 21 to 45	–
v)	Wash basins	2 for every 30 beds or part thereof. Add 1 per additional 30 beds or part thereof		1 for up to 15 2 for 16 to 35	1 for up to 12 2 for 13 to 25
vi)	Drinking water fountain	1 per ward		1 per 100 persons or part thereof	
vii)	Cleaner's sink	1 per ward		–	
viii)	Bed pan sink	1 per ward		–	
ix)	Kitchen sink	1 per ward		–	

NOTES

1 Some WCs may be of Indian style if desired.

2 Male population may be assumed as half and female population as half.

3 Provision for additional and special hospital fittings where required shall be made.

4 Drinking water fountains are not recommended for hospitals for reasons of infection control. This to be decided by the health authority recommendation.

Table 7 Hospitals with Outdoor Patient Department

(*Clause* 4.2.5.1)

Sl No.	Fixtures	Patient Toilets		Staff Toilets	
		Males	Females	Males	Females
(1)	(2)	(3)	(4)	(5)	(6)
i)	Toilet suite comprising one WC and one washbasin (with optional shower stall if building used for 24 h)	For up to 4 patients		For individual doctor's/officer's rooms	
ii)	Water closets	1 per 100 persons or part thereof	2 per 100 persons or part thereof	1 for up to 15 2 for 16 to 35	1 for up to 12 2 for 13 to 25
iii)	Ablution tap	One in each water closet	One in each water closet	One in each water closet	One in each water closet
		1 water tap with draining arrangements shall be provided for every 50 persons or part thereof in the vicinity of water closets and urinals			
iv)	Urinals	1 per 50 persons or part thereof	–	Nil up to 6 1 for 7 to 20 2 for 21 to 45	–
v)	Wash basins	2 per 100 persons of part thereof	2 per 100 persons or part thereof	1 for up to 15 2 for 16 to 35	1 for up to 12 2 for 13 to 25
vi)	Drinking water fountain	*See* Note 2		1 per 100 persons or part thereof	

NOTES

1 Some WCs may be Indian style if desired.

2 Drinking water fountains are not recommended for hospitals for reasons of infection control. This to be decided by the health authority recommendation.

3 The WCs shall be provided keeping in view the location of main OPD waiting hall and sub-waiting halls, floor wise, so as to serve the people effectively. The number of patients shall be calculated floor wise. The OPD population shall include patient attendants @ at least 1 per patient.

4 Male population may be assumed as half and female population as half.

5 Provision for additional and special hospital fittings where required shall be made.

Table 8 Hospitals, Administrative Buildings

(*Clause* 4.2.5.1)

Sl No.	Fixtures	Staff Toilets	
		Males	Females
(1)	(2)	(3)	(4)
i)	Toilet suite comprising one WC, one urinal and one washbasin (with optional shower stall if building used for 24 h)	For individual doctor's/officer's rooms	
ii)	Water closets	1 per 25 persons or part thereof	1 per 15 persons or part thereof
iii)	Ablution tap	One in each water closet	One in each water closet
		1 water tap with draining arrangements shall be provided for every 50 persons or part thereof in the vicinity of water closets and urinals	
iv)	Urinals	1 for 6 to 15	–
		2 for 16 to 50	–
v)	Wash basins	1 per 25 persons or part thereof	1 per 25 persons or part thereof
vi)	Drinking water fountain	1 per 100 persons or part thereof (*See* Note 2)	
vii)	Cleaner's sink	1 per floor, *Min*	
viii)	Kitchen sink	1 per floor, *Min*	

NOTES

1 Some WCs may be Indian style if desired.

2 Drinking water fountains to be provided only when it is a separate block and patients will not use it.

Table 9 Hospitals Staff Quarters and Nurses Homes

(*Clause* 4.2.5.1)

Sl No.	Fixtures	Staff Quarters		Nurses Homes	
		Males	Females	Males	Females
(1)	(2)	(3)	(4)	(5)	(6)
i)	Water closets	1 per 4 persons or part thereof	1 per 4 persons or part thereof	1 per 4 persons or part thereof 2 for 5 to 35	1 per 4 persons or part thereof 2 for 5 to 25
ii)	Ablution tap	One in each water closet	One in each water closet	One in each water closet	One in each water closet
		1 water tap with draining arrangements shall be provided for every 50 persons or part thereof in the vicinity of water closets and urinals			
iii)	Wash basins	1 per 8 persons or part thereof		1 per 8 persons or part thereof	
iv)	Bath (showers)	1 per 4 persons or part thereof		1 per 4 to 6 persons or part thereof	
v)	Drinking water fountain	1 per 100 persons or part thereof, *Min* 1 per floor		1 per 100 persons or part thereof, *Min* 1 per floor	
vi)	Cleaner's sink	1 per Floor		1 per Floor	

NOTES

1 Some WCs may be Indian style if desired.

2 For independent housing units, fixtures shall be provided as for residences.

Table 10 Hotels

(*Clause* 4.2.5.1)

Sl No.	Fixtures	Public Rooms		Non-Residential Staff	
		Males	Females	Males	Females
(1)	(2)	(3)	(4)	(5)	(6)
i)	Toilet suite comprising one WC, wash basin with Shower or a bathtub	Individual guest rooms with attached toilets		–	
	Guest rooms with common facilities, and public areas like reception, health club, waiting lounge, business centre, recreation area				
ii)	Water closets	1 per 100 persons up to 300 Over 300 add at 1 per 200 or part thereof	2 per 100 persons up to 200 Over 200 add at 1 per 100 or part thereof	1 for up to 15 2 for 16 to 35 3 for 36 to 65 4 for 66 to 100	1 for up to 12 2 for 13 to 25 3 for 26 to 40 4 for 41 to 57 5 for 58 to 77 6 for 78 to 100
iii)	Ablution tap	One in each water closet	One in each water closet	One in each water closet	One in each water closet
		1 water tap with draining arrangements shall be provided for every 50 persons or part thereof in the vicinity of water closets and urinals			
iv)	Urinals	1 per 50 persons or part thereof	–	Nil up to 6 1 for 7 to 20 2 for 21 to 45 3 for 46 to 70 4 for 71 to 100	–
v)	Wash basins	1 per WC/urinal	1 per WC	1 for up to 15 2 for 16 to 35 3 for 36 to 65 4 for 66 to 100	1 for up to 12 2 for 13 to 25 3 for 26 to 40 4 for 41 to 57
vi)	Bath (showers)	1 per 10 persons or part thereof		–	–
vii)	Cleaner's sink	1 per 30 rooms, *Min* 1 per floor			
viii)	Kitchen sink	1 per kitchen			

NOTES

1 Some WCs may be Indian style if desired.

2 Male population may be assumed as half and female population as half.

3 Provision for additional and special fittings where required shall be made based on end user or operator guidelines.

Table 11 Restaurants

(*Clause* 4.2.5.1)

Sl No.	Fixtures	Public Rooms		Non Residential Staff	
		Males	Females	Males	Females
(1)	(2)	(3)	(4)	(5)	(6)
i)	Water closets	1 per 50 seats up to 200 Over 200 add at 1 per 100 or part thereof	2 per 50 seats up to 200 Over 200 add at 1 per 100 or part thereof	1 for up to 15 2 for 16 to 35 3 for 36 to 65 4 for 66 to 100	1 for up to 12 2 for 13 to 25 3 for 26 to 40 4 for 41 to 57 5 for 58 to 77 6 for 78 to 100
ii)	Ablution tap	One in each water closet	One in each water closet	One in each water closet	One in each water closet
		1 water tap with draining arrangements shall be provided for every 50 persons or part thereof in the vicinity of water closets and urinals			
iii)	Urinals	1 per 50 persons or part thereof	–	Nil up to 6 1 for 7 to 20 2 for 21 to 45 3 for 46 to 70 4 for 71 to 100	–
iv)	Wash basins	1 per WC	1 per WC	1 per WC	1 per WC
v)	Cleaner's sink	1 per each restaurant			
vi)	Kitchen sink/dish washer	1 per kitchen			

NOTES

1 Some WCs may be Indian style if desired.

2 Male population may be assumed as half and female population as half.

3 Provision for additional and special fittings where required shall be made.

Table 12 Microbrewery, Special Restaurants and Food Court Area

(*Clause* 4.2.5.1)

Sl No.	Fixtures	Public Rooms		Staff	
		Males	Females	Males	Females
(1)	(2)	(3)	(4)	(5)	(6)
i)	Water closets	1 per 50 seats up to 300 Over 300 add at 1 per 100 or part thereof	2 per 50 seats up to 200 Over 200 add at 1 per 100 or part thereof	3 percent for every 100	4 percent for every 100
ii)	Ablution tap	One in each water closet	One in each water closet	One in each water closet	One in each water closet
		1 water tap with draining arrangements shall be provided for every 50 persons or part thereof in the vicinity of water closets and urinals			
iii)	Urinals	3 percent for every 100	–	2.5 percent for every 100	–
iv)	Wash basins	1 per WC	1 per WC	1 per WC	1 per WC
v)	Cleaner's sink	1 per each floor			

NOTES

1 Some WCs may be Indian style if desired.

2 Male population may be assumed as half and female population as half.

3 Provision for additional and special fittings where required shall be made.

4 Kitchen sinks and washers shall be provided as per the kitchen design layout.

Table 13 Schools, Colleges and Educational Institutions

(*Clause* 4.2.5.1)

Sl No.	Fixtures	Nursery School	Non-Residential		Residential	
			Boys	Girls	Boys	Girls
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	Water closets	1 per 15 pupils or part thereof	1 per 40 pupils or part thereof	1 per 25 pupils or part thereof	1 per 8 pupils or part thereof	1 per 6 pupils or part thereof
ii)	Ablution tap	One in each water closet	One in each water closet	One in each water closet	One in each water closet	One in each water closet
		1 water tap with draining arrangements shall be provided for every 50 persons or part thereof in the vicinity of water closets and urinals				
iii)	Urinals	–	1 per 20 pupils or part thereof	–	1 per 25 pupils or part thereof	–
iv)	Wash basins	1 per 15 pupils or part thereof	1 per 60 pupils or part thereof	1 per 40 pupils or part thereof	1 per 8 pupils or part thereof	1 per 6 pupils or part thereof
v)	Bath/showers	1 per 40 pupils or part thereof	–	–	1 per 8 pupils or part thereof	1 per 6 pupils or part thereof
vi)	Drinking water fountain or taps	1 per 50 pupils or part thereof	1 per 50 pupils or part thereof	1 per 50 pupils or part thereof	1 per 50 pupils or part thereof	1 per 50 pupils or part thereof
vii)	Cleaner's sink	1 per each floor				

NOTES

1 Some WCs may be Indian style if desired.

2 For teaching staff, the schedule of fixtures to be provided shall be the same as in case of office building.

3 Male population may be assumed as half and female population as half.

Table 14 Hostels

(*Clause* 4.2.5.1)

Sl No.	Fixtures	Resident		Non-Resident		Visitor/Common Rooms	
		Males	Females	Males	Females	Males	Females
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	Water closets	1 per 8 or part thereof	1 per 6 or part thereof	1 for up to 15 2 for 16 to 35 3 for 36 to 65 4 for 66 to 100	1 for up to 12 2 for 13 to 25 3 for 26 to 40 4 for 41 to 57 5 for 58 to 77 6 for 78 to 100	1 per 100 up to 400 Over 400 add at 1 per 250	2 per 100 up to 200 Over 200 add at 1 per 100
ii)	Ablution tap	One in each water closet	One in each water closet	One in each water closet	One in each water closet	One in each water closet	One in each water closet
		1 water tap with draining arrangements shall be provided for every 50 persons or part thereof in the vicinity of water closets and urinals					
iii)	Urinals	1 per 25 or part thereof	–	Nil up to 6 1 for 7 to 20 2 for 21 to 45 3 for 46 to 70 4 for 71 to 100	–	1 per 50 or part thereof	–
iv)	Wash basins	1 per 8 persons or part thereof	1 per 6 persons or part thereof	1 for up to 15 2 for 16 to 35 3 for 36 to 65 4 for 66 to 100	1 for up to 12 2 for 13 to 25 3 for 26 to 40 4 for 41 to 57 5 for 58 to 77 6 for 78 to 100	1 per WC/ Urinal	1 per WC
v)	Bath/showers	1 per 8 persons or part thereof	1 per 6 persons or part thereof	–	–	–	–
vi)	Cleaner's sink	1 per each floor					

NOTE — Some WCs may be Indian style if desired.

Table 15 Fruit and Vegetable Markets

(*Clause* 4.2.5.1)

Sl No.	Fixtures	Shop Owners		Common Toilets in Market Building		Public Toilet for Floating Population	
		Males	Females	Males	Females	Males	Females
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	Water closets	1 per 8 or part thereof		1 for up to 15 2 for 16 to 35 3 for 36 to 65 4 for 66 to 100	1 for up to 12 2 for 13 to 25 3 for 26 to 40 4 for 41 to 57 5 for 58 to 77 6 for 78 to 100	1 per 50 (Min 2)	1 per 50 (Min 2)
ii)	Ablution tap	One in each water closet	One in each water closet	One in each water closet	One in each water closet	One in each water closet	One in each water closet
		1 water tap with draining arrangements shall be provided in receiving/ sale area of each shop and for every 50 persons or part thereof in the vicinity of water closets and urinals					
iii)	Urinals	–	–	Nil up to 6 1 for 7 to 20 2 for 21 to 45 3 for 46 to 70 4 for 71 to 100	–	1 per 50	–
iv)	Wash basins	1 per 8 or part thereof		1 for up to 15 2 for 16 to 35 3 for 36 to 65 4 for 66 to 100	1 for up to 12 2 for 13 to 25 3 for 26 to 40 4 for 41 to 57	–	–
v)	Bath/showers	1 per 8 persons or part thereof	1 per 6 persons or part thereof	–	–	1 per 50 persons	1 per 50 persons

NOTES

1 Toilet facilities for individual buildings in a market should be taken same as that for office buildings.

2 Common toilets in the market buildings provide facilities for persons working in shops and their regular visitors.

3 Special toilet facilities for a large floating population of out of town buyers/sellers, labour, drivers of vehicles for whom special toilet (public toilets).

Table 16 Bus Stations, Airports and Railway Stations

(*Clause* 4.2.5.1)

Sl No.	**Fixtures**	**Junction Stations, Intermediate Stations and Bus Stations**		**Terminal Railway and Bus Stations**		**Domestic and International Airports**	
		Males	Females	Males	Females	Males	Females
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	Water closets	3 for up to 1 000 Add 1 per additional 1 000 or part thereof	4 for up to 1 000 Add 1 per additional 1 000 or part thereof	4 for up to 1 000 Add 1 per additional 1 000 or part thereof	5 for up to 1 000 Add 1 per additional 1 000 or part thereof	*Min* 2 For 200 : 5 For 400 : 9 For 600 : 12 For 800 : 16 For 1 000 : 18	*Min* 2 For 200 : 8 For 400 : 15 For 600 : 20 For 800 : 26 For 1 000 : 29
ii)	Ablution tap	One in each water closet	One in each water closet	One in each water closet	One in each water closet	One in each water closet	One in each water closet
		1 water tap with draining arrangements shall be provided for every 50 persons or part thereof in the vicinity of water closets and urinals					
iii)	Urinals	4 for up to 1 000 Add 1 per additional 1 000	–	6 for up to 1 000 Add 1 per additional 1 000	–	1 per 40 or part thereof	–
iv)	Wash basins	1 per WC/ Urinal	1 per WC	1 per WC/ Urinal	1 per WC	1 per WC/ Urinal	1 per WC
v)	Bath/showers	2 per 1 000		3 per 1 000		4 per 1 000	
vi)	Drinking water fountain or taps (in common lobby for male/female)	2 per 1 000 or part thereof		3 per 1 000 or part thereof		4 per 1 000 or part thereof	
vii)	Cleaner's sink	1 per toilet compartment with 3 WC's	1 per toilet compartment with 3 WC's	1 per toilet compartment with 3 WC's	1 per toilet compartment with 3 WC's	1 per toilet compartment with 3 WC's	1 per toilet compartment with 3 WC's

NOTES

1 Some WCs may be Indian style if desired.

2 Male population may be assumed as three-fifth and female population as two-fifth.

3 Separate provision shall be made for staff and workers.

Table 17 Shopping Malls and Retail Buildings

(*Clause* 4.2.5.1)

Sl No.	Fixtures	Staff Toilets in Shopping Building		Public Toilet for Floating Population	
		Males	Females	Males	Females
(1)	(2)	(5)	(6)	(7)	(8)
i)	Water closets	1 for up to 15 2 for 16 to 35 3 for 36 to 65 4 for 66 to 100	1 for up to 12 2 for 13 to 25 3 for 26 to 40 4 for 41 to 57 5 for 58 to 77 6 for 78 to 100	1 per 50 (2, *Min*)	1 per 50 (2, *Min*)
ii)	Ablution tap	One in each water closet	One in each water closet	One in each water closet	One in each water closet
iii)	Urinals	Nil up to 6 1 for 7 to 20 2 for 21 to 45 3 for 46 to 70 4 for 71 to 100	–	1 per 50	–
iv)	Wash basins	1 for up to 15 2 for 16 to 35 3 for 36 to 65 4 for 66 to 100	1 for up to 12 2 for 13 to 25 3 for 26 to 40 4 for 41 to 57	1 per 50 (2, *Min*)	1 per 50 (2, *Min*)
v)	Bath/showers	1 per 100 persons	1 per 100 persons	–	–

NOTES

1 Toilet facilities for individual facilities in a shopping building should be taken same as that for office buildings.

2 Staff toilets in the shopping buildings provide facilities for persons working in shops and building, as well as for maintenance staff.

3 The number of persons against the fixture bath/showers represent the maintenance staff requiring such facility.

4 Public toilet facilities are provided for a large floating population for buyers and visitors.

5 Drinking water facility should be planned at two locations per floor, with water quality fit for drinking as per the applicable codes/standards.

4.3 Materials, Fittings and Appliances

4.3.1 *Standards for Materials, Fittings and Sanitary Appliances*

All materials, fittings and sanitary appliances shall conform to Part B ‘Building Materials’ of this NBCS.

4.3.2 *Choice of Material for Pipes*

4.3.2.1 *Salt glazed stoneware pipe*

For all sewers and drains in all soils, except where supports are required as in made-up ground, glazed stoneware pipe shall be used as far as possible in preference to other types of pipes. These pipes are particularly suitable where acid effluents or acid subsoil conditions are likely to be encountered. Salt glazed stoneware pipes shall conform to accepted standards [E-2(5)].

4.3.2.2 *Cement concrete pipes*

When properly ventilated, cement concrete pipes with spigot and socket or collar joints present an alternative to glazed stoneware sewers of over 150 mm diameter. These shall not be used to carry acid effluents or sewage under conditions favourable for the production of hydrogen sulphide and shall not be laid in those subsoils that are likely to affect adversely the quality or strength of concrete. However, where these pipes are employed for conveying liquid containing sulphates, the pipes used shall be manufactured using sulphate resisting Portland cement. Owing to the longer lengths of pipes available, the joints would be lesser in the case of cements concrete pipes. These pipes may be used for surface water drains in all diameters. Cement concrete pipes shall conform to accepted standards [E-2(6)].

4.3.2.3 *Cast iron pipes*

4.3.2.3.1 These pipes shall be used in the following situation:

a) In bed or unstable ground where soil movement is expected;

b) In made-up or tipped ground;

c) To provide for increased strength where a sewer is laid at insufficient depth, where it is exposed or where it has to be carried on piers or above ground;

d) Under buildings and where pipes are suspended in basements and like situations;

e) In reaches where the velocity is more than 2.4 m/s; and

f) For crossings of watercourses.

NOTE — In difficult foundation condition such as in the case of black cotton soil, the cast iron pipes shall be used only when suitable supporting arrangements are made.

4.3.2.3.2 It shall be noted that cast iron pipes even when given a protective paint are liable to severe external corrosion in certain soils; among such soils are:

a) Soils permeated by peaty waters; and

b) Soils in which the subsoil contains appreciable concentrations of sulphates. Local experiences shall be ascertained before cast iron pipes are used where corrosive soil conditions are suspected. Where so used, suitable measures for the protection of the pipes may be resorted to as an adequate safeguard.

4.3.2.3.3 Cast iron pipes shall conform to accepted standards [E-2(7)].

4.3.2.4 *Asbestos cement pipes*

Asbestos cement pipes are commonly used for house drainage systems and they shall conform to accepted standards [E-2(8)]. They are not recommended for underground situations. However, asbestos cement pressure pipes conforming to accepted standards [E-2(8)] may be used in underground situations also, provided they are not subject to heavy superimposed loads. These shall not be used to carry acid effluents or sewage under conditions favourable for the production of hydrogen sulphide and shall not be laid in those subsoils which are likely to affect adversely the quality or strength of asbestos cement pipes. Where so desired, the life of asbestos cement pipes may be increased by lining inside of the pipe with suitable coatings like epoxy/polyester resins, etc.

4.3.2.5 *PVC pipes*

Unplasticized PVC pipes may be used for drainage purposes; however, where hot water discharge is anticipated, the wall thickness shall be minimum 3 mm irrespective of the size and flow load.

PVC and HDPE pipes shall conform to accepted standards [E-2(9)].

NOTE — Where possible, high density polyethylene pipes (HDPE) and PVC pipes may be used for drainage and sanitation purposes, depending upon the suitability.

4.3.2.6 *Corrugated pipes*

These pipes (externally corrugated) are used for sewerage and drainage applications. They are light weight and have long life. The leakage and infiltration at joints are less. The operational cost is low and can easily withstand natural settlements without suffering cracks or leakages. They consume fewer raw material and have less carbon dioxide emission.

4.3.2.7 *Low noise pipes*

Wastewater systems encompass the system of drainage and pressure relief pipes within a building and terminate 0.5 m outside the external wall. Waste water systems are based on the primary pressure-relief system in which water and air-flow occurs in the same pipe. The wastewater system shall be separated from the roof drainage system.

Noise is a variance in air pressure that spreads like a wave. If quick changes in pressure occur between 20 and 20 000 times a second (frequency 20 Hz and 20 kHz), they are audible to humans. The loudness of noise is determined by the amplitude of the wave, which is measured in decibels (dB).

The main cause of noise in indoor drainage systems (primarily focused on the downpipe) are the choice of the pipe system, the bracket type and the design of drainage system. Optimizing these factors will therefore have the best influence on noise reduction.

4.3.2.8 *Under slung pipes*

In under slung plumbing, the toilet slab is built at the same level as the slabs outside the toilet. Holes/core cuts are punctured through the slab wherever pipes have to pass through, and the plumbing is clamped to the bottom of the slab. It is then concealed above a false ceiling, which is accessible above the false ceiling for routine maintenance. In this type of plumbing, any leaks will drip onto the false ceiling which is easily detectable thus allow quick maintenance without much damage to the structure or occupied premises.

4.4 Preliminary Data for Design

4.4.1 *General*

Before the drainage system for a building or group of buildings is designed and constructed, accurate information regarding the site conditions is essential. This information may vary with the individual scheme but shall, in general, be covered by the following:

a) Site plan (*see* 3.2.2)*;*

b) Drainage plan (*see* 3.2.3);

c) *Use* — A description of the use for which the building is intended and periods of occupation in order that peak discharges may be estimated;

d) *Nature of waste* — While dealing with sewage from domestic premises, special problems under this head may not arise; however, note shall be taken of any possibility of trade effluents being discharged into the pipes at a future date;

e) *Outlet connection* — The availability of sewers or other outlets;

f) *Cover* — The depth (below ground) of the proposed sewers and drains and the nature and weight of the traffic on the ground above them;

g) *Subsoil condition*

   1) The approximate level of the subsoil water, and any available records of flood levels shall be ascertained, as also the depth of the water table relative to all sewer connections, unless it is known to be considerably below the level of the latter;

   2) In the case of deep manholes, this information will influence largely the type of construction to be adopted. The probable safe bearing capacity of the subsoil at invert level may be ascertained in the case of a deep manhole;

3) Where work of any magnitude is to be undertaken, trial pits or boreholes shall be put at intervals along the line of the proposed sewer or drain and the data therefrom tabulated, together with any information available from previous works carried out in the vicinity. In general, the information derived from trial pits is more reliable than that derived from boreholes. For a long length of sewer or drain, information derived from a few trial pits at carefully chosen points may be supplemented by that obtained from number of intermediate boreholes;

   Much useful information is often obtained economically and quickly by the use of a soil auger;

4) The positions of trial pits or boreholes shall be shown on the plans, together with sections showing the strata found and the dates on which water levels are recorded;

h) *Location of other services* — The position, depth and size of all other pipes, mains, cables, or other services, in the vicinity of the proposed work, may be ascertained from the Authority, if necessary;

j) *Reinstatement of surfaces* — Information about the requirements of the highway authority is necessary where any part of the sewer or drain is to be taken under a highway. Those responsible for the sewer or drain shall be also responsible for the maintenance of the surface until permanently reinstated. The written consent of the highway authority to break up the surface and arrangement as to the charges thereof and the method and type of surface reinstatement shall always be obtained before any work is commenced;

k) *Diversion and control of traffic*

   1) In cases where sewers cross roads or foot-paths, cooperation shall be maintained with the police and Authorities regarding the control and diversion of vehicular and/or pedestrian traffic as may be necessary. Access to properties along the road shall always be maintained and adequate notice shall be given to the occupiers of any shops or business premises, particularly if obstruction is likely; and

   2) During the period of diversion, necessary danger lights, red flags, diversion boards, caution boards, watchmen, etc, shall be provided as required by the Authority.

m) *Way-leaves* (*easements*) — The individual or authority carrying out the work is responsible for negotiating way-leaves where the sewer crosses land in other ownership. The full extend and conditions of such way-leaves shall be made known to the contractor and his employees, and prior notice of commencement of excavation shall always be given to the owners concerned, and cooperation with them shall be maintained at all stages, where sewers run across fields or open ground, the exact location of manholes shall be shown on way-leaves or easement plans. The right of access to manhole covers and the right to maintain the sewer shall be specifically included in any way-leave or easement arrangements which may be made with the owner of the land; and

n) *Damage to buildings and structures* — When sewer trenches have to be excavated near buildings or walls a joint inspection with the owners of the property shall be made to establish whether any damage or cracks exist before starting the work, and a properly authenticated survey and record of the condition of buildings likely to be affected shall be made. Tell tales may be placed across outside cracks and dated, and kept under observation. Un-retouched photographs taken by an independent photographer may provide useful evidence.

4.4.2 *Drainage into a Public Sewer*

Where public sewerage is available, the following information is particularly necessary and may be obtained from the Authority:

a) The position of the public sewer or sewers in relation to the proposed buildings;

b) The invert level of the public sewer;

c) The system on which the public sewers are designed (combined, separate or partially separate), the lowest level at which connection may be made to it, and the Authority in which it is vested;

d) The material of construction and condition of the sewer if connection is not to be made by the Authority;

e) The extent to which surcharge in the sewer may influence the drainage scheme;

f) Whether the connection to the public sewer is made, or any part of the drain laid, by the Authority, or whether the owner is responsible for this work; if the latter, whether the Authority imposes any special conditions;

g) Whether an intercepting trap is required by the Authority on the drain near the boundary of the curtilage; and

h) Where manholes are constructed under roads, the approval of the Highway Authority for the type of cover to be fitted shall be obtained.

4.4.3 *Other Methods of Disposal of Sewage*

4.4.3.1 Where discharge into a public sewer is not possible, the drainage of the building/building campus shall be on a separate system. Foul water shall be disposed of by adequate treatment approved by the Authority on the site. The effluent from the plant shall be discharged after meeting the norms specified by the statutory authority into a natural watercourse or on the surface of the ground or disposed of subsoil dispersion preferably draining to a suitable outlet channel.

4.4.3.2 In the case of dilution into a natural stream course, the quality of the effluent shall conform and the requirements of the Authority controlling the prevention of pollution of streams.

4.4.3.3 In the case of subsoil dispersion, the requirements of the Authority for water supply shall be observed to avoid any possible pollution of local water supplies or wells.

4.4.3.4 The general subsoil water level and the subsoil conditions shall be ascertained, including the absorptive capacity of the soil.

4.4.3.5 A subsoil dispersion is not desirable near a building or in such positions that the ground below the foundations is likely to be affected.

4.4.3.6 Where no other method of disposal is possible, foul water may be diverted to cesspools and arrangements made with the Authority for satisfactory periodical removal and conveyance to a disposal works.

4.4.3.7 Under the separate system, drainage of the building shall be done through septic tanks of different sizes or by stabilization ponds or by any other treatment methods such as extended aeration activated process, sequential batch process, fluidized bio-reactors, membrane bio-reactor, submerged aerobic fixed film, rotating biological contactor, electrolyte process, etc, as approved by the Authority.

For detailed information on the design and construction of septic tanks and waste stabilization ponds, sewage treatment plants reference may be made to good practice [E-2(10)].

4.4.3.8 *Biodigester or bio-toilet* (or *eco-toilet*)

Refer **4.13.3(k)**, (*see* Fig. 5).

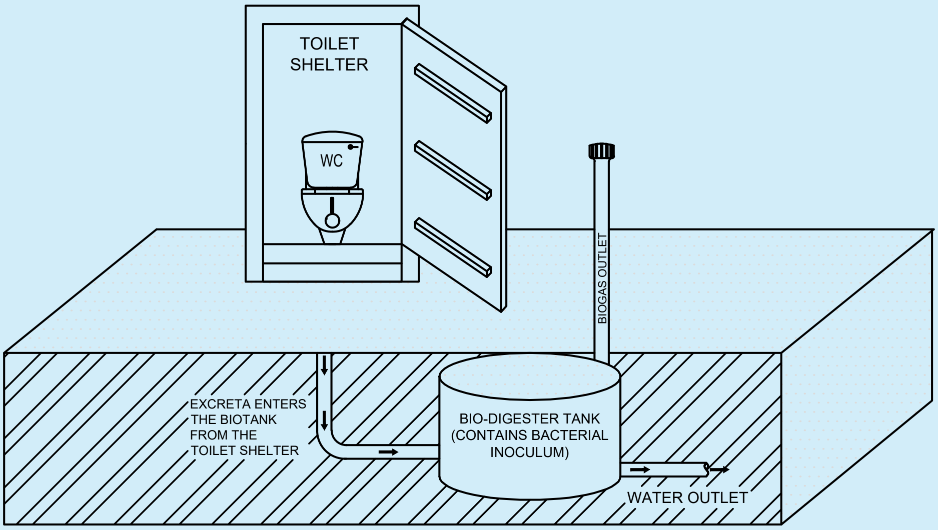

TOILET SHELTER
WC
BIOGAS OUTLET
EXCRETA ENTERS THE BIOTANK FROM THE TOILET SHELTER
BIO-DIGESTER TANK (CONTAINS BACTERIAL INOCULUM)
WATER OUTLET

FIG. 5 BIO-TOILET (OR ECO-TOILET)

4.4.3.9 *Packaged sewage treatment plant*

Refer **4.13.3(j)**.

4.4.4 *Disposal of Surface and Subsoil Waters*

All information which may influence the choice of methods of disposal of surface and/or subsoil waters shall be obtained. In the absence of surface water drainage system and if practicable and permissible, disposal into a natural water-course or soakaway may be adopted. The location and flood levels of the water course as also the requirements of the Authority controlling the river or the waterway shall be ascertained.

4.5 Planning and Design Considerations

4.5.1 *Aim*

The efficient disposal of foul and surface water from a building is of great importance to public health and is an essential part of the construction of the building. In designing a drainage system for an individual building or a housing colony, the aim shall be to provide a system of self-cleaning conduits for the conveyance of foul, waste, surface or subsurface waters and for the removal of such wastes speedily and efficiently to a sewer or other outlet without risk of nuisance and hazard to health. Also, intent should be to take into consideration that, waste water, storm water and solid waste are potential resources.

4.5.1.1 To achieve this aim, a drainage system shall satisfy the following requirements:

a) Rapid and efficient removal of liquid wastes without leakage;

b) Prevention of access of foul gases to the building and provision for their escape from the system.

c) Adequate and easy access for clearing obstructions;

d) Prevention of undue external or internal corrosion, or erosion of joints and protection of materials of construction; and

e) Avoidance of air locks, siphonage, proneness to obstruction, deposit and damage.

4.5.1.2 The realization of an economical drainage system is added by compact grouping of fitments in both horizontal and vertical directions. This implies that if care is taken and ingenuity brought into play when designing the original building or buildings to be drained, it is possible to group the sanitary fittings and other equipment requiring drainage; both in vertical and horizontal planes, as to simplify the drainage system and make it most economical.

4.5.1.3 Efficient and an economical plumbing system can be achieved by planning the toilets in compact grouping with the layout of the bathrooms and observing the following guidelines:

a) Placing of plumbing fixtures around an easily accessible pipe shaft; in high rise buildings the pipe shafts may have to be within the building envelope and easy provision for access panels and doors should be planned in advance, in such cases so as not to cause inconvenience during maintenance;

b) Adopting repetitive layout of toilets in the horizontal and vertical directions;

c) In planning for malls, the required public and toilet facilities shall be located not more than one storey above or below the space to be served with such facilities and the path of travel to such facilities shall not exceed 91 m;

In other occupancies, the required public and toilet facilities shall be located not more than one storey above or below the space to be served with such facilities and the path of travel to such facilities shall not exceed 152 m.

However, in the above buildings, toilet rooms shall not open directly into a room used for preparation of food for service to public.

d) Avoiding any conflict with the reinforced cement concrete structure by avoiding embedding pipes in it, avoiding pipe crossings in beams, columns and major structural elements;

e) Identifying open terraces and areas subject to ingress of rainwater directly or indirectly and providing for location of inlets at each level for down takes for disposal at ground levels;

f) Avoiding crossing of services of individual property through property of other owners;

g) Planning to avoid accumulation of rainwater or any backflow from sewers particularly in planned low elevation areas in a building;

h) *Setting of sanitary fixtures* — A water closet, urinal, lavatory or bidet shall not be set closer than 380 mm from the centre to any side wall partition, vanity or other obstruction, or closer than 760 mm centre-to-centre between adjacent fixtures. There shall not be less than 530 mm clearance in front of the water closet, urinal, lavatory or bidet to any wall, fixture or door. Water closet compartment shall not be less than 760 mm in width and 1 520 mm in depth for floor mounted closets, and not less than 760 mm in width and 1 420 mm in depth for wall hung water closets;

   The urinal partitions shall begin at a height not greater than 305 mm from and extend not less than 1 520 mm above the finished floor surface. The walls or partitions shall extend from the wall surface at each side of the urinal not less than 460 mm or to a point not less than 150 mm beyond the outermost front lip of the urinal measured from the finished back wall surface, whichever is greater.

j) Usually, the vertical distance between two horizontal connections to a vertical drain should be more than 200 mm in order to avoid back flow.

4.5.1.4 Typical mounting arrangements for various plumbing fixtures, including drainage systems and ventilation are illustrated in Annex D.

4.5.2 *Layout*

4.5.2.1 *General*

Rainwater should preferably be dealt separately from sewage and sullage. Sewage and sullage shall be connected to sewers. However, storm water from the courtyard may be connected to the sewer where it is not possible to drain otherwise; after obtaining permission of the authority.

4.5.2.2 *Additional requirements*

The following requirements are suggested to be considered in the design of drainage system:

a) The layout shall be as simple and direct as practicable;

b) The pipes should be laid in straight lines, as far as possible, in both vertical and horizontal planes;

c) Anything that is likely to cause irregularity of flow, such as abrupt changes of direction, shall be avoided;

d) The pipes should be non-absorbent, durable, smooth in bore and of adequate strength;

e) The pipes should be adequately supported without restricting movement;

f) Drains should be well ventilated, to prevent the accumulation of foul gases and fluctuation of air pressure within the pipe, which could lead to unsealing (siphoning) of gully or water closet traps;

g) All the parts of the drainage system should be accessible for feasibility of inspection and practical maintenance;

h) No bends and junctions whatsoever shall be permitted in sewers except at manholes and inspection chambers;

j) Sewer drain shall be laid for self-cleaning velocity of 0.75 m/s and generally should not flow more than half-full;

k) Pipes crossing in walls and floors shall be through mild steel sleeves of diameter leaving an annular space of 5 mm around the outer diameter of the pipe crossing the wall;

m) Pipes should not be laid close to building foundation;

n) Pipes should not pass near large trees because of possibility of damage by the roots;

p) Branch connections should be swept in the direction of flow;

q) Sewer pipes should be at least 900 mm below road and at least 600 mm below fields and gardens;

r) Pipes should not pass under a building unless absolutely necessary. Where it is necessary to lay pipes under a building, the following conditions shall be observed:
   1) Pipes shall be centrifugally cast (spun) iron pressure pipe as per good practice [E-2(11)];
   2) The pipe shall be laid in straight line and at uniform gradient;
   3) Means of access in form of manholes/inspection chamber shall be provided at each end, immediately outside the building;
   4) In case the pipe or any part of it is laid above the natural surface of the ground, it shall be laid on concrete supports, the bottom of which goes at least 150 mm below the ground surface.

   NOTE — It is desirable that pipe/drains should not be taken through a living room or kitchen and shall preferably be taken under a staircase room or passage.

s) Consideration shall be given to alternative layouts so as to ensure that the most economical and practical solution is adopted. The possibility of alterations shall be avoided by exercising due care and forethought.

4.5.2.3 *Protection against vermin and dirt*

The installation of sanitary fittings shall not introduce crevices which are not possible to inspect and clean readily.

Pipes, if not embedded, shall be run well clear of the wall. Holes through walls to lay pipes shall be made good on both sides to prevent entry of insects. Materials used for embedding pipes shall be rodent-proof. Passage of rodents from room-to-room or from floor-to-floor shall be prevented by suitable sealing. The intermediate lengths of ducts and chases shall be capable of easy inspection. Any unused drains, sewers, etc, shall be demolished or filled in to keep them free from rodents.

All pipe shafts shall be plastered before any pipes are installed in the shaft. It is advisable to lay pipes on the steel supports with adequate gap between plastered wall and support structure. This will provide a smooth surface and prevent location for survival of insects and vermins.

4.5.2.4 *Choice of plumbing system*

4.5.2.4.1 In selecting one or more of the type of piping systems, the building and the layout of toilets/fixtures, relationship with other services, acceptability to the Authority, and any special requirements of users, shall be studied.

a) *Single stack system* [*see* 2.73(a)]
   1) The single stack system is ideal when the toilet/fixture layouts are repetitive and there is less space for pipes on the wall;
   2) In any system so selected there should be not more than two toilet connections per floor;
   3) The system requires minimum 100 mm diameter stack for a maximum of 5 floors in a building;
   4) In this system, care shall be taken of the horizontal distance of sanitary fixtures from the drainage stack and vertical distance between connections of branches from fixtures to drainage stack; and
   5) All the safeguards for the use of this system given in 4.5.2.4.2 shall be complied with.

b) *One pipe – partially ventilated system* [*see* 2.73(b)]

   The system and the applicable safeguards under this system are the same as for single stack system. The prime modification is to vent the soil appliance(s).

c) *One pipe – fully ventilated system* [*see* 2.73(c)]
   1) This system is suitable for buildings where the toilet/fixture layouts and the shafts are repetitive. It requires less shaft space and is economical;
   2) Continuous flow of water in the pipe from waste appliances makes it less prone to blockage and makes the system more efficient;

3) The system eliminates the need for a gully trap which requires constant cleaning;
4) This system requires individual vent pipes installed either in suspended ceiling or in the wall above the floor level in the toilet, provided construction details of the building allow provision of vent pipes for individual fixtures and routing of vent pipes to remote shafts where main vent stacks may have been located;
5) The system requires minimum 100 mm diameter stack;
6) The system is ideal when the main pipes run at the ceiling of the lowest floor or in a service floor.

d) *Two pipe system* [*see* 2.73(d)]

1) This system provides safety and flexibility in layouts for larger toilets and for buildings having higher requirement of performance due to its height and type of occupancy;
2) In large buildings and houses with open ground and gardens, the sullage water from the waste system can be suitably treated and usefully utilized for gardening and agriculture; and
3) In larger and multi-storeyed buildings, the sullage is treated within the building for reuse as makeup water for cooling towers for air conditioning system and is also used for flushing water closets provided it has absolutely no connection with any water supply line, tank or system used for domestic and drinking supply.

e) *Vacuum sewage system* — Vacuum based sewage disposal system is efficient and environmentally friendly alternative. This system is easier to construct compared to conventional systems. The system operates with a closed, leak-proof vacuum network and requires shallower excavation compared to conventional systems. It is suitable for flat terrain, high water table areas, seaside locations, and environmentally sensitive zones.

The system comprises the following:

1) House gravity connection;
2) Collection chamber with interface unit;
3) Vacuum connection and piping;
4) Vacuum station; and
5) Odour fitter and ring main.

One of the characteristic features of this system is the presence of the collection chamber. The collection chamber serves or reserve storage for a day, during any power failure.

Sewage flows by gravity into a collection chamber and remains for a short time with reserve storage availability. When the level rises, a starter valve activates the vacuum piston valve to open and to allow the sewage water with air to be derived in the vacuum network. Multiple connections can be linked to a single collection chamber.

The system can be used in the following applications:

i) Septic tank replacements;
ii) Ribbon development and new residential layouts;
iii) Villages;
iv) Industrial areas;
v) Islands;
vi) Rocky terrain; and
vii) Environmentally sensitive areas.

For detailed information regarding design and installation of soil, waste and vent pipes, reference may be made to good practice [E-2(12)].

4.5.2.4.2 *Safeguards for single stack system*

a) As far as practicable, the fixtures on a floor shall be connected to stack in order of increasing discharge rate in the downward direction;

b) The size of the vent pipe (terminating to the outdoor) shall be same as the size of drainage stack in the case of single stack system;

c) Water closets shall be connected to the stack through a sanitary tee; the maximum horizontal distance from the stack being 2 400 mm;

d) For fixtures other than water closets, the maximum horizontal distance from the stack shall be 3 500 mm.

e) The vertical distance between the waste branch (from floor trap or from the individual appliance) and the soil branch connection, when soil pipe is connected to stack above the waste pipe, shall be not less than 200 mm;

f) Depth of water seal traps from different fixtures shall be as follows:

Water closets : 50 mm

Floor traps : 50 mm

Other fixtures directly connected to the stack:

1) Where attached to branch : 40 mm waste pipes of 75 mm dia or more

2) Where attached to branch : 75 mm waste pipes of less than 75 mm dia

NOTE — When connection is made through floor trap, no separate seals are required for individual fixtures.

g) Branches and stacks which receive discharges from WC pans should not be less than 100 mm, except where the outlet from the siphonic water closet is 80 mm, in which case a branch pipe of 80 mm may be used. For outlet of floor traps 75 mm dia pipes may be used;

h) The horizontal branch distance for fixtures from stack, bend(s) at the foot of stack to avoid back pressure as well as vertical distance between the lowest connection and the invert of drain shall be as good practice [E-2(12)]; and

j) For tall buildings, ground floor appliances are recommended to be connected directly to manhole/ inspection chamber.

4.5.2.4.2.1 Drainage stack shall be sized in accordance with Table 18. The drainage stack and branch piping shall be the vents for the drainage system. Stack shall be uniformly sized based on the total connected drainage fixture unit load.

Table 18 Single Stack Sizing

(*Clause* 4.5.2.4.2.1)

Sl No.	Stack Size mm	Maximum Connected Drainage Fixture Units (DFU)[2]		
		Stacks Less than 23 m in Height	Stacks 23 m to Less than 49 m in Height	Stacks 49 m and Greater in Height[1]
(1)	(2)	(3)	(4)	(5)
i)	75	24	–	–
ii)	100	225	24	–
iii)	125	480	225	24
iv)	150	1 015	480	225
v)	200	2 320	1 015	480
vi)	250	4 500	2 320	1 015
vii)	300	8 100	4 500	2 320
viii)	375	13 600	8 100	4 500

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[1] To be considered for one pipe – partially ventilated system only.

[2] 1 DFU may be taken as equivalent to 0.47 L/s.

4.5.2.4.2.2 An alternative design approach for designing the single stack system is also used in some of the countries, which may be followed if approved by the Authority. Such an approach may utilize the following, and may also require reference to available specialist literature:

a) The size of the vent pipe (terminating to the outdoor) shall be same as the size of drainage stack in the case of single stack system;

b) Using branch discharge pipes, self and external siphonage of the water seal of traps can be avoided;

c) In respect of branch discharge pipes, the entire developed length including fittings up to farthest connection is 4.0 m;

d) A 45° bend shall be used for the horizontal branch pipe with a drop connection after the connection from the appliance;

e) To match the crowns of small and larger pipes, an eccentric reducer is used with straight portion on top;

f) A non-ventilated discharge pipe shall be connected to discharge stack with a sweep junction having an angle of 87° to 88.5°;

g) In respect of vertical discharge stacks, concentric or eccentric reducers may be permitted;

h) In respect of stacks not exceeding 10 m in height, from the upper most connection to change of direction, no branch discharge pipe shall be connected to the stack or horizontal side for a distance of 1.0 m. In respect of second change in direction, no branch discharge pipe shall be connected within a distance of 0.5 m after the change of direction. The pipe stack shall not be connected to sanitary appliances from the lowest floor;

j) In respect of stacks exceeding 10 m in height, from the upper most connection to change of direction, no branch discharge pipe shall be connected to the stack or horizontal side for a distance of 2.0 m. The connection of the ventilated branch to the main stack shall not be within 2.0 m from the change of direction. In respect of second change in direction, no branch discharge pipe shall be connected within a distance of 0.5 m after the change of direction. The pipe stack shall not be connected to sanitary appliances from the lowest floor;

k) The connection of branch discharge pipes to the vertical stack shall be such that back flow will not cross flow into fixtures on the opposite ends; and

m) The single stack system shall be designed and installed based on the principles of sanitary appliance usage, proper dimensioning, and installation guidelines.

4.5.3 *Drainage* (*Soil*, *Waste and Vent*) *Pipes*

4.5.3.1 *General considerations*

4.5.3.1.1 Drainage pipes shall be kept clear of all other services. Provisions shall be made during the construction of the building for the entry of the drainage pipes. In most cases this may be done conveniently by installing sleeves or conduit pipes into or under the structure in appropriate positions. This will facilitate the installation and maintenance of the services.

4.5.3.1.2 Horizontal drainage piping should be so routed as not to pass over any equipment or fixture where leakage from the line could possibly cause damage or contamination. Drainage piping shall never pass over switch-gear or other electrical equipment. If it is impossible to avoid these areas and piping shall run in these locations, then a pan or drain tray should be installed below the pipe to collect any leakage or condensation. A drain line should run from this pan to a convenient floor drain or service sink.

4.5.3.1.3 All vertical soil, waste, ventilating and anti-siphonage pipes shall be covered on top with a copper or heavily galvanized iron wire dome or cast iron terminal guards. All cast iron pipes, which are to be painted periodically, shall be fixed to give a minimum clearance of 50 mm clear from the finished surface of the wall by means of a suitable clamp.

NOTE — Asbestos cement cowls may be used in case asbestos cement pipes are used as soil pipes.

4.5.3.1.4 Drainage pipes shall be carried to a height above the buildings as specified for ventilating pipe (*see* 4.5.3.4).

4.5.3.2 *Soil pipes*

A soil pipe, conveying to a drain, any solid or liquid filth, shall be circular and shall have a minimum diameter of 100 mm.

4.5.3.2.1 Except where it is impracticable, the soil pipe shall be situated outside the building or in suitably designed pipe shafts and shall be continued upwards without diminution of its diameter, and (except where it is unavoidable) without any bend or angle, to such a height and position as to afford by means of its open end a safe outlet for foul air. The position of the open end with its covering shall be such as to comply with the conditions set out in 4.5.3.4 relating to ventilating pipe. Even if the pipes are laid externally, the soil pipes shall not be permitted on a wall abutting a street unless the Authority is satisfied that it is unavoidable. Where shafts for pipes are provided, the cross section area of the shaft shall be suitable to allow free and unhampered access to the pipes and fittings proposed to be installed in the shaft. However, in no case cross section area of the shaft shall be less than a square of one-meter side. All pipe shafts shall be provided with an access door at ground level and facilities for shaft ventilation.

4.5.3.2.2 Soil pipes, whether inside or outside the building, shall not be connected with any rainwater pipe and there shall not be any trap in such soil pipe or between it and any drain with which it is connected.

4.5.3.2.3 The soil pipe shall be provided with heel rest bend which shall rest on sound footing, if terminating at firm ground level. When the stack is terminating at the ceiling of a floor, the bend shall be provided with sufficient structural support to cater for the stack dead weight and the thrust developed from the falling soil/waste. Vertical stack shall be fixed at least 50 mm clear of the finished surface of the wall by means of a suitable clamp of approved type.

4.5.3.3 *Waste pipes*

Every pipe in a building for carrying off the waste or overflow water from every bath, wash basin or sink to a drain shall be of 32 mm to 50 mm diameter, and shall be trapped immediately beneath such wash basins or sink by an efficient siphon trap – P trap with adequate means for inspection and cleaning. Such P traps shall be ventilated into the external air whenever such ventilation is necessary to preserve the seal of the trap. Waste pipes, P traps, etc, shall be constructed of iron, lead, brass, PVC, engineering plastics, stoneware, asbestos cement or other approved material. The overflow pipe from wash basin, sinks, etc, shall be connected with the waste pipe immediately above the trap. Vertical pipes carrying off waste water shall have a minimum diameter of 75 mm.

NOTE — Whenever wash basins and sinks have in-built overflow arrangements, there is no need to provide overflow pipes in such cases.

4.5.3.3.1 Every pipe in a building for carrying off waste water to a drain shall be taken through an external wall of the building by the shortest practicable line, and shall discharge below the grating or surface box of the chamber but above the inlet of a properly trapped gully. The waste pipe shall be continued upwards without any diminution in its diameter and (except when unavoidable) without any bend or angle to such a height and position as to afford by means of the open end of the waste pipe, a safe outlet for foul air, the position of the open end and its covering being such as to comply with the conditions.

4.5.3.3.2 Except where it is impracticable, the common waste pipe shall be situated outside the building and shall be continued upwards without diminution of its diameter (except where it is unavoidable) without any bend or angle being formed to such a height and position as to avoid by means of the open end a safe outlet for foul air, the position of the open end and the covering threat being such as to comply with the conditions set out in 4.5.3.4 relating to ventilating pipe.

4.5.3.3.3 If the waste pipe is of cast iron, it shall be firmly attached 50 mm clear of the finished surface of the wall by means of a suitable clamps or with properly fixed holder bats or equally suitable and efficient means.

4.5.3.4 *Vent pipes*

Ventilating pipes should be so installed that water cannot be retained in them. They should be fixed vertically. Whenever possible, horizontal runs should be avoided. Ventilating pipe shall be carried to such a height and in such a position as to afford by means of the open end of such pipe or vent shaft, a safe outlet for foul air with the least possible nuisance.

4.5.3.4.1 The upper end of the main ventilating pipe may be continued to the open air above roof level as a separate pipe, or it may join the MSP and/or MWP above the floor level of the highest appliance. Its lower end may be carried down to join the drain, at a point where air relief may always be maintained.

4.5.3.4.2 Branch ventilating pipes should be connected to the top of the BSP and BWP between 75 mm and 450 mm from the crown of the trap.

4.5.3.4.3 The ventilating pipe shall always be taken to a point 1 500 mm above the level of the eaves or flat roof or terrace parapet whichever is higher or the top of any window within a horizontal distance of 3 m. The least dimension shall be taken as a minimum and local conditions shall be taken into account. The upper end of every ventilating pipe shall be protected by means of a cowl.

4.5.3.4.4 In case the adjoining building is taller, the ventilating pipe shall be carried higher than the roof of the adjacent building, wherever it is possible.

4.5.3.4.5 The building drain intended for carrying waste water and sewage from a building shall be provided with at least one ventilating pipe situated as near as practicable to the building from an inspection chamber and as far away as possible from the point at which the drain empties into the sewer or other carrier.

4.5.3.4.6 *Size of ventilating pipe*

a) The building drain ventilating pipe shall be of not less than 75 mm diameter. When, however, it is used as MSP or MWP, the upper portion, which does not carry discharges, shall not be of lesser diameter than the remaining portion;

b) The diameter of the main ventilating pipe in any case should not be less than 50 mm;

c) A branch ventilating pipe on a waste pipe in both one and two-pipe systems shall be of not less than two-thirds the diameter of the branch waste pipe, subject to a minimum of 25 mm;

d) A branch ventilating pipe on a soil pipe in both one and two-pipe systems shall be not less than 32 mm in diameter; and

e) Ventilating pipes to be sized/designed considering the drainage fixture units of individual fixtures/appliances as per good engineering practices (*see* 4.5.3.4.7).

4.5.3.4.7 *Venting system for high rise buildings*

In the case of fully ventilated system, suitable sized pipe stacks carry soil and waste drainage, wherein each sanitary fixture is individually vented. The practical way of implementation of this system is by venting each water closet and floor drain. A fully ventilated one pipe drainage system is most popular in advanced plumbing installations.

Properly sized ventilating pipe would ensure maintenance of atmospheric pressure within gravity drainage pipes.

Sizing of ventilating pipe is based on cumulative drainage fixture units of all fixtures served by the pipe. Sizing also depends on maximum permissible lengths. Maximum lengths are also subject to the limitation that one-third of length shall be horizontal. Horizontal pipes always rise towards termination point, avoiding vertical loops.

The minimum required diameter of stack vents and vent stacks shall be determined from the developed length and the total drainage fixture units (DFU) connected thereto, in accordance with Table 19. However, in no case, the diameter shall be less than half the diameter of the drain served or less than 32 mm.

NOTE — In case, if fully ventilated one-pipe system is not implemented then it shall indicate the case of two-pipe system along with common ventilating pipe for which the guideline for sizing shall be provided. Also, it shall provide a sketch for two-pipe system along with connection of branch pipes from wash basin to the deep seal trap through inlet fitting as per prevailing conditions as approved by Authority.

Table 19 Size and Developed Length of Stack Vents and Vent Stacks

(*Clause* 4.5.3.4.7)

Sl No.	Diameter of Soil and/or Waste Stack mm	Total Fixture Units Being Vented (DFU)	Maximum Developed Length of Vent for the Diameter of Vent m										
			32 mm	40 mm	50 mm	65 mm	75 mm	100 mm	125 mm	150 mm	200 mm	250 mm	300 mm
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
i)	32	2	9	–	–	–	–	–	–	–	–	–	–
ii)	40	8	15	45	–	–	–	–	–	–	–	–	–
iii)	40	10	9	30	–	–	–	–	–	–	–	–	–
iv)	50	12	–	23	61	–	–	–	–	–	–	–	–
v)	50	20	9	15	45	–	–	–	–	–	–	–	–
vi)	65	42	8	9	30	91	–	–	–	–	–	–	–
vii)	75	10	–	13	45	110	317	–	–	–	–	–	–
viii)	75	21	–	10	34	82	247	–	–	–	–	–	–
ix)	75	53	–	8	29	70	207	–	–	–	–	–	–
x)	75	102	–	–	26	64	189	–	–	–	–	–	–
xi)	100	43	–	8	11	26	76	299	–	–	–	–	–
xii)	100	140	–	–	8	20	61	229	–	–	–	–	–
xiii)	100	320	–	–	7	17	52	195	–	–	–	–	–
xiv)	100	540	–	–	6	15	46	177	–	–	–	–	–
xv)	125	190	–	–	–	8.5	25	98	302	–	–	–	–
xvi)	125	490	–	–	–	6.4	19	76	232	–	–	–	–
xvii)	125	940	–	–	–	5.5	16	64	204	–	–	–	–
xviii)	125	1 400	–	–	–	4.9	15	58	180	–	–	–	–
xix)	150	500	–	–	–	–	10	40	122	305	–	–	–
xx)	150	1 100	–	–	–	–	8	30	94	238	–	–	–
xxi)	150	2 000	–	–	–	–	7	26	79	201	–	–	–

Table 19 (*Concluded*)

Sl No.	Diameter of Soil and/or Waste Stack mm	Total Fixture Units Being Vented (DFU)	Maximum Developed Length of Vent for the Diameter of Vent m										
			32 mm	40 mm	50 mm	65 mm	75 mm	100 mm	125 mm	150 mm	200 mm	250 mm	300 mm
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
xxii)	150	2 900	–	–	–	–	6	23	73	183	–	–	–
xxiii)	200	1 800	–	–	–	–	–	9	29	73	287	–	–
xxiv)	200	3 400	–	–	–	–	–	7	22	58	222	–	–
xxv)	200	5 600	–	–	–	–	–	6	19	49	186	–	–
xxvi)	200	7 600	–	–	–	–	–	5	17	43	171	–	–
xxvii)	250	4 000	–	–	–	–	–	–	9	24	94	293	–
xxviii)	250	7 200	–	–	–	–	–	–	7	18	73	226	–
xxix)	250	11 000	–	–	–	–	–	–	6	16	61	192	–
xxx)	250	15 000	–	–	–	–	–	–	5	14	55	174	–
xxxi)	300	7 300	–	–	–	–	–	–	–	9	37	116	287
xxxii)	300	13 000	–	–	–	–	–	–	–	7	29	91	219
xxxiii)	300	20 000	–	–	–	–	–	–	–	6	24	76	186
xxxiv)	300	26 000	–	–	–	–	–	–	–	5	22	70	152
xxxv)	375	15 000	–	–	–	–	–	–	–	–	12	40	94
xxxvi)	375	25 000	–	–	–	–	–	–	–	–	9	29	73
xxxvii)	375	38 000	–	–	–	–	–	–	–	–	8	25	61
xxxviii)	375	50 000	–	–	–	–	–	–	–	–	7	23	55

NOTE — The developed length shall be measured from the vent connection to the open air.

4.5.3.5 *Design of drainage pipes*

A stack is the main vertical pipe that carries away discharge from water closets and urinals (soil stack) or other clear wastewater from equipment (waste stack) with adequate suitable fittings, which may be a long-turn, tee-wye or short-turn or sanitary tee. Special fittings may also be used, provided that their drainage capacity has been certified in accordance with the relevant Indian Standards or by approved laboratories. Depending on the rate of flow into the drain stack, the diameter of the stack, the type of stack fittings and the flow down the stack from higher levels (if any), the discharge from the fixture drain may or may not fill the cross section of the stack at the level of entry. In any event, as soon as the water enters the stack, the force of gravity rapidly accelerates it downward and before it travels very far, it assumes the form of a sheet around the wall of the stack, leaving the centre of the pipe open for the flow of air.

This sheet of water continues to accelerate until the frictional force exerted by the wall of the falling sheet of water equals the gravitational force. If the distance the water travel is sufficient enough and provided that no flow enters the stack at lower levels to interfere the sheet, the sheet remains unchanged in thickness and velocity until it reaches the bottom of the stack. The ultimate vertical velocity the sheet attains is called the 'terminal velocity'. The distance the sheet should fall to attain this terminal velocity is called the 'terminal length'.

Following formulae may be used for calculating the terminal velocity and terminal length:

$$V_t = 3.0\,(Q/d)^{2/5}$$

$$L_t = 0.052\,V_t^2$$

where

V_t = terminal velocity in the stack, m/s;

Q = quantity rate of flow, l/s;

d = diameter of stack, mm; and

L_t = terminal length below the point of flow entry, m;

At the centre of the stack is a core of air that is dragged along with the water by friction. A supply source of air shall be provided to avoid excessive pressures in the stack. The usual means of supplying this air are through the stack vent or vent stack. The entrained air in the stack causes a pressure reducing inside the stack, which is caused by the frictional effect of the falling sheet of water dragging the core of air with it.

4.5.3.5.1 *Estimation of maximum flow of sewer*

a) *Simultaneous discharge flow*

1) The maximum flow in a building drain or a stack depends on the probable maximum number of simultaneous discharging appliances. For the calculation of this peak flow certain loading factors have been assigned to appliances in terms of fixture units, considering their probability and frequency of use. These fixture unit values are given in Table 20;

2) For any fixtures not covered under Table 20, Table 21 may be referred to for deciding their fixture unit rating depending on their drain or trap size;

3) From Table 20 and Table 21, the total load on any pipe in terms of fixtures units may be calculated knowing the number and type of appliances connected to this pipe;

4) For converting the total load in fixture units to the peak flow in litre per minute, Fig. 6 is to be used.

5) The maximum number of fixture units that are permissible for various recommended pipe size in the drainage system are given in Table 22 and Table 23; and

6) Results should be checked to see that the soil, waste and building sewer pipes are not reduced in diameter in the direction of flow. Where appliances are to be added in fixture, these should be taken into account in assessing the pipe sizes by using the fixture units given in Table 20 and Table 21.

b) *Maximum discharge flow* — The maximum rate of *discharge* flow shall be taken as thrice the average rate; allowance being made in addition for any exceptional peak discharges. A good average rule is to allow for a flow of liquid wastes from buildings at the rate of 3 litre per minute per 10 persons.

4.5.3.5.2 *Gradients*

4.5.3.5.2.1 The discharge of water through a domestic drain is intermittent and limited in quantity and, therefore, small accumulations of solid matter are liable to form in the drains between the building and the public sewer. There is usually a gradual shifting of these deposits as discharges take place. Gradients should be sufficient to prevent these temporary accumulations building up and blocking the drains:

a) *Drainage loads* — Single family dwellings contain plumbing fixtures, such as one or more bathroom groups, each consisting of a toilet, wash basin and bathtub or shower unit, a kitchen sink, dishwasher and washing machine. Large buildings also have other fixtures, slop sinks and drinking water coolers. The important characteristic of these fixtures is that they are not used continuously. Rather, they are used with irregular frequencies that vary greatly during the day. In addition, the various fixtures have quite different discharge characteristics regarding both the average flow rate per use and the duration of a single discharge. Consequently, the probability of all the fixtures in the building operating simultaneously is small; and

b) *Stack capacities* — The criterion of flow capacities in drainage stacks is based on the limitation of the water occupied cross section to a specified fraction of the cross section of the stack where terminal velocity exists, as suggested by earlier investigations.

Flow capacity can be expressed in terms of the stack diameter and the water cross section, as follows:

$$Q = 27.8 \times r_s^{5/3} \times D^{8/3}$$

where

Q = capacity, l/s;

r_s = ratio of the cross-sectional area of the sheet of water to the cross-sectional area of the stack; and

D = diameter of the stack, mm.

Table 20 Drainage Fixture Units (DFU) for Different Fixtures with Minimum Pipe Sizes

(*Clause* 4.5.3.5.1)

Sl No.	**Type of Fixture**	**Application**		**Minimum Trap Size** mm
		Private	Public	
(1)	(2)	(3)	(4)	(6)
i)	Bathroom group (water closet, wash basin, bidet and tub or shower):			
	a) Water closet (flush valve)	8	–	–
	b) Water closet (flush tank)	6	–	–
ii)	Bathtub	3	–	40
iii)	Bar sink	1	2	40
iv)	Ablution faucet/Bidet	1	2	40
v)	Clothes washer	3	3	50
vi)	Dishwasher	2	2	40
vii)	Drinking fountain	–	0.5 (0.75)	32
viii)	Floor drain	1	2	50

Table 20 (*Concluded*)

Sl No.	Type of Fixture	Application		Minimum Trap Size mm
		Private	Public	
(1)	(2)	(3)	(4)	(6)
ix)	Wash basin	1	1	32
x)	Service or mop basin/sink	–	3	50
xi)	Kitchen sink	2	2	40
xii)	Shower	2	2	50
xiii)	Laundry sink	2	2	40
xiv)	Clinical or surgeon’s scrub sink	–	6	80
xv)	Urinal (with flush valve)	2	2	50
xvi)	Urinal (with flush tank)	2	2	50
xvii)	Urinal with sensor operated	2	2	50
xviii)	Water closet (flush valve)	4	6 (8)	80
xix)	Water closet (flush tank)	3	4 (6)	80
xx)	Combination fixture (faucet)	1	2	40

NOTES

1 A shower head over a bath tub does not increase the fixture unit value.

2 Size of floor trap shall be determined by the area of surface water to be drained.

3 Wash basins with 32 mm and 40 mm trap have the same load value.

4 Trap size shall be consistent with the fixture outlet size.

5 For fixtures added to bathroom group, the DFU value is added to those additional fixtures to the bathroom group fixture count.

6 No floor traps to be provided inside operating rooms, procedure rooms, AIIR isolation rooms and PE isolation rooms.

7 The values given in parentheses pertain to such public use buildings where an enhanced requirement is expected to be encountered as compared to the normal maximum use in public use buildings.

Table 21 Fixture Unit Values for Fixtures Based on Fixture Drain on Trap Size

(*Clause* 4.5.3.5.1)

Sl No.	Fixture Drain on Trap Size	Fixture Unit Value
(1)	(2)	(3)
i)	32 mm and smaller	1
ii)	40 mm	2
iii)	50 mm	3
iv)	65 mm	4
v)	80 mm	5
vi)	100 mm	6

Table 22 Horizontal Fixture Branches and Stacks[1]

(*Clause* 4.5.3.5.1)

Sl No.	Diameter of Pipe mm	Maximum Number of Drainage Fixture Units[2] (DFU) that can be Connected to			
		Branch Total for Horizontal Branch	Stacks[3]		
			Total Discharge into One Branch Interval	Total for Stack of Three Branch Intervals or Less	Total for Stack Greater than Three Branch Intervals
(1)	(2)	(3)	(4)	(5)	(6)
i)	32	1	2	2	2
ii)	40	3	2	4	8
iii)	50	6	6	10	24
iv)	65	12	9	20	42
v)	75	20	20	48	72
vi)	100	160	90	240	500
vii)	125	360	200	540	1 100
viii)	150	620	350	960	1 900
ix)	200	1 400	600	2 200	3 600
x)	250	2 500	1 000	3 800	5 600
xi)	300	3 900	1 500	6 000	8 400
xii)	375	7 000	*See* Note	*See* Note	*See* Note

NOTE — Sizing load based on design criteria.

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[1] Does not include branches of the building sewer.

[2] Depending upon the probability of simultaneous use of appliances considering the frequency of use and peak discharge rate.

[3] Stacks shall be sized based on the total accumulated connected load at each story or branch interval. As the total accumulated connected load decreases, stacks are permitted to be reduced in size. Stack diameters shall not be reduced to less than one-half of the diameter of the larger stack size required.

Table 23 Building Drains and Sewers[1]

(*Clause* 4.5.3.5.1)

Sl No.	Diameter of Pipe mm	Maximum Number of Drainage Fixture Units (DFU) that can be Connected to any Portion of the Building Drain or the Building Sewer Including Branches of the Building Drain[2], for Slope			
		1/200	1/100	1/50	1/25
(1)	(2)	(3)	(4)	(5)	(6)
i)	32	–	–	1	1
ii)	40	–	–	3	3
iii)	50	–	–	21	26
iv)	65	–	–	24	31
v)	75	–	36	42	50
vi)	100	–	180	216	250
vii)	125	–	390	480	575
viii)	150	–	700	840	1 000
ix)	200	1 400	1 600	1 920	2 300
x)	250	2 500	2 900	3 300	4 200
xi)	300	3 900	4 600	5 600	6 700
xii)	375	7 000	8 300	10 000	12 000

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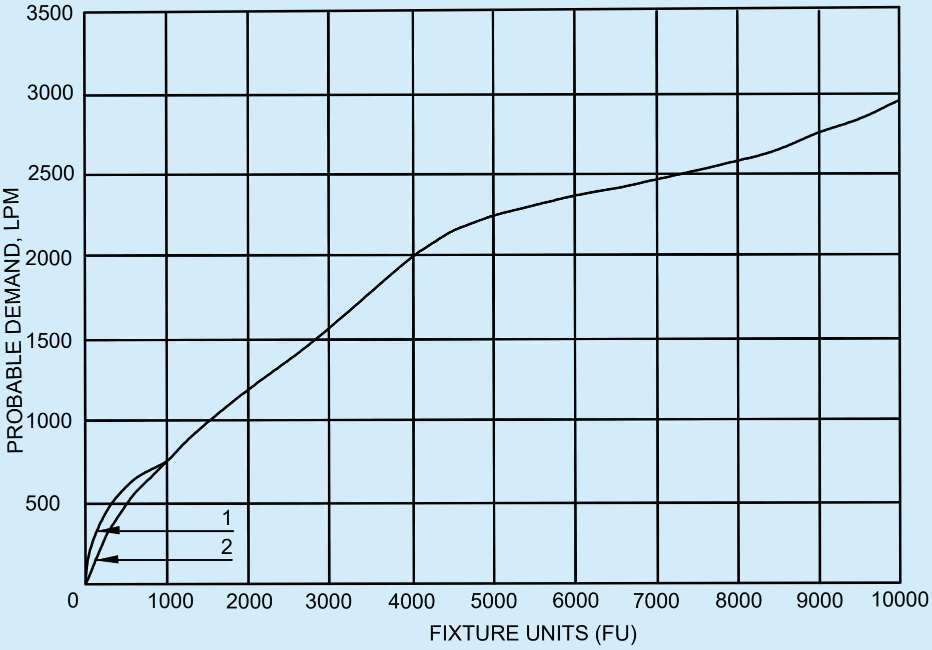
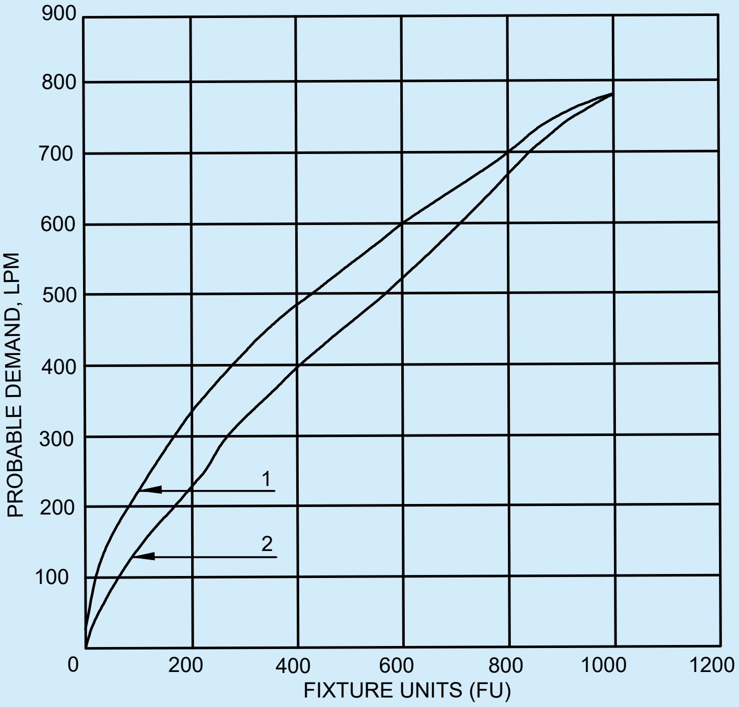
[1] Includes branches of the building sewer.

[2] The minimum size of any building drain serving a water closet shall be 75 mm.

c) *Design requirement for high rise buildings drainage system* — Drainage pipe stacks are sized for one third of their carrying capacity. Plumbing codes provides values of drainage fixture units for each fixture. Different values for fixture units are based on the nature of occupancy and the place of installation. Sizing of drainage pipes is based on the cumulative values of drainage fixture units connected to the pipe. A vertical pipe shall always have larger carrying capacity when compared to horizontal pipe of same size. Carrying capacity of horizontal pipe is dependent on gradient provided. Carrying capacities of vertical pipes are restricted by their maximum permissible lengths. This restriction does not apply to horizontal pipes. Irrespective of drainage fixture units, the minimum size for the fixture shall be adopted. The minimum size of horizontal pipe is critical to ensure self cleansing velocities in sewers.



6A GRAPH FOR PROBABLE DEMAND UP TO 10 000 FU



6B GRAPH FOR PROBABLE DEMAND UP TO 1000 FU

CURVE 1 - SYSTEM WITH FLUSH VALVES
CURVE 2 - SYSTEM WITH FLUSH TANKS

FIG. 6 GRAPH FOR PROBABLE DEMAND

4.5.3.5.2.2 When flow occurs in drain piping, it should not entirely fill the cross section of the pipe under flow condition. If the pipe were to flow full, pressure fluctuations would occur which could possibly destroy the seal of the traps within the building. Normally, the sewer shall be designed for discharging the peak flow as given in **4.5.3.5.1**, flowing half-full with a minimum self-cleansing velocity of 0.75 m/s. The approximate gradients which give this velocity for the sizes of pipes likely to be used in building drainage and the corresponding discharges when following half-full are given in Table 24.

4.5.3.5.2.3 In cases where it is practically not possible to conform to the ruling gradients, a flatter gradient may be used, but the minimum velocity in such cases shall on no account be less than 0.61 m/s and adequate flushing should be done.

NOTE — Where gradients are restricted, the practice of using a pipe of larger diameter than that required by the normal flow, in order to justify laying at a flatter gradient does not result in increasing the velocity of flow, further this reduces the depth of flow and thus for this reasons the above mentioned practice should be discouraged.

4.5.3.5.2.4 On the other hand, it is undesirable to employ gradients giving a velocity of flow greater than 2.4 m/s. Where it is unavoidable, cast iron pipes shall be used. The approximate gradients, which give a velocity of 2.4 m/s for pipes of various sizes and the corresponding discharge when flowing half-full are given in Table 24.

4.5.3.5.2.5 The discharge values corresponding to nominal diameter and gradient given in Table 24 are based on Manning's formula ($n = 0.015$).

NOTE — Subject to the minimum size of 100 m, the sizes of pipes shall be decided in relation to the estimated quantity of flow and the available gradient.

Table 24 Different Diameter Pipes Giving Velocity and Corresponding Discharge at Minimum and Maximum Gradient

(*Clauses* 4.5.3.5.2.2, 4.5.3.5.2.4 *and* 4.5.3.5.2.5)

Sl No.	Diameter (mm)	Minimum Gradient (Velocity : 0.75 m/s)	Discharge at the Minimum Gradient m^3/min	Maximum Gradient (Velocity : 2.4 m/s)	Discharge at the Maximum Gradient m^3/min
(1)	(2)	(3)	(4)	(5)	(6)
i)	100	1 in 57	0.18	1 in 5.6	0.59
ii)	150	1 in 100	0.42	1 in 9.7	1.32
iii)	200	1 in 145	0.73	1 in 14	2.40
iv)	230	1 in 175	0.93	1 in 17	2.98
v)	250	1 in 195	1.10	1 in 19	3.60
vi)	300	1 in 250	1.70	1 in 24.5	5.30

4.5.3.6 *Drain appurtenances*

4.5.3.6.1 *Trap*

All traps shall be protected against siphonage and back pressure ensuring access to atmospheric air for air circulation and preserving the trap seal in all conditions.

4.5.3.6.1.1 A trap may be formed as an integral trap with the appliance during manufacture or may be a separate fitting called an attached trap which may be connected to the waste outlet of the appliance.

4.5.3.6.1.2 Traps should always be of a self-cleansing pattern. A trap, which is not an integral part of an appliance, should be directly attached to its outlet and the pipe should be uniform throughout and have a smooth surface.

4.5.3.6.1.3 The trap should have minimum size of outlet/exit, same as that of largest waste inlet pipe.

4.5.3.6.1.4 Traps for use in domestic waste installations and all other traps should be conveniently accessible and provided with cleansing eyes or other means of cleaning.

4.5.3.6.1.5 The minimum internal diameter for sanitary appliances shall be as follows:

Sl No.	*Sanitary Appliance*	*Minimum Internal Diameter of Waste Outlet* mm
(1)	(2)	(3)
i)	*Soil appliances:*	
	a) Indian and European type water closets	100
	b) Bed pan washers and slop sinks	100
	c) Urinal with integral traps	75
	d) Stall urinals (with not more than 120 mm of channel drainage)	50
	e) Lipped urinal small/large	40
ii)	*Waste appliances:*	
	a) Drinking fountain	25
	b) Wash basin	32
	c) Bidets	32
	d) Domestic sinks and baths	40
	e) Shower bath trays	40
	f) Domestic bath tubs	50
	g) Hotel and canteen sinks	50
	h) Floor traps (outlet diameter)	75

4.5.3.6.2 *Floor drains*

All toilets/bathrooms in a building desirably should be provided with floor drains to facilitate cleaning.

4.5.3.6.2.1 Floor drains shall connect into a trap so constructed that it can be readily cleaned and of a size to serve efficiently the purpose for which it is intended. The trap shall be either accessible from the floor drain or by a separate cleanout within the drain.

4.5.3.6.2.2 Floor drain also receives, waste piping which does not connect to the sanitary system, known as indirect waste. This discharge from an indirect waste should be conveyed into a water supplied, trapped and vented floor drain.

4.5.3.6.2.3 Floor drain should be provided in mechanical equipment rooms, where pumps, boilers, water chillers, heat exchangers and other air conditioning equipment are periodically drained for maintenance and repair. Boiler requires drain at safety relief valve discharge.

4.5.3.6.2.4 Strategically floor drains are required to be located in buildings with wet fire protection sprinkler systems to drain water in case of activation of sprinkler heads.

4.5.3.6.2.5 The minimum diameter for floor drains outlets before connecting to floor trap is 75 mm.

4.5.3.6.3 *Cleanouts*

The cleanout provides access to horizontal and vertical lines and stacks to facilitate inspection and means to remove obstructions common to all piping systems, such as solid objects, greasy wastes, hair and the like.

4.5.3.6.3.1 Cleanouts in general should be gas and water tight, provide quick and easy plug removal, allow ample space for rodding tools, have means of adjustments to finished floor level, be attractive and be designed to support whatever load is directed over them.

4.5.3.6.3.2 Waste lines are normally laid beneath the floor slab at a sufficient distance to provide adequate back-fill over the joints. Cleanouts are then brought up to floor level grade by pipe extension pieces.

4.5.3.6.3.3 The size of the cleanout within a building should be the same size as the piping up to 100 mm. For larger size piping 100 mm cleanouts are adequate for their intended purpose.

4.5.3.6.3.4 Cleanouts are suggested to be provided at the following locations:

a) Inside the building at a point of exit. Use a wye branch or a trap;

b) At every change of direction greater than 45°;

c) At the base of all stacks; and

d) At the horizontal header, receiving vertical stacks and serving the purpose of offset header.

4.5.3.6.3.5 *Supports for drainage and sewerage pipes*

The supports for the above pipes and fittings shall be in accordance with manufacturer's recommendations and shall comply with the applicable standards.

4.5.4 *Indirect Wastes*

4.5.4.1 *General*

Waste, overflow and drain pipes from the following types of equipment shall not be connected into any drainage system directly to prevent backflow from the drainage system into the equipment/installation:

a) *Plumbing and kitchen appliances*:
   1) Underground or overhead water tanks;
   2) Drinking water fountains;
   3) Dishwashing sinks and culinary sinks used for soaking and preparation of food;
   4) Cooling counters for food and beverages;
   5) Kitchen equipment for keeping food warm; and
   6) Pressure drainage connections from equipment.

b) *Air conditioning, heating and other mechanical equipment*:
   1) Air handling equipment;
   2) Cooling tower and other equipment;
   3) Condensate lines from equipment;
   4) Storage tanks;
   5) Condensate lines;
   6) Boiler blow down lines; and
   7) Steam trap drain lines.

c) *Laboratories and other areas:*
   1) Water stills;
   2) Waste from laboratory in specified sinks;
   3) Sterlizers and similar equipment; and
   4) Water purification equipment.

4.5.4.2 *Indirect waste receptors*

All plumbing fixtures or other receptors receiving the discharge of indirect waste pipes shall be of such shape and capacity as to prevent splashing or flooding and shall be located where they are readily accessible for inspection and cleaning.

4.5.4.3 *Pressure drainage connections*

Indirect waste connections shall be provided for drains, overflows or relief vents from the water supply system, and no piping or equipment carrying wastes or producing wastes or other discharges under pressure shall be directly connected to any part of the drainage system.

The above shall not apply to any approved sump pump or to any approved plumbing fixture discharging pressurized waste or device when the Authority has been satisfied that the drainage system has the capacity to carry the waste from the pressurized discharge.

An indirect waste is required for any type of fixture or equipment that may come in contact with the food. The purpose is to isolate the fixture or equipment from drainage system waste.

Indirect waste piping shall be a minimum of 25 mm in size, but not smaller than drain of the equipment or fixture. There is no limitation on the length of indirect waste piping.

4.5.5 *Special Wastes*

4.5.5.1 *General*

Wastes having characteristics which may be detrimental to the pipes in which it is disposed as well as to the persons handling it. Such wastes used in a building need to be specially identified and a suitable and safe method of its disposal installed to ensure that the piping system is not corroded nor the health and safety of the occupants is affected in any way.

Whenever the occupant or the user of any wastes is unaware of the dangers of the consequences of disposing the waste, he shall be made aware of the dangers of his action along with providing suitable warning and instruction for correct disposal be provided to him.

Piping system for all special wastes should be separate and independent for each type of waste and should not be connected to the building drainage system. Other applicable provisions for installation of soil and waste pipe system shall be however be followed.

4.5.5.2 *Laboratory wastes*

A study of the possible chemical and corrosive and toxic properties of wastes handled and disposed of in a laboratory need to be ascertained in advance. The relevant statutory rules and regulation regarding the method of disposal of strong and objectionable wastes shall be followed.

All sinks, receptacles, traps, pipes, fittings and joints shall be of materials resistant to the liquids disposed of in the system.

In laboratories for educational, research and medical institutions, handling mildly corrosive and toxic wastes, they may be neutralized in chambers using appropriate neutralizing agents. The chamber shall be provided with chambers at inlet and outlet for collecting samples of the incoming and outgoing waste for monitoring its characteristics.

4.5.5.3 *Infected wastes*

Infected liquid wastes are generated in hospitals from patient excreta, operation theatres, laboratories testing samples of stools, urine, blood, flesh, etc, which shall not be disposed of into the drainage system. Such waste shall be collected separately and pre-treated, and sterilized, if required, before disposal into the building drainage system.

Soiled linen from infectious patients needs to be collected from the respective areas of the hospital in separate linen bins and pre-washed in dirty utility room in a sluice tub and sterilized in the laundry (sluice machine) before its regular washing in the hospital laundry. Liquid wastes from the washing operations shall be neutralized to prevent any cross contamination before discharge in the building's drainage system.

4.5.5.4 *Research laboratory wastes*

Research laboratories conducting research in all areas of science and technology, for example, chemical industry, pharmacy, metallurgy, bio-sciences, agriculture, atomic energy, medicine, etc, shall follow the established procedures laid down by statutory bodies to handle, treat and dispose wastes which are highly toxic, corrosive, infectious, inflammable, explosive and having bacterial cultures, complex organic and inorganic chemicals. Such wastes shall not be disposed of in a building drainage system or the city sewerage system unless they are pre-treated and meet the disposal criteria in accordance with the relevant rules/regulations.

It requires a liquid waste decontamination system which consists of at least one reactor or sterilizer plus a holding tank. An ideal system would consist of two or more sterilizers to provide redundancy with two or more tanks. There should be a sampling tank between this system and building drainage. The final treated waste water should flow to ETP and not STP.

4.5.6 *Grease Traps*

Oil and grease are found in wastes generated from kitchens in hotels, industrial canteens, restaurant, food and beverage areas, butcheries, some laboratories and manufacturing units having a high content of oil and greases in their final waste.

Waste exceeding temperature of 60 ºC should not be allowed in the grease trap. When so encountered, it may be allowed to cool in a holding chamber before entering the grease trap.

Oil and greases tend to solidify as they cool within the drainage system. The solidified matter clogs the drains and the other matter in the waste stick to it due to the adhesion properties of the grease. Oil and greases are lighter than water and tend to float on the top of the wastewater.

Grease traps shall be installed in building having the above types of wastes. In principle the grease laden water is allowed to retain in a grease trap which enables any solids to be settled or separated for manual disposal. The retention time allows the incoming waste to cool and allow the grease to solidify. The clear waste is then allowed to discharge into the building's drainage system.

4.5.7 *Oil Interceptors*

Oils and lubricants are found in wastes from vehicle service stations, workshops manufacturing units whose waste may contain high content of oils. Oils for example, petroleum, kerosene and diesel used as fuel, cooking, lubricant oils and similar liquids are lighter than water and thus float on water in a pipe line or in a chamber when stored. Such oils have a low ignition point and are prone to catch fire if exposed to any flame or a spark and may cause explosion inside or outside the drainage system. The flames from such a fire spread rapidly if not confined or prevented at the possible source. Lighter oils and lubricants are removed from the system by passing them through an oil interceptor/petrol gully. They are chambers in various compartments which allow the solids to settle and allow the oils to float to the top. The oil is then decanted in separate containers for disposal in an approved manner. The oil free waste collected from the bottom of the chamber is disposed in the building drainage system.

4.5.8 *Radioactive Waste*

Scientific research institutions, hospital and many types of manufacturing processes use radioactive material in the form of radio-isotopes and other radioactive sources for their activities. Manufacture, sale, use and disposal of radioactive material is regulated by the statutory rules and regulation. Proposal for usage and disposal of radioactive materials shall be done in consultation with and prior permission of the Authority by the users of the materials. No radioactive material shall be disposed off in any building drainage system without the authorization of the Authority.

NOTE — All procedures followed and precautions taken shall be in accordance with AERB regulations, including regarding employing delay and decay tanks. Where applicable, the toilets may be designated as 'hot toilets' and should be clearly indicated. All drainage plumbing needs to be isolated and connected to delay and decay tanks (usually required for PET CT scan room, SPECT CT scan room and iodine therapy ward, and may be also required for cyclotron liquid waste).

4.5.9 *Special Situations of Waste Water Disposal*

Buildings may generate uncontaminated waste water from various sources continuously, intermittently or in large volumes for a short time for example, emptying any water tanks or pools, testing fire and water lines for flow conditions, etc. Connections from all such sources shall be made to the building drainage system indirectly through a trap. It should be ensured in advance that the building drain or a sump with a pump has the capacity to receive to rate of flow. In case the capacity is less the rate of discharge from the appliances should be regulated to meet the capacity of the disposal. Under no circumstances shall any waste water described above shall be disposed of in any storm water drains.

4.5.10 *Manholes*

4.5.10.1 *General*

A manhole or inspection chamber shall be capable of sustaining the loads which may be imposed on it, exclude subsoil water and be water tight. The size of the chamber should be sufficient to permit ready access to the drain or sewer for inspection, cleaning and rodding and should have a removable cover of adequate strength, constructed of suitable and durable material. Where the depth of the chamber so requires, access rungs, step irons, ladders or other means should be provided to ensure safe access to the level of the drain or sewer. If the chamber contains an open channel, benching should be provided having a smooth finish and formed so as to allow the foul matter to flow towards the pipe and also ensure a safe foothold.

No manhole or inspection chamber shall be permitted inside a building or in any passage therein. The minimum depth of the manhole shall not be less than 800 mm to facilitate gully trap connection. Further, ventilating covers shall not be used for domestic drains. At every change of alignment, gradient or diameter of a drain, there shall be a manhole or inspection chamber. Bends and junctions in the drains shall be grouped together in manholes as far as possible.

Alternative materials of manholes using RCC rings and PVC in sewer lines are being used in some sites. These may be considered subject to ensuring their proper design, keeping in view the lateral and vertical loads at the place of installation.

The holes over the surfaces of covers/gratings of various manholes, gullys and other chambers/drains shall comply with the requirements given in good practice [E-2(2)].

4.5.10.2 *Spacing of manholes*

The spacing of manholes for a given pipe size should be as follows:

Sl No. (1)	*Pipe Diameter* mm (2)	*Spacing of Manhole* m (3)
i)	Up to 300	45
ii)	301 to 500	75
iii)	501 to 900	90
iv)	Beyond 900	Spacing shall depend upon local condition and shall be gotten approved by the Authority

Where the diameter of a drain is increased, the crown of the pipes shall be fixed at the same level and the necessary slope given in the invert of the manhole chamber. In exceptional cases and where unavoidable, the crown of the branch sewer may be fixed at a lower level, but in such cases the peak flow level of the two sewers shall be kept the same.

4.5.10.3 *Size of manhole*

The manhole or chamber shall be of such size as will allow necessary examination or clearance of drains. The size of shall be adjusted to take into account any increase in the number of entries into the chamber.

4.5.10.3.1 Manholes may be rectangular, arch or circular type. The minimum internal size of manholes, chambers (between faces of masonry) shall be as follows:

a) Rectangular manholes:

1) For depths less than 0.90 m : 900 mm × 800 mm
2) For depths from 0.90 m and up to 2.5 m : 1 200 mm × 900 mm

NOTE — For depths up to 0.60 m, 600 mm × 600 mm manhole may be used.

b) Arch type manholes:

For depths of 2.5 m and above : 1 400 mm × 900 mm

NOTE — The width of manhole chamber shall be suitably increased more than 900 mm on bends, junctions or pipes with diameter greater than 450 mm so that benching width in either side of channel is minimum 200 mm.

c) Circular manholes:

1) For depths above 0.90 m and up to 1.65 m : 900 mm diameter
2) For depths above 1.65 m and up to 2.30 m : 1 200 mm diameter
3) For depths above 2.30 m and up to 9.00 m : 1 500 mm diameter
4) For depths above 9.00 m and up to 14.00 m : 1 800 mm diameter

NOTES

1 In adopting the above sizes of chambers, it should be ensured that these sizes accord with full or half bricks with standard thickness of mortar joints so as to avoid wasteful cutting of bricks.

2 The sizes of the chambers/manhole may be adjusted to suit the availability of local building materials, economics of construction and to meet local authority approval.

3 The access shaft shall be corbelled inwards on three sides at the top to reduce its size to that of the cover frame to be fitted or alternatively the access shaft shall be covered over by a reinforced concrete slab of suitable dimensions with an opening for manhole cover and frame.

4 The minimum sewer pipe diameter is 200 mm based on good practice [E-2(13)].

4.5.10.4 *Construction*

4.5.10.4.1 *Excavation*

The manhole shall be excavated true to dimensions and levels as shown on the plan. The excavation of deep manholes shall be accompanied with safety measures like timbering, staging, etc. In areas where necessary, appropriate measures for dewatering should be made.

4.5.10.4.2 *Bed concrete*

The manhole shall be built on a bed of concrete 1 : 4 : 8 (1 cement : 4 coarse sand : 8 graded stone aggregate 40 mm nominal size). The thickness of bed concrete shall be at least 150 mm for manholes up to 0.9 m in depth, at least 200 mm for manholes from 0.90 m up to 2.5 min depth and at least 300 mm for manholes of greater depth, unless the structural design demands higher thickness.

This thickness may be verified considering the weight of wall, cover, the wheel loads, impact of traffic which are transmitted through cover and the shaft walls and for water pressure, if any. In case of weak soil, special foundation as suitable shall be provided

4.5.10.4.3 *Brickwork*

The thickness of walls shall be designed depending upon its shape and taking onto account all loads coming over it, including earth pressure and water pressure.

Generally, the brickwork shall be with first class bricks in cement mortar 1 : 5 (1 cement : 5 coarse sand). All brickwork in manhole chambers and shafts shall be carefully built in English Bond, the jointing faces of each brick being well ‘buttered’ with cement mortar before laying, so as to ensure a full joint. The construction of walls in brickwork shall be done in accordance with good practice [E-2(14)].

For various depths the recommended thickness of wall may be as follows:

	Depth of the Chamber		*Thickness of Wall*
a)	Up to 2.25 m	:	200 mm (one brick length)
b)	From 2.25 m up to 3.0 m	:	300 mm (one and half brick length)
c)	From 3.00 m up to 5.0 m	:	400 mm (two brick length)
d)	From 5.00 m up to 9.0 m	:	500 mm (two and half brick length)
e)	Above 9.00 m	:	600 mm (three brick length)

The actual thickness in any case shall be calculated on the basis of engineering design. Typical sections of the manholes are illustrated in Fig. 7, Fig. 8 and Fig. 9.

NOTES

1 Rich mix of cement mortar, not weaker than 1 : 3, should be used in brick masonry, where subsoil water conditions are encountered.

2 For arched type of manholes, the brick masonry in arches and arching over pipes shall be in cement mortar 1 : 3.

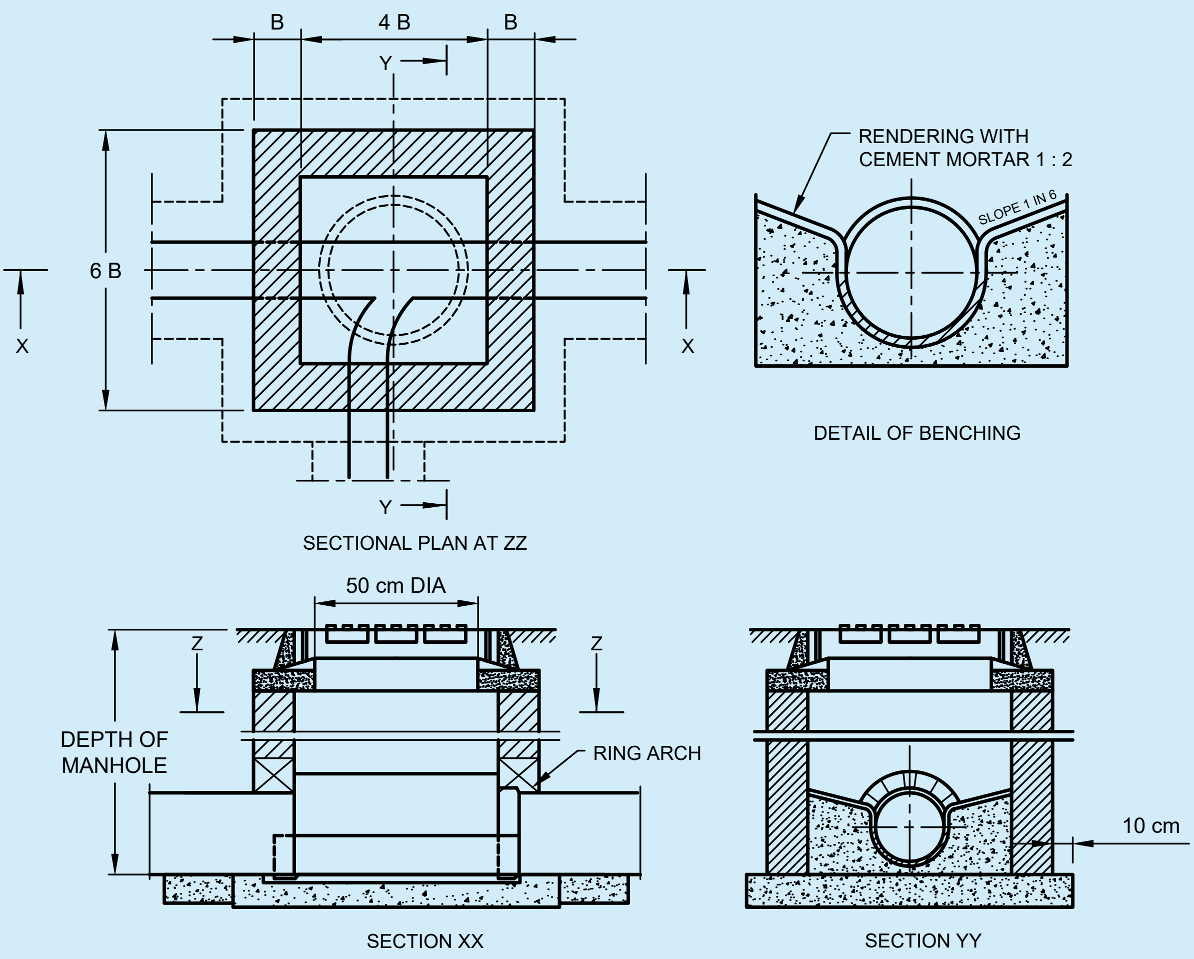
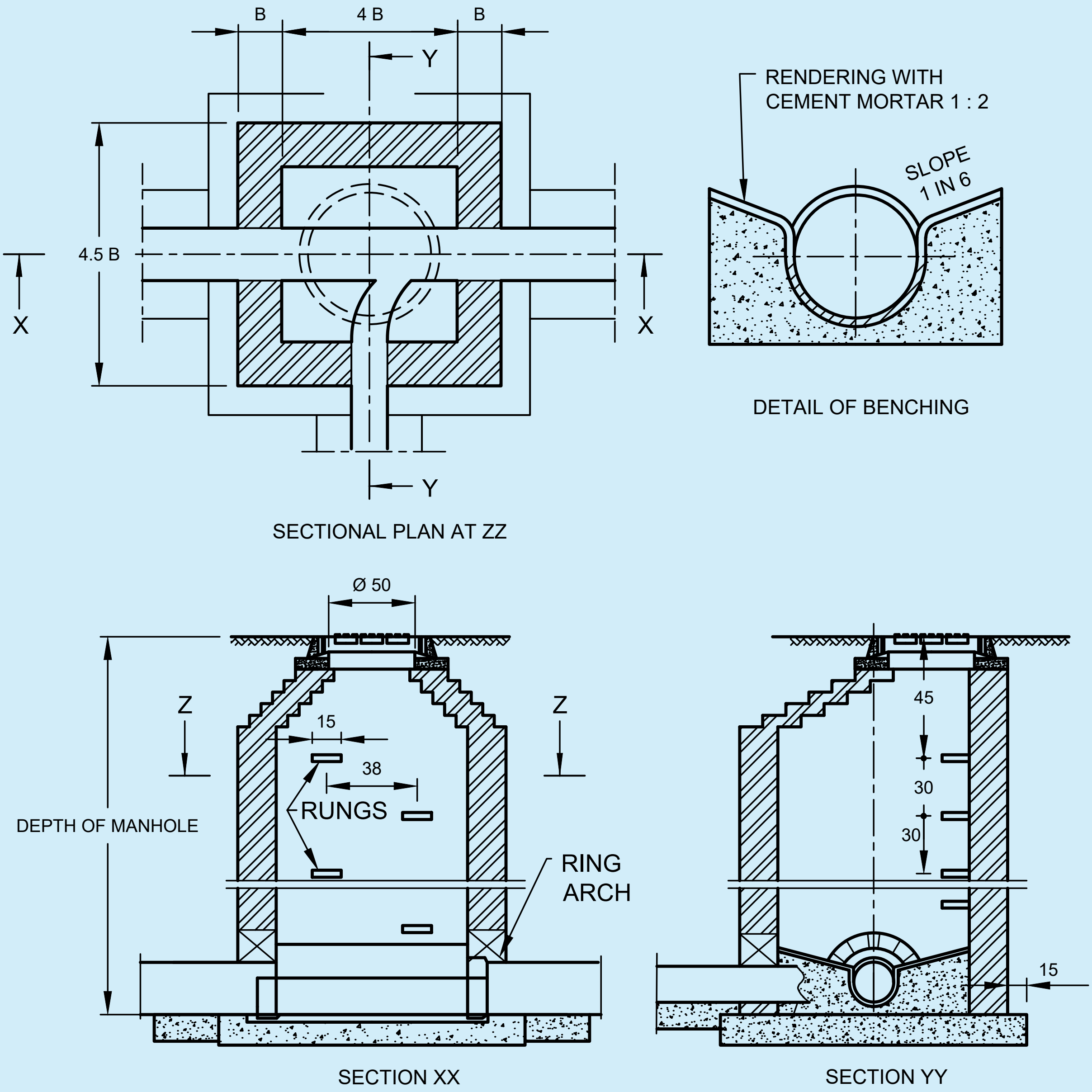
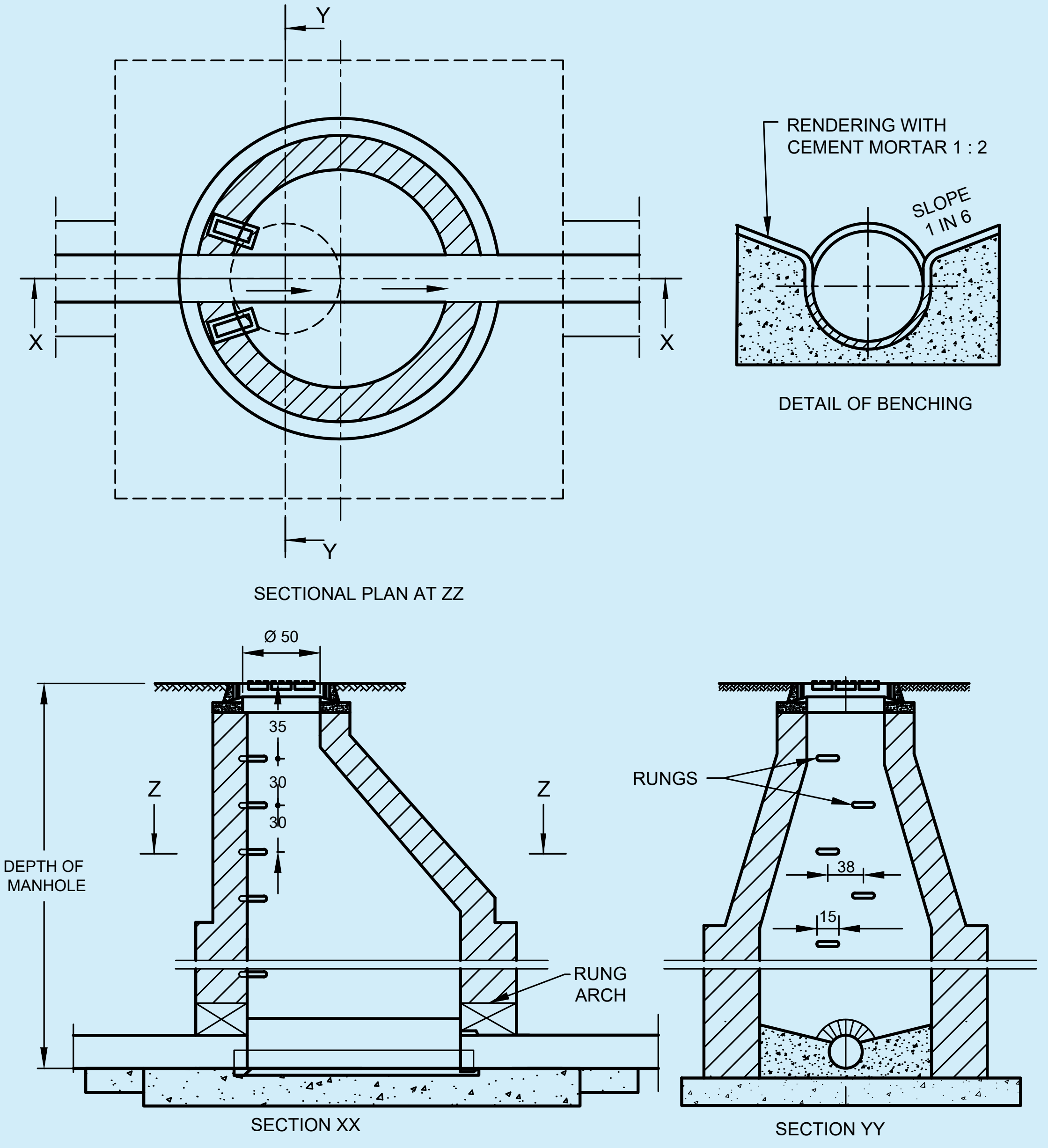

B
4 B
B
Y
Y
6 B
X
X
SECTIONAL PLAN AT ZZ
RENDERING WITH CEMENT MORTAR 1 : 2
SLOPE 1 IN 6
DETAIL OF BENCHING
50 cm DIA
Z
Z
DEPTH OF MANHOLE
RING ARCH
SECTION XX
10 cm
SECTION YY

FIG. 7 DETAIL OF MANHOLE (DEPTH LESS THAN 0.90 m)


B
4 B
B
Y
4.5 B
X
X
Y
SECTIONAL PLAN AT ZZ
RENDERING WITH
CEMENT MORTAR 1 : 2
SLOPE
1 IN 6
DETAIL OF BENCHING
Ø 50
Z
Z
15
38
RUNGS
DEPTH OF MANHOLE
RING
ARCH
SECTION XX
45
30
30
15
SECTION YY

All dimensions in centimetres.

FIG. 8 DETAIL OF MANHOLE (DEPTH FROM 0.9 m AND UP TO 2.5 m)


Y
RENDERING WITH
CEMENT MORTAR 1 : 2
SLOPE
1 IN 6
X
X
DETAIL OF BENCHING
Y
SECTIONAL PLAN AT ZZ
Ø 50
35
30
30
Z
Z
DEPTH OF
MANHOLE
RUNGS
38
15
RUNG
ARCH
SECTION XX
SECTION YY

All dimensions in centimetres.

FIG. 9 DETAIL OF MANHOLE (DEPTH 2.5 m AND ABOVE)

4.5.10.4.4 *Plastering*

The wall shall be plastered (15 mm, min) both inside and outside within cement mortar 1 : 3 and finished smooth with a coat of neat cement. Where subsoil water conditions exit, a richer mix may be used and it shall further be waterproofed with addition of approved waterproofing compound in a quantity as per manufacturer specifications.

All manholes shall be so constructed as to be water-tight under test.

All angles shall be rounded to 75 mm radius and all rendered internal surface shall have hard impervious finish obtained using a steel trowel.

4.5.10.4.5 *Channels and benching*

These shall be semi-circular in the bottom half and of diameter equal to that of the sewer. Above the horizontal diameter, the sides shall be extended vertically 50 mm above the crown of sewer pipe and the top edge shall be suitably rounded off. The branch channels shall also be similarly constructed with respect to the benching, but at their junction with the main channel an appropriate fall, if required suitably rounded off in the direction of flow in the main channel shall be given.

The channel/drain and benching at the bottom of the chamber shall be done in cement concrete 1 : 2 : 4 and subsequently plastered with cement mortar of 1 : 2 proportion or weaker cement mortar with a suitable waterproofing compound and finished smooth, to the grade (where required). The benching at the sides shall be carried up in such a manner as to provide no lodgment for any splashing in case of accidental flooding of the chamber.

Channels shall be rendered smooth and benchings shall have slopes towards the channel.

4.5.10.4.6 *Rungs*

Rungs shall be provided in all manholes over 0.8 m in depth and shall be of cast iron, or PVC encapsulated or composite non-corrosive materials, and of suitable dimensions, conforming to accepted standards [E-2(15)]. These rungs may be set staggered in two vertical rungs which may be 300 mm apart horizontally as well as vertically and shall project a minimum of 100 mm beyond the finished surface if the manhole wall. The top rung shall be 450 mm below the manhole cover and the lowest not more than 300 mm above the benching.

4.5.10.4.7 *Manhole covers and frames*

The size of manhole covers shall be such that there shall be a clear opening of at least 500 mm in diameter for manholes exceeding 0.90 m in depth. The manhole covers and frames used shall conform to accepted standards [E-2(16)].

The frame of manhole shall be firmly embedded to concrete alignment and level in plain concrete on the top of masonry.

4.5.10.5 *Drop manhole*

Where it is uneconomic or impracticable to arrange the connection within 600 mm height above the invert of the manholes, the connection shall be made by constructing a vertical shaft outside the manhole chamber, as shown in Fig. 10. If the difference in level between the incoming drain and the sewer does not exceed 600 mm and there is sufficient room in the manhole, the connecting pipe may be directly brought through the manhole wall and the fall accommodated by constructing a ramp in the benching of the manhole.

For detailed information regarding manholes in sewerage system, reference may be made to good practice [E-2(17)].

4.5.10.6 *Manhole covers and recommended locations*

Manhole covers were traditionally and presently manufactured from concrete, steel fibre reinforced concrete, cast iron and ductile iron or PVC materials and these materials are used based on the load carrying capacity and for the following type of applications:

a) Inspection chambers for sewerage;

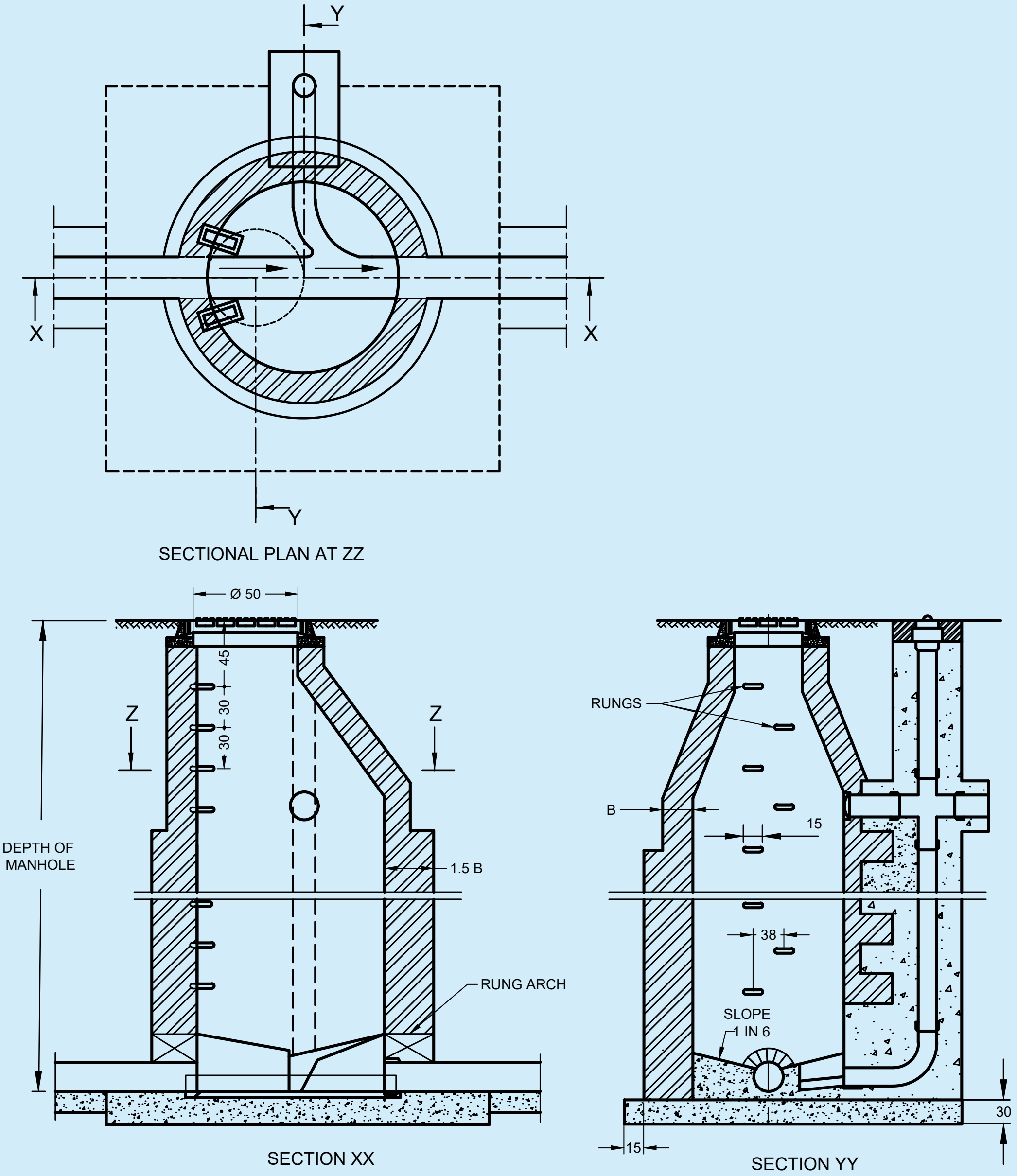
b) Underground electrical cabling;

c) Telecom cabling;

d) Water, gas and petroleum installations; and

e) Beautification of gardens and landscapes.

Recommended locations conforming to load capacity shall be as per accepted standard [E-2(16)].



SECTIONAL PLAN AT ZZ

SECTION XX

SECTION YY

NOTE – Wall thickness have been indicated in brick length to provide for use of modular bricks or traditional bricks. In the figure, B = one brick length, 1.5 B = one and a half brick length, etc.

All dimensions in centimetres.

FIG. 10 DROP MANHOLE

4.5.11 *Storm Water Drainage*

4.5.11.1 *General*

The object of storm water drainage is to collect and carry, the rainwater collected within the premises of the building, for suitable disposal.

4.5.11.2 *Design factors*

Estimate of the quantity that reaches the storm water drain (runoff) depends on the following factors:

a) Type of soil and its absorption capacity determined by its soil group;

b) Ground slope and the time in which the area is drained;

c) Intensity of the rainfall for a design period; and

d) Duration of the rain/storm.

The runoff reaching the sewer may be given by the expression:

$$Q = 10\ C \times i \times A$$

where

Q = runoff, m^3/h;

C = coefficient of runoff;

i = intensity of rainfall, mm/h; and

A = area of the drainage district, hectares.

Coefficient of runoff for various surfaces may be taken as:

Sl No. (1)	*Type of Surface* (2)	*Coefficient of Runoff* (3)
i)	Concrete roof area	0.9
ii)	Paved podium areas and asphalted roads	0.8
iii)	Unpaved ground	0.3
iv)	Lawns and parks	0.15

4.5.11.2.1 *Imperviousness*

The soil conditions and the ground slope determine the impermeability factor. Impermeability factor is the proportion of the total rainfall received on the surface which will be discharging into a storm water drain after allowing for initial abstraction (in local pond and lakes), ground absorption by evaporation, vegetation and other losses. The net flow reaching the storm water drain is called runoff.

The percentage of imperviousness of the drainage area may be obtained from available data for a particular area. In the absence of such data, the following figures may serve as a guide:

Sl No. (1)	*Type of Area* (2)	*Imperviousness Factor* Percent (3)
i)	Commercial and industrial areas	70 to 90
ii)	Residential areas (high density)	60 to 75
iii)	Residential areas (low density)	35 to 60
iv)	Parks and underdeveloped areas	10 to 20

4.5.11.2.2 *Terrain modelling*

Areas planned for urbanization from agricultural land, forest or low grade land for example, low lying areas prone to flooding, marshy or abandoned quarries, etc, need detailed and careful consideration with respect to its drainage. A detailed contour survey shall be carried out not only with respect to the site but also the surrounding areas to verify the quantity/area contributing runoff, presence of any low lying and natural water body acting as holding pond or any natural drain passing through the area and beyond whose filling up or diversion may cause water logging problem on the site or to the surrounding areas.

The planning of the area should ensure that:

a) All areas become self draining by gravity with respect to the high flood level of the area or the drainage channels passing, whichever is higher;

b) As far as possible, natural drainage pattern with respect to the whole area be maintained except when low lying areas need to be filled up for grading purposes;

c) The drainage in the area shall be planned in accordance with the natural slopes; and

d) Levels of the main highway or road connecting to the property shall be determined to ensure proper drainage and protection of the site.

The formation levels of the entire area shall be prepared to determine proposed formation levels by preparing a terrain model which will show the proposed site contours, ground and road levels and connections to all services including storm water disposal system.

4.5.11.2.3 *Rainfall intensity*

The intensity of rainfall is the amount of rain falling in unit time and is expressed in centimetre or millimetre per hour. For design purposes, the mean rainfall intensity is collected for 50 years.

NOTE — For storm water drainage design, the hourly maximum rainfall may be referred from the relevant Indian Roads Congress guidelines.

4.5.11.2.4 *Design frequency*

Storm water drainage system for an urbanized area is planned on the basis of the design frequency of the storm which shall be determined by the designer. Frequency is the period in which the selected design intensity recurs in a given period of time in years.

NOTE — The rainfall intensity varies with the period, which includes good, bad and average years of rainfall. Meteorological department has long term data regarding the rainfall and have graphs for different periods, and the designers are advised to consult the department before designing any scheme.

4.5.11.2.5 *Time of concentration*

Time of concentration is the time required for the rainwater to flow to reach the farthest point of the drainage system or the outfall under consideration. Time of concentration is equal to the inlet time plus the time required for the flow to reach the main or branch drain. The inlet time is the time dependent on the distance of the farthest point in the drainage area to the inlet of the manhole and the surface slopes, etc, and will vary between 5 min and 30 min.

In highly developed sections for example with impervious surfaces it may be as low as 3 min or lower (with good slopes) as in building terraces and paved areas. Correspondingly the design intensity for the drainage for such areas will be much higher. Rainwater pipes have to be designed for an intensity for a very low time of concentration.

4.5.11.2.6 *Natural infiltration*

In planning any area with buildings, layout with paved and non-permeable surfaces, care should be taken to allow maximum discharge of the rainwater to flow directly or indirectly to permeate into the ground for enabling the ground water to be recharged. Some of the techniques which allow infiltration that may be considered are:

a) Use of brick paved open jointed storm water drains;

b) Providing bore holes in the storm water drains; and

c) Using paving tiles with open joints which enable water to percolates as it flows on it.

4.5.11.3 *Combined system*

A combined system of drainage is one which carries the sewerage as well as the runoff from the storm water drainage. Relevant applicable statutory rules/regulations may not allow such system in new areas and the sewerage and the storm water drainage have to be separate and independent of each other. Such systems are however existing in many old cities and the storm water may have to be discharged into the combined drainage system.

Where levels do not permit for connection to a public storm water drain, storm water from courtyards of buildings may be connected to the public sewer, provided it is designed to or has the capacity to convey combined discharge. In such cases, the surface water shall be admitted to the soil sewer through trapped gullies in order to prevent the escape of foul air.

4.5.11.4 *Discharging into a watercourse*

It may often be convenient to discharge surface water to a nearby stream or a watercourse. The invert level of the outfall shall be about the same as the normal water level in the watercourse or ideally should be above the highest flood level of the watercourse. The out-fall shall be protected against floating debris by a screen.

4.5.11.5 *Discharge to a public storm water drain*

Where it is necessary to connect the discharge rainwater into a public storm water drain, such drains shall be designed for the intensity of rain based on local conditions, but in no case shall they be designed for intensity of rainfall of less than 50 mm/h. Rainwater from each building plot shall be connected to the storm water drainage through a separate pipe or an open public drain directly. No trap shall be installed before the connection.

4.5.11.6 *Rainwater pipes for roof drainage*

4.5.11.6.1 The roofs of a building shall be so constructed or framed as to permit effectual drainage of the rainwater therefrom by means of a sufficient number of rainwater pipes of adequate size so arranged, jointed and fixed as to ensure that the rainwater is carried away from the building without causing dampness in any part of the walls or foundations of the building or those of an adjacent building.

4.5.11.6.2 The rainwater pipes shall be fixed to the outside of the external walls of the building or in recesses or chases cut or formed in such external wall or in such other manner as may be approved by the Authority.

4.5.11.6.3 Rainwater pipes conveying rainwater shall discharge directly or by means of a channel into or over an inlet to a surface drain or shall discharge freely in a compound, drained to surface drain but in no case shall it discharge directly into any closed drain.

4.5.11.6.4 Whenever it is not possible to discharge a rainwater pipe into or over an inlet to a surface drain or in a compound or in a street drain within 30 m from the boundary of the premises, such rainwater pipe shall discharge into a gully trap which shall be connected with the street drain for storm water and such a gully-trap shall have a screen and a silt catcher incorporated in its design.

4.5.11.6.5 If such streets drain is not available within 30 m of the boundary of the premises, a rainwater pipe may discharge directly into the kerb drain and shall be taken through a pipe outlet across the foot path, if any, without obstructing the path.

4.5.11.6.6 A rainwater pipe shall not discharge into or connect with any soil pipe or its vent pipe or any waste pipe or its vent pipe nor shall it discharge into a sewer unless specifically permitted to do so by the Authority, in which case such discharge into a sewer shall be intercepted by means of a gully trap.

4.5.11.6.7 Rainwater pipes shall be constructed of cast iron, PVC, asbestos cement, galvanized sheet or other equally suitable material and shall be securely fixed.

4.5.11.6.8 The factors that decide the quantity of rainwater entering are:

a) Intensity of rainfall; and

b) Time of concentration selected for rainwater pipe.

A bell mouth inlet at the roof surface is found to give better drainage effect, provided proper slopes are given to the roof surface. The spacing of rainwater pipes depends on the locations available for the down takes and the area which each pipe serves. The spacing will also be determined by the amount of slopes that can be given to the roof. The recommended slopes for the flat roofs with smooth finish would be 1 : 150 to 1 : 133, with rough stone/tiles 1 : 100 and for gravel set in cement or loosely packed concrete finish 1 : 75 to 1 : 66. The effective strainer area should preferably be 1.5 times to 2 times the area of pipe to which it connects to considerably enhance the capacity of rainwater pipes.

The rainwater pipes of cast iron (coefficient of roughness 0.013) shall normally be sized on the basis of roof areas according to Table 25. The vertical down take rainwater pipes, having a bell mouth inlet on the roof surface with effective cross sectional area of grating 1.5 to 2 times the rainwater pipe area, may be designed by considering the outlet pipe as weir.

For full circumference of pipe acting as weir, the roof area (RA) for drainage may be worked out by using:

$$RA = 0.084 \times d^{5/2}/I$$

where

RA = roof area, m^2 (*see* Note);

d = pipe diameter, mm; and

I = intensity of rainfall, mm/h.

NOTES

1 For one adjacent wall, add 50 percent of the wall area to the roof.

2 For two adjacent walls, add 35 percent of the wall area to the roof.

Table 25 Sizing of Rainwater Pipes for Roof Drainage

(*Clause* 4.5.11.6.8)

Sl No.	Diameter of Pipe mm	Roof Area, in m^2 for Average Rate of Rainfall in mm/h					
		50	75	100	125	150	200
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	50	29.70	19.80	14.85	11.88	9.90	7.42
ii)	65	57.23	38.15	28.61	22.89	19.08	14.31
iii)	75	81.84	54.56	40.92	32.74	27.28	20.46
iv)	100	168.00	112.00	84.00	67.20	56.00	42.00
v)	125	293.48	195.66	146.74	117.39	97.83	73.37
vi)	150	462.95	308.64	231.48	185.18	154.32	115.74

NOTE — For rainwater pipes of other materials, the roof areas shall be multiplied by (0.013/coefficient of roughness of surface of that material). For example, for rainwater pipes of PVC (coefficient of roughness = 0.009), the above values of roof area shall be multiplied by 0.013/0.009 = 1.44.

4.5.11.6.9 The storm water may be led off in a suitable open drain to a watercourse. The open drain, if not a *Pucca* masonry throughout, shall be so at least where there is either a change in direction or gradient.

4.5.11.6.10 Flat roof should have an emergency drain as secondary drain, in the form of down take or spout. Horizontal outlets should be considered for 100 percent flow and side gratings to be considered for 50 percent flow (*see* Fig. 11).

NOTE — Care should be taken to design the roof for the additional load due to ponded water.

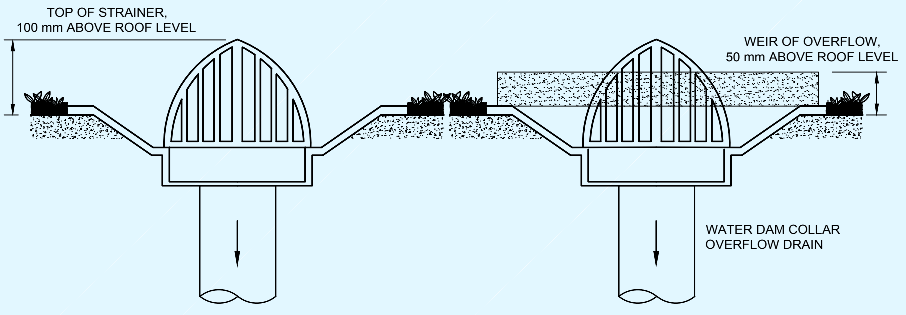


FIG. 11A TYPICAL VIEW OF ROOF DRAIN (LEFT) AND ROOF DRAIN WITH WEIR (RIGHT)

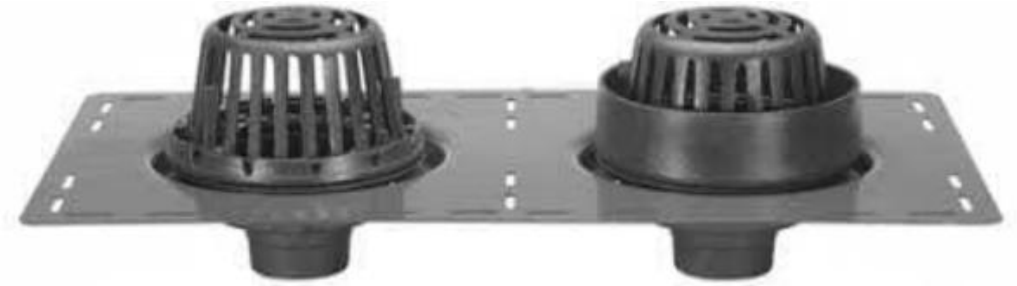


FIG. 11B ACTUAL DEPICTION OF ROOF DRAIN (LEFT) AND ROOF DRAIN WITH WEIR (RIGHT)

FIG. 11 ROOF DRAIN IN FLAT ROOFS

4.5.12 *Rainwater Harvesting*

4.5.12.1 *General*

To supplement the ever growing shortage of protected, pure and safe water supply for human consumption, rainwater is an ideal source which can be conserved and used in a useful manner by the people. The amount of rainfall available varies from region to region. Each area has to develop its own method and system to conserve, store and use it to suit its requirement and local conditions. There are several methods by which rainwater can be stored, used and conserved. Each system depends on the amount of precipitation, the period in which the rainfall occurs in a year and the physical infrastructure, for example space available to store the water, etc.

There are several techniques available for catching and storing the rainwater. Most of the techniques are applicable for large open areas, farms, sloping grounds, etc, with a low population base. Two major systems that are ideal for urban and semi-urban developed areas are:

a) Artificial ground water recharge; and

b) Roof top rainwater harvesting.

NOTE — Type and number of recharge pits and roof top rainwater harvesting capacity shall be provided as per the local/state bye-laws.

4.5.12.2 *Artificial ground water recharge*

With increase in the impermeable surfaces in modern built up areas, there is gross reduction in the original catchment area. This prevents the natural percolation that would have recharged the area in the normal course if the ground was in its natural condition, for example a farm, open ground, forest, etc. This results in a large quantity of water, normally percolating into the ground, running off to the natural drains and into the rivers, causing increased runoff and flooding of downstream areas.

It is therefore essential to catch the runoff and use it for augmentation of ground water reservoir by modifying the natural movement of surface water by recharging it by artificial means, for example construction of recharge structures (*see* Fig. 12). The main objectives achieved may be:

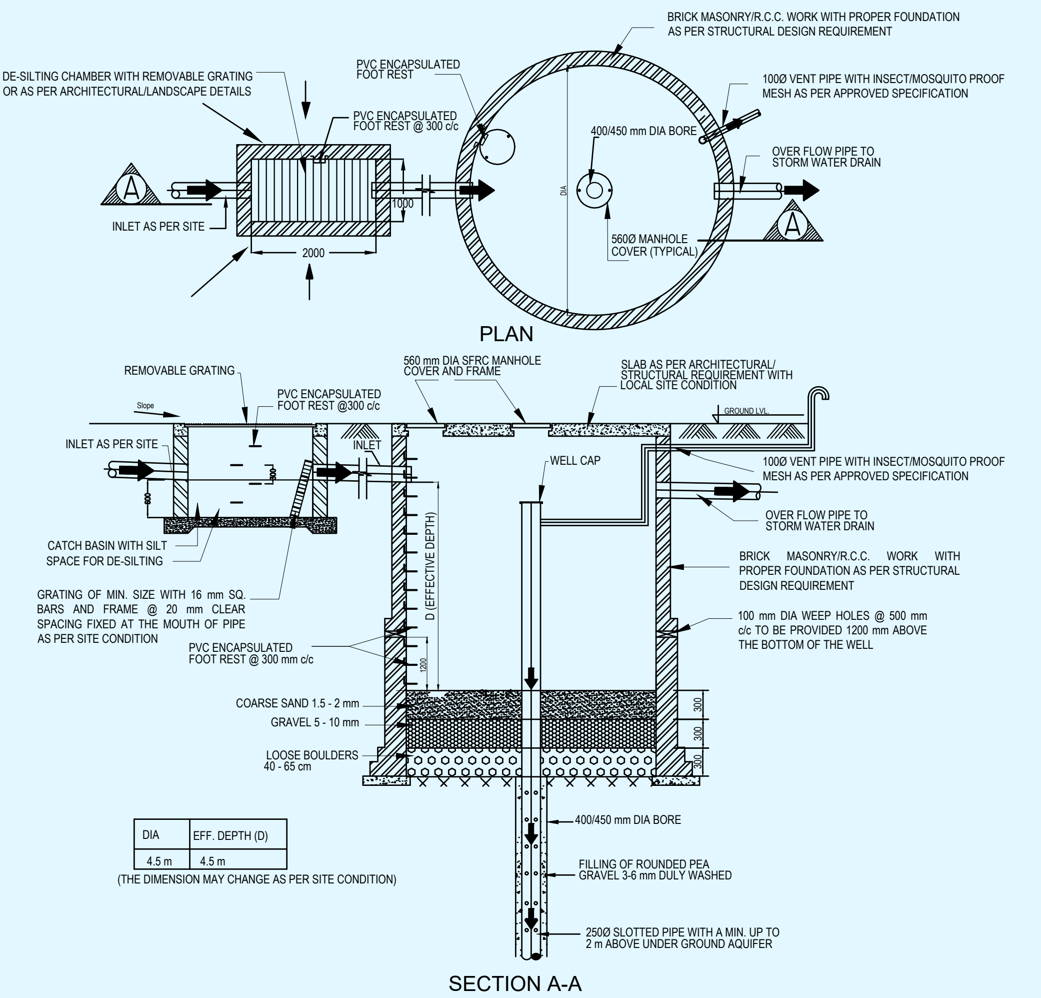
a) Enhancement of sustainable yield in areas where over development and depletion of the aquifers;

b) Conservation and storage of excess surface water in the aquifers;

c) Improve the quality of the existing ground water through dilution;

d) Remove bacteriological and suspended impurities during the surface water transition within the subsoil; and

e) Maintain the natural balance of the ground water and its usage as the rainwater is a renewable supply source. A well managed and controlled tapping of the aquifers will provide constant, dependable and safe water supply.


BRICK MASONRY/R.C.C. WORK WITH PROPER FOUNDATION AS PER STRUCTURAL DESIGN REQUIREMENT
DE-SILTING CHAMBER WITH REMOVABLE GRATING OR AS PER ARCHITECTURAL/LANDSCAPE DETAILS
PVC ENCAPSULATED FOOT REST
PVC ENCAPSULATED FOOT REST @ 300 c/c
100Ø VENT PIPE WITH INSECT/MOSQUITO PROOF MESH AS PER APPROVED SPECIFICATION
400/450 mm DIA BORE
OVER FLOW PIPE TO STORM WATER DRAIN
A
1000
DIA
A
INLET AS PER SITE
560Ø MANHOLE COVER (TYPICAL)
2000
PLAN
REMOVABLE GRATING
560 mm DIA SFRC MANHOLE COVER AND FRAME
SLAB AS PER ARCHITECTURAL/ STRUCTURAL REQUIREMENT WITH LOCAL SITE CONDITION
PVC ENCAPSULATED FOOT REST @300 c/c
Slope
GROUND LVL.
INLET AS PER SITE
INLET
WELL CAP
100Ø VENT PIPE WITH INSECT/MOSQUITO PROOF MESH AS PER APPROVED SPECIFICATION
OVER FLOW PIPE TO STORM WATER DRAIN
CATCH BASIN WITH SILT SPACE FOR DE-SILTING
D (EFFECTIVE DEPTH)
BRICK MASONRY/R.C.C. WORK WITH PROPER FOUNDATION AS PER STRUCTURAL DESIGN REQUIREMENT
GRATING OF MIN. SIZE WITH 16 mm SQ. BARS AND FRAME @ 20 mm CLEAR SPACING FIXED AT THE MOUTH OF PIPE AS PER SITE CONDITION
100 mm DIA WEEP HOLES @ 500 mm c/c TO BE PROVIDED 1200 mm ABOVE THE BOTTOM OF THE WELL
PVC ENCAPSULATED FOOT REST @ 300 mm c/c
1200
COARSE SAND 1.5 - 2 mm
GRAVEL 5 - 10 mm
300
300
LOOSE BOULDERS 40 - 65 cm
300
DIA | EFF. DEPTH (D)
4.5 m | 4.5 m
(THE DIMENSION MAY CHANGE AS PER SITE CONDITION)
400/450 mm DIA BORE
FILLING OF ROUNDED PEA GRAVEL 3-6 mm DULY WASHED
250Ø SLOTTED PIPE WITH A MIN. UP TO 2 m ABOVE UNDER GROUND AQUIFER
SECTION A-A

NOTES

1 Depending on site soil condition and keeping the above plumbing details and dimensions in view, the detailed structural/shop drawing to be prepared, before executing the work.

2 All dimensions are in miillimetres unless specified.

FIG. 12 ARTIFICIAL GROUND WATER RECHARGE STRUCTURE

In planning and designing the ground water recharge structures, following should be taken into consideration:

a) Annual rainfall (for estimating approximately rainwater recharge per year);

b) Peak intensity and duration of each storm;

c) Type of soil and subsoil conditions and their permeability factor;

d) Ground slopes and run off which cannot be caught;

e) Location of recharge structures and its overflow outfall; and

f) Rainwater measuring devices for finding the flow of water in the system.

For artificial recharge to ground water, good practice [E-2(18)] may be referred.

NOTE — Rainwater harvesting with underground recharging will depend from region to region as per the climatic, topography, soil conditions and data about intensity of rainfall and retention time for calculating the capacity of recharge wells to be obtained from reference documents from the Authority.

4.5.12.3 *Roof top rainwater harvesting*

4.5.12.3.1 *Harvesting in regular rainfall areas*

In areas having rainfall over a large period in a year, for example in hilly areas, coastal regions, etc, constant and regular rainfall can be usefully harvested and stored in suitable water tanks. Water shall be collected through roof gutters and down take pipes. Provision should be made to divert the 1st rainfall after a dry spell so that ant dust, soot and leaves, etc are drained away before the water is collected into the water tank. The capacity of the water tank should be enough for storing water required for consumption between two dry spells. The water tank shall be located in a well protected area and shall not be exposed to any hazards of water contamination from any other sources. The water shall be chlorinated using chlorine tablets or solution to maintain a residual chlorine of approximately 1 mg/l. The tank shall have an overflow leading to natural water courses or to any additional tanks (*see* Table 26).

4.5.12.3.2 *Harvesting in limited rainfall areas*

In areas with the rainfall limited during the monsoon period (usually from 15 days to 90 days), roof top rainwater can be stored and used for non-potable purposes, after proper treatment, in the premises itself as mentioned above; excess water, if any, is best used for recharging the ground water. For individual properties and plots the roof top rainwater can be diverted to underground or above ground water storage tank(s), pretreated, stored and used for non-potable purposes. Excess water, if any, may be discharged to existing open or abandoned tube wells. In a well-planned building complex, a system should be laid out so that the runoff is collected in underground or above ground water storage tank(s), pretreated, stored, and used for non-potable purposes. Excess water, if any, shall be discharged in bore-wells as per designs specified by the Central Ground Water Board of the Government of India.

For roof top rainwater harvesting, reference may be made to good practice [E-2(19)].

4.5.12.4 *Care to be taken in rainwater harvesting*

Water conservation technique discussed above shall be constructed with due care taking following precautions:

a) No sewage or waste water should be admitted into the system;

b) No waste water from areas likely to have oil, grease or other pollutants should be connected to the system;

c) Each structure/well shall have an inlet chamber with a silt trap to prevent any silt from finding its way into the subsoil water;

d) The wells should be terminated at least 5 m above the natural static subsoil water at its highest level so that the incoming flow passes through the natural ground condition and prevent contamination hazards; and

e) No recharge structure or a well shall be used for drawing water for any purpose.

Table 26 Rainwater Available from Roof Top Harvesting

(*Clause* 4.5.12.3.1)

Rain fall, mm →	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**900**	**1 000**	**1 100**	**1 200**	**1 300**	**1 400**	**1 500**	**1 600**	**1 700**	**1 800**	**1 900**	**2 000**
Roof Top Area m^2 ↓	Harvested Water from Roof Tops, m^3 (80 percent of gross precipitation)																			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)
20	2	3	5	6	8	10	11	13	14	16	18	19	21	22	24	26	27	29	30	32
30	2	5	7	10	12	14	17	19	22	24	26	29	31	34	36	38	41	43	46	48
40	3	6	10	13	16	19	22	26	29	32	35	38	42	45	48	51	54	58	61	64
50	4	8	12	16	20	24	28	32	36	40	44	48	52	56	60	64	68	72	76	80
60	5	10	14	19	24	29	34	38	43	48	53	58	62	67	72	77	82	86	91	96
70	6	11	17	22	28	34	39	45	50	56	62	67	73	78	84	90	95	101	106	112
80	6	13	19	26	32	38	45	51	58	64	70	77	83	90	96	102	109	115	122	128
90	7	14	22	29	36	43	50	58	65	72	79	86	94	101	108	115	122	130	137	144
100	8	16	24	32	40	48	56	64	72	80	88	96	104	112	120	128	136	144	152	160
110	9	18	26	35	44	53	62	70	79	88	97	106	114	123	132	141	150	158	167	176
120	10	19	29	38	48	58	67	77	86	96	106	115	125	134	144	154	163	173	182	192
130	10	21	31	42	52	62	73	83	94	104	114	125	135	146	156	166	177	187	198	208
140	11	22	34	45	56	67	78	90	101	112	123	134	146	157	168	179	190	202	213	224
150	12	24	36	48	60	72	84	96	108	120	132	144	156	168	180	192	204	216	228	240
200	16	32	48	64	80	96	112	128	144	160	176	192	208	224	240	256	272	288	304	320
250	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	380	400
300	24	48	72	96	120	144	168	192	216	240	264	288	312	336	360	384	408	432	456	480
400	32	64	96	128	160	192	224	256	288	320	352	384	416	448	480	512	544	576	608	640
500	40	80	120	160	200	240	280	320	360	400	440	480	520	560	600	640	680	720	760	800
1 000	80	160	240	320	400	480	560	640	720	800	880	960	1 040	1 120	1 200	1 280	1 360	1 440	1 520	1 600
2 000	160	320	480	640	800	960	1 120	1 280	1 440	1 600	1 760	1 920	2 080	2 240	2 400	2 560	2 720	2 880	3 040	3 200
3 000	240	480	720	960	1 200	1 440	1 680	1 920	2 160	2 400	2 640	2 880	3 120	3 360	3 600	3 840	4 080	4 320	4 560	4 800

4.5.12.5 *Siphonic drainage system*

It is an installation generally used for special situations such as roofs with large spans for structures like hangars, airport terminals, stadia and industrial sheds, where the number of down pipes has to be limited. These are designed for full flow of pipes and the roof outlets are different from conventional ones.

Siphonic roof drainage systems are engineered on the concept of a full bore (a fill rate of 100 percent). This implies that rainwater flows at high speed through small diameter pipe work, at normally zero gradient.

This siphonic effect is created by the (kinetic) energy derived from the hydraulic head, caused by the difference in height between the roof outlet and the discharge point in a building. Specialist roof outlets prevent air being sucked into the system (*see* Fig. 13).

The engineering principle of siphonic roof drainage design is based on the Bernoulli energy equation for a steady flow of an incompressible fluid with constant density. In order to balance the equation, and to guarantee the required siphonic effect according to the rainfall intensity, the ideal pipe dimensions per flow path need to be determined.

In case of syphon system, the outlets of drainage system prevent vortex formation, thereby preventing air from entering the pipeline ensuring the entire system is running at full flow. It uses design that complies with Bernoulli's principle where equal energy is created under positive and negative pressure.

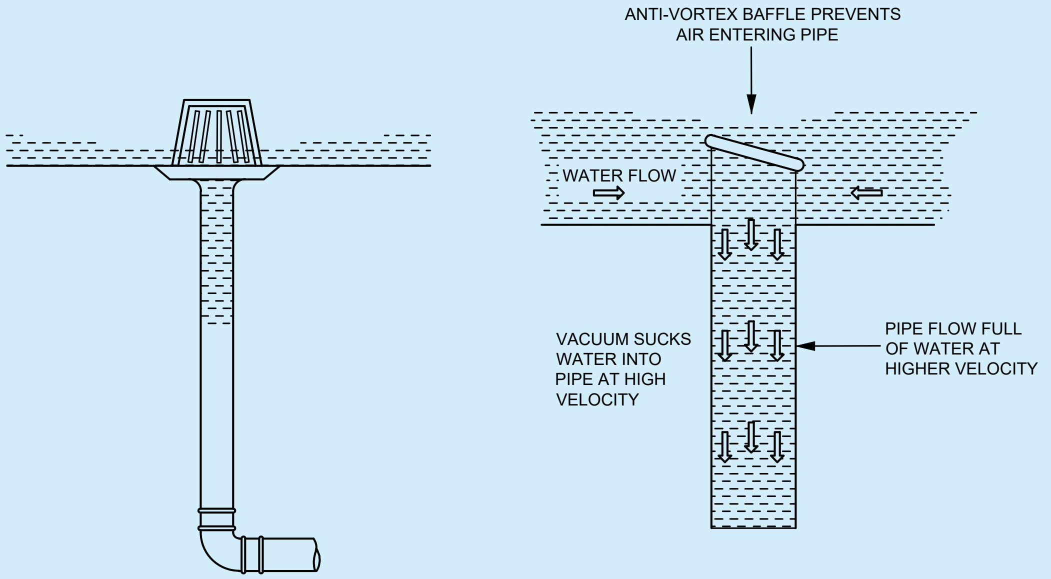

ANTI-VORTEX BAFFLE PREVENTS AIR ENTERING PIPE
WATER FLOW
VACUUM SUCKS WATER INTO PIPE AT HIGH VELOCITY
PIPE FLOW FULL OF WATER AT HIGHER VELOCITY

FIG. 13 SIPHONIC DRAINAGE SYSTEM

4.5.12.6 *Rainwater harvesting for plotted/group housing developments*

The rainwater harvesting methods adopted for plotted and group housing are through collection of rooftop rainwater and surface runoff harvesting.

A network of storm water drains in the entire residential area is used for harvesting rooftop rainwater and surface runoff. Appropriate number of recharge wells measuring 1 m × 1 m × 2 m may be constructed in the storm water drain for facilitating groundwater recharge. The quality of runoff, which passes through the borewell installed inside the recharge well, is ensured through a filter bed of pebbles (*see* Fig. 12).

4.5.12.7 *Other methods of rainwater harvesting*

a) *Creation of artificial reservoirs/lakes for utilization of available storm water* — This shall be based on estimation of amount of runoff volume based on rainfall data (for a period of 10 years) considering the percolation and evaporation losses and efforts to be made to collect all available runoff for proper utilization; and

b) *Water balancing methods* — This refers to optimum utilization of available water from different sources, namely ground water, recycled waste water, storm water and municipal supply and its adoption would ensure that there is no wastage of water.

4.5.13 *Subsoil Water Drainage*

4.5.13.1 *General*

Subsoil water is that portion of the rainfall which is absorbed into the ground.

The drainage of subsoil water may be necessary for the following reasons:

a) To increase the stability of the surface;

b) To avoid surface flooding;

c) To alleviate or to avoid causing dampness in the building, especially in the cellars;

d) To reduce the humidity in the immediate vicinity of the building; and

e) To increase the workability of the soil.

4.5.13.2 *Depth of water table*

The standing level of the subsoil water will vary with the season, the amount of rainfall and the proximity and level of drainage channels. Information regarding this level may be obtained by means of boreholes or trial pits, preferably the latter. It is desirable though not always practicable to ascertain the level of the standing water over a considerable period so as to enable the seasonal variations to be recorded and in particular the high water level. The direction of flow of the subsoil water may usually be judged by the general inclination of the land surface and the main lines of the subsoil drains shall follow the natural falls, wherever possible.

4.5.13.3 *Precautions*

Subsoil drains shall be so sited as not to endanger the stability of the buildings or earthwork. In some portions of the drain, it may be necessary to use non-porous jointed pipes.

4.5.13.3.1 No field pipe shall be laid in such a manner or in such a position as to communicate directly with any drain constructed or adopted to be used for conveying sewage, except where absolutely unavoidable and in such case a suitable efficient trap shall be provided between subsoil drain and such sewer.

4.5.13.4 *Systems of subsoil drainage*

Clay or concrete porous field drain pipes may be used and shall be laid in one of the following ways (*see also* Fig. 14):

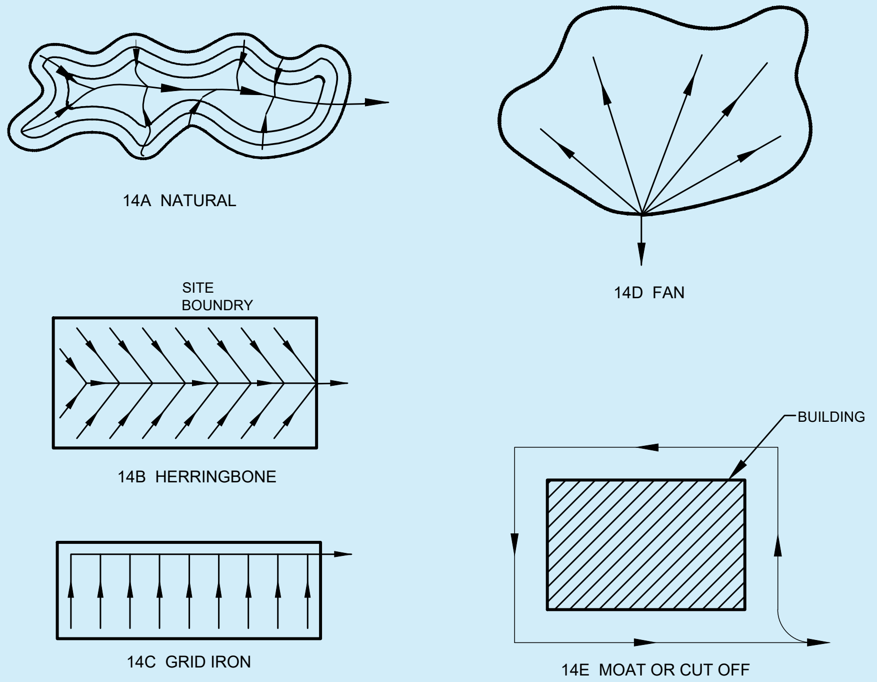
a) *Natural* — The pipes are laid to follow the natural depressions or valleys of the site; branches discharge into the main as tributaries do into a river;

b) *Herringbone* — The system consists of a number of drains into which discharges from both sides smaller subsidiary branch drains parallel to each other, but an angle to the mains forming a series of herringbone pattern. Normally these branch drains should not exceed 30 m in length;

c) *Grid* — A main or mains drain is laid to the boundaries if the site into which subsidiary branches discharge from one side only;

d) *Fan-shaper* — The drains are laid converging to a single outlet at one point on the boundary of a site, without the use of main or collecting drains; and

e) *Moat or cut-off system* — This system consists of drains laid on one or more sides of a building to intercept the flow of subsoil water and carry it away, thereby protecting the foundations of a building.



14A NATURAL

14D FAN

14B HERRINGBONE

14C GRID IRON

14E MOAT OR CUT OFF

FIG. 14 DETAILS OF SUBSOIL DRAINAGE SYSTEM

The choice of one or more of these systems will naturally depend on the local conditions of the site. For building sites, the mains shall be not less than 75 mm in diameter and the branches not less than 65 mm in diameter but normal practice tends towards the use of 100 mm and 75 mm, respectively. The pipes shall generally be laid at 60 cm to 90 cm depth, or to such a depth to which it is desirable to lower the water-table and the gradients are determined rather by the fall of the land than by considerations of self-cleansing velocity. The connection of the subsidiary drain to the main drain is best made by means of a clayware or concrete junction pipe. The outlet of a subsoil system may discharge into a soakaway or through a catch pit into the nearest ditch or watercourse. Where these are not available, the subsoil drains may be connected, with the approval of the Authority, through an intercepting trap to the surface water drainage system.

NOTE — Care shall be taken that there is no backflow from sub-surface drains during heavy rains.

4.5.13.5 *Deep well/borewell recharging*

Recharge well is one which pushes back surface water into ground water system. The recharge well may be of 1 m in diameter and 6 m deep lined with concrete rings having perforations.

Direct recharge is recommended when the well has gone dry and is yielding negligible amount of water. Indirect recharge is adopted for functioning borewells.

4.5.14 *Waste Disposal Systems in High Altitudes and/or Sub-zero Temperature Regions*

4.5.14.1 In general, all the care to be exercised regarding water supply systems shall also be applicable in the case of waste disposal systems. The biological and chemical reduction of organic material proceeds slowly under low temperature conditions, consequently affecting the waste disposal systems. The waste disposal methods given in 4.5.14.2, 4.5.14.3 and 4.5.14.4 shall be used only where it is not practical to install water carriage system.

4.5.14.2 *Box and can system*

Where box and can systems are employed, adequate arrangements shall be made for the cleaning and disinfection of the can after it is emptied of its contents. The excrement from the can shall be disposed of by burial in isolated spots far from habitation or by incineration, where feasible. The can shall be fitted with a tight fitting lid for use when it is carried for emptying.

4.5.14.3 *Trench or pit latrines*

Trench or pit latrines shall be used only where soil and subsoil conditions favour their use. Whenever they are used, they shall not be closer than 18 m from any source of drinking water, such as well, to eliminate the possibility of bacterial pollution of water.

4.5.14.4 *Chemical toilets*

For the successful functioning of chemical toilets, they shall preferably be installed in heated rooms or enclosures.

NOTE — Chemical toilet essentially consists of small cylindrical tanks with a water-closer seat for the use of 8 persons to 10 persons. A ventilation pipe is fitted to the seat. A strong solution of caustic soda is used as a disinfectant. It kills bacteria, liquefies the solids and thus checks the decomposition of organic matter. The tank is provided with a drain plug for which liquid runs to a soak pit at the time of disposal.

4.5.14.5 *Water-borne sanitation systems*

Water-borne sanitation systems shall be used, where practicable. Sanitation systems for the collection of sewage should be constructed in such a manner that maximum heat is retained by insulation, if necessary.

4.5.14.5.1 *Sewerage laying*

Under normal circumstances, sewers shall be laid below the frost line. Manholes shall be made of air-tight construction so as to prevent the cold air from gaining access inside and freezing the contents. The trenches for sewers shall be loosely filled with earth after laying sewers, since loose soil is a better insulator than compacted soil. Consequently, sewers laid under traffic ways and other places where soil compaction may be expected are required to be given adequate insulation. Where feasible, sewers shall be so located that the trench line is not in shadow, when the sun is shining. Concrete, cast iron and stoneware pipes conduct heat relatively rapidly and as such should be adequately insulated.

4.5.14.5.2 *Septic tanks*

Septic tanks can function only when it can be ensured that the contents inside these do not freeze at low temperature. For this purpose, the septic tanks shall be located well below the frost line. The location of manhole openings shall be marked by staves. Fencing around the septic tanks shall be provided for discouraging traffic over them. As the rate of biological activity is reduced by 50 percent for every 10 °C fall in temperature, the capacity of septic tanks shall be increased by 100 percent for operation at 10 °C over that for operation at 20 °C.

The construction of septic tanks is preferred in rural and fringe areas of suburban and isolated buildings where underground system may neither be feasible nor economical. Septic tanks are only recommended for small communities and institutions whose contributory population does not exceed 300.

For other details, refer good practice [E-2(10)].

4.5.14.5.3 *Seepage pits*

Seepage pits can function only when the soil and subsoil conditions are favourable. Frozen soil extending to a great depth would preclude the use of such disposal devices in view of the lower water absorption capacity. The discharge of effluent should be made below the frost line.

4.5.14.5.4 *Sewage treatment plants*

Suitable design modifications for sedimentation, chemical and biological processes shall be applied to sewage treatment plants for satisfactory functioning (*see also* 4.13).

NOTE — Lavatories and bathrooms shall be kept heated to avoid freezing of water inside traps and flushing cisterns.

4.6 Construction Relating to Conveyance of Sanitary Wastes

4.6.1 *Excavation*

4.6.1.1 *General*

The safety provisions as given in relevant guidelines/best practices (Handbook on 'Construction Management, Practices and Safety in Buildings') should be referred for guidance purpose.

4.6.1.2 Turf, topsoil or other surface material shall be set aside, turf being carefully rolled and stacked for use in reinstatement. All suitable broken surface material and hard-core shall be set on one side for use in subsequent reinstatement.

4.6.1.3 Excavated material shall be stacked sufficiently away from the edge of the trench and the size of the spoil bank shall not be allowed to become such as to endanger the stability of the excavation. Spoil may be carried away and used for filling the trench behind the work.

4.6.1.4 Excavation shall proceed to within about 75 mm of the finished formation level. This final 75 mm is to be trimmed and removed as a separate operation immediately prior to the laying of the pipes or their foundations.

4.6.1.5 Unless specified otherwise by the Authority, the width at bottom of trenches for pipes of different diameters laid at different depths shall be as given below:

a) For all diameters, up to an average depth of 1 200 mm,

   Width of trench, in mm = Diameter of pipe + 300 mm;

b) For all diameters for depths above 1 200 mm,

   Width of trench, in mm = Diameter of pipe + 400 mm; and

c) Notwithstanding (a) and (b), the total width of trench at the top should not be less than 750 mm for depths exceeding 900 mm.

4.6.1.6 Excavation in roads shall be so arranged, in agreement with the proper authority, as to cause the minimum obstruction to traffic. The methods to be adopted shall depend on local circumstances.

4.6.1.7 All pipes, ducts, cables, mains or other services exposed in the trench shall be effectively supported by timber and/or chain or rope-slings.

4.6.1.8 All drainage sumps shall be sunk clear of the work outside the trench or at the sides of manholes. After the completion of the work, any pipes or drains leading to such sumps or temporary subsoil drains under permanent work shall be filled in properly with sand and consolidated.

4.6.2 *Laying of Pipes*

Laying of pipes shall be done in accordance with good practice [E-2(20)].

4.6.3 *Jointing*

All soil pipes, waste pipes, vent pipes and other such pipes above ground shall be gas-tight. All sewers and drains laid below the ground shall be water-tight. Jointing shall be done in accordance with good practice [E-2(20)].

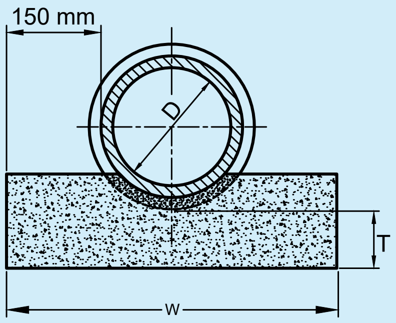
4.6.4 *Support or Protection for Pipes*

4.6.4.1 *General*

It may be necessary to support or surround pipe sewers or drains by means of concrete in certain circumstances. Some of the suggested methods are given in **4.6.4.2** to **4.6.4.4**.

4.6.4.2 *Bedding*

Bedding (*see* Fig. 15) shall be rectangular in section and shall extend laterally at least 150 mm beyond and on both sides of the projection of the barrel of the pipe. The thickness of the concrete below the barrel of the pipe shall be not less than 100 mm for pipes under 150 mm diameter and 150 mm for pipes 150 mm and over in diameter. Where bedding is used alone, the concrete shall be brought up at least to the invert level of the pipe to form a cradle and to avoid line contact between the pipe and the bed.



W = D + 300 mm
where D is external diameter of the pipe

T = { 100 mm for pipes under 150 mm nominal dia
150 mm for pipes of 150 mm nominal dia and over

FIG. 15 BEDDING

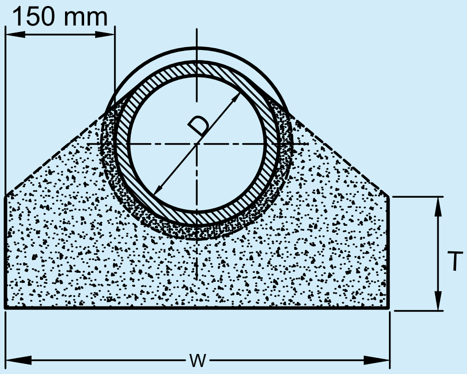
4.6.4.3 *Haunching*

Concrete haunching (*see* Fig. 16) shall consist of:

a) a concrete bed as described for bedding (*see* **4.6.4.2**);

b) the full width of the bed carried up to the level of the horizontal diameter of the pipe; and

c) splays from this level carried up on both sides of the pipe, from the full width of the bed to meet the pipe barrel tangentially.



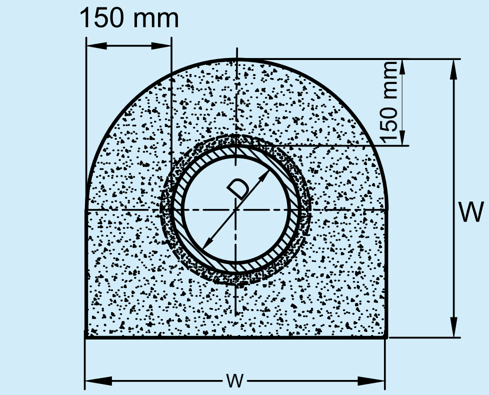
W = D + 300 mm
where D is external diameter of the pipe

T = { 100 mm for pipes under 150 mm nominal dia
150 mm for pipes of 150 mm nominal dia and over

FIG. 16 HAUNCHING

4.6.4.4 *Surround or encasing*

The surround or encasing (*see* Fig. 17) shall be similar to haunching up to the horizontal diameter of the pipe and the top portion over this shall be finished in a semicircular form to give a uniform encasing for the top half of the pipe.



W = D + 300 mm
where D is external diameter of the pipe

FIG. 17 SURROUND OR ENCASING

4.6.5 *Connection to Existing Sewers*

The connection to an existing sewer shall, as far as possible, be done at the manholes. Where it is unavoidable to make connection in between two manholes, the work of breaking into the existing sewer and forming the connection shall be carried out by the Authority or under its supervision.

4.6.5.1 Breaking into the sewer shall be effected by the cautious enlargement of a small hole and every precaution shall be taken to prevent any material from entering the sewer. No connection shall be formed in such a way as to constitute a projection into the sewer or to cause any diminution in its effective size.

4.6.6 *Back-Filling*

4.6.6.1 Filling of the trench shall not be commenced until the length of pipes therein has been tested and passed (*see* **4.10.2**).

4.6.6.2 All timber which may be withdrawn with safety shall be removed as filling proceeds.

4.6.6.3 Where the pipes are unprotected by concrete haunching, the first operation in filling shall be carefully done to hand-pack and tamp selected fine material around the lower half of the pipes so as to buttress them to the sides of the trench.

4.6.6.4 The filling shall then be continued to 150 mm over the top of the pipe using selected fine hand-packed material, watered and rammed on both sides of the pipe with a wooden rammer. On no account shall material be tipped into the trench until the first 150 mm of filling has been completed. The process of filling and tamping shall proceed evenly so as to maintain an equal pressure on both sides of the pipeline.

4.6.6.5 Filling shall be continued in layers not exceeding 150 mm in thickness, each layer being watered and well rammed.

4.6.6.6 In roads, surface materials previously excavated shall be replaced as the top layer of the filling, consolidated and maintained satisfactorily till the permanent reinstatement of the surface is made by the Authority.

4.6.6.7 In gardens, the top soil and turf, if any, shall be carefully replaced.

4.7 Construction Relating to Conveyance of Rain or Storm Water

4.7.1 *Roof Gutters*

Roof gutters shall be of any material of suitable thickness. All junctions and joints shall be water-tight.

4.7.2 *Rainwater Pipes*

Rainwater pipes shall conform to the accepted standards [E-2(21)].

4.7.3 *Subsoil Drain Pipes*

4.7.3.1 *Field drain pipes*

Suitable pipes for this purpose are plain cylindrical glazed water pipes, or concrete porous pipes, though the latter may prove unsuitable where subsoil water carries sulphates or is acidic owing to the presence of peat. Trenches for these pipes need be just wide enough at the bottom to permit laying the pipes, which shall be laid with open joints to proper lines and gradients.

It is advisable to cover the pipes with clinker free from fine ash, brick ballast or other suitable rubble, or a layer of inverted turf, brush-wood or straw before refilling the trench, in order to prevent the infiltration of silt through the open joints. Where the subsoil drain is also to serve the purpose of collecting surface water, the rubble shall be carried up to a suitable level and when required for a lawn or playing field, the remainder of the trench shall be filled with pervious top soil. When refilling the trenches, care shall be taken to prevent displacement of pipes in line of levels. When they pass near trees or through hedges, socket pipes with cement or bitumen joints shall be used to prevent penetration by roots.

4.7.3.2 *French drain*

A shallow trench is excavated, the bottom neatly trimmed to the gradient and the trench filled with broken stone, gravel or clinker, coarse at the bottom and finer towards the top.

4.8 Selection and Installation of Sanitary Appliances

Selection, installation and maintenance of sanitary appliances shall be done in accordance with good practice [E-2(22)].

4.9 Refuse Chute System

The refuse chute system provided shall be in accordance with Part E 'Plumbing Services, Section 3 Solid Waste Management' of this NBCS.

4.10 Inspection and Testing

4.10.1 *Inspection*

4.10.1.1 All sanitary appliances and fitments shall be carefully examined for defects before they are installed and also on the completion of the work.

4.10.1.2 Pipes are liable to get damaged in transit and, not withstanding tests that may have been made before despatch, each pipe shall be carefully examined on arrival on the site. Preferably, each pipe shall be rung with a hammer or mallet and those that do not ring true and clear shall be rejected. Sound pipes shall be carefully stored to prevent damage. Any defective pipes shall be segregated, marked in a conspicuous manner and their use in the works prevented.

4.10.1.3 Cast iron pipes shall be carefully examined for damage to the protective coating. Minor damage shall be made good by painting over with hot tar or preferably bitumen. But if major defects in coating exist, the pipes shall not be used unless recoated. Each pipe shall be carefully re-examined for soundness before laying.

4.10.1.4 Close inspection shall be maintained at every stage in the work, particularly as to the adequacy of timber supports used in excavation and the care and thoroughness exercised in filling.

4.10.1.4.1 Careful note shall be kept of the condition of any sewer, manhole or other existing work which may be uncovered and any defects evident shall be pointed out immediately to the Authority.

4.10.1.4.2 No work shall be covered over or surrounded with concrete until it has been inspected and approved by the Authority.

4.10.2 *Testing*

4.10.2.1 Comprehensive tests of all appliances shall be made by simulating conditions of use. Overflow shall be examined for obstructions.

4.10.2.2 *Smoke test*

All soil pipes, waste pipes, and vent pipes and all other pipes when above ground shall be approved gas-tight by a smoke test conducted under a pressure of 25 mm of water and maintained for 15 min after all trap seals have been filled with water. The smoke is produced by burning only waste or tar paper or similar material in the combustion chamber of a smoke machine. Chemical smokes are not satisfactory.

4.10.2.3 *Water test*

4.10.2.3.1 *For pipes other than cast iron*

Glazed and concrete pipes shall be subjected to a test pressure of at least 1.5 m head of water at the highest point of the section under test. The tolerance figure of 2 litre/cm of diameter/km may be allowed during a period of 10 min. The test shall be carried out by suitably plugging the low end of the drain and the ends of connections, if any, and filling the system with water. A knuckle bend shall be temporarily jointed in at the top end and a sufficient length of the vertical pipe jointed to it so as to provide the required test head, or the top end may be plugged with a connection to a hose ending in a funnel which could be raised or lowered till the required head is obtained and fixed suitably for observation.

Subsidence of the test water may be due to one or more of the following causes:

a) Absorption by pipes and joints;
b) Sweating of pipes or joints;
c) Leakage at joints or from defective pipes; and
d) Trapped air.

Allowance shall be made for (a) by adding water until absorption has ceased after which the test proper should commence. Any leakage will be visible and the defective part of the work should be cut out and made good. A slight amount of sweating which is uniform may be overlooked, but excessive sweating from a particular pipe or joint shall be watched for and taken as indicating a defect to be made good. A slight amount of sweating which is uniform may be overlooked, but excessive sweating from a particular pipe or joint shall be watched for and taken as indicating a defect to be made good.

NOTE — This test will not be applicable to sanitary pipe work above ground level.

4.10.2.3.2 *For cast iron pipes*

Cast iron sewers and drains shall be tested as for glazed and concrete pipes. The drain plug shall be suitably strutted to prevent their being forced out of the pipe during the test.

4.10.2.4 *Tests for straightness and obstruction*

The following tests shall be carried out:

a) By inserting at the high end of the sewer or drain a smooth ball of a diameter 13 mm less than the pipe bore. In the absence of obstruction, such as yarn or mortar projecting through the joints, the ball should roll down the invert of the pipe and emerge at the lower end; and

b) By means of a mirror at one end of the line and lamp at the other. If the pipeline is straight, the full circle of light may be observed. If the pipe line is not straight, this will be apparent. The mirror will also indicate obstruction in the barrel.

4.10.2.5 *Test records*

Complete records shall be kept of all tests carried out on sewers and drains both during construction and after being put into service.

4.11 Maintenance

4.11.1 *General*

Domestic drainage system shall be inspected at regular intervals. The system shall be thoroughly cleaned out at the same time and any defects discovered shall be made good.

4.11.2 *Cleaning of Drainage System*

4.11.2.1 Sewer maintenance crews, when entering a deep manhole or sewer where dangerous gas or oxygen deficiencies may be present, shall follow the following procedures:

a) Allow no smoking or open flames and guard against parks;

b) Erect warning signs;

c) Use only safety gas-proof, electric lighting equipment;

d) Test the atmosphere for noxious gases and oxygen deficiencies (presence of hydrogen sulphide is detected using lead acetate paper and that of oxygen by safety lamps);

e) If the atmosphere is normal, workmen may enter with a safety belt attached and with two men available at the top. For extended jobs, the gas tests shall be repeated at frequent intervals, depending on circumstances;

f) If oxygen deficiency or noxious gas is found, the structure shall be ventilated with pure air by keeping open at least one manhole cover each on upstream and downstream side for quick exit of toxic gases or by artificial means. The gas tests shall be repeated and the atmosphere cleared before entering. Adequate ventilation shall be maintained during this work and the tests repeated frequently;

g) If the gas or oxygen deficiency is present and it is not practicable to ventilate adequately before workers enter, a hose mask shall be worn and extreme care taken to avoid all sources of ignition. Workers shall be taught how to use the hose equipment. In these cases, they shall always use permissible safety lights (not ordinary flash lights), rubber boots or non-sparking shoes and non-sparking tools;

h) Workmen descending a manhole shaft to inspect or clean sewers shall try each ladder step or rung carefully before putting the full weight on it to guard against insecure fastening due to corrosion of the rung at the manhole wall. When work is going on in deep sewers, at least two men shall be available for lifting workers from the manhole in the event of serious injury; and

j) Portable air blowers, for ventilating manhole, are recommended for all tank, pit or manhole work where there is a question as to the presence of noxious gas, vapours or oxygen deficiency. The motors for these shall be of weather proof and flame-proof types; compression ignition diesel type (without sparking plug) may be used. When used, these shall be placed not less than 2 m away from the opening and on the leeward side protected from wind, so that they will not serve as a source of ignition for any inflammable gas which might be present. Provision should be made for ventilation and it should be of the forced type which can be provided by a blower located at ground level with suitable flexible ducting to displace out air from the manhole.

4.11.2.2 The following operations shall be carried out during periodical cleaning of a drainage system:

a) The covers of inspection chambers and manholes shall be removed and the side benching and channels scrubbed;

b) The interceptive trap, if fitted, shall be adequately cleaned and flushed with clean water. Are shall be taken to see that the stopper in the rodding arm is securely replaced;

c) All lengths of main and branch drains shall be rodded by means of drain rods and a suitable rubber or leather plunger. After rodding, the drains shall be thoroughly flushed with clean water. Any obstruction found shall be removed with suitable drain cleaning tools and the system thereafter shall be flushed with clean water;

d) The covers of access plates to all gullies shall be removed and the traps plunged and flushed out thoroughly with clean water. Care shall be taken not to flush the gully deposit into the system;

e) Any defects revealed as a result of inspection or test shall be made good;

f) The covers or inspection chambers and gullies shall be replaced, bedding them in suitable grease or other materials; and

g) Painting of ladders/rings in deep manholes and external painting of manhole covers shall be done with approved paints.

4.11.3 All surface water drains shall be periodically rodded by means of drain rods and a suitable rubber or leather plunger. After rodding, they shall be thoroughly flushed with clean water. Any obstruction found shall be removed with suitable drain cleaning tools.

4.11.4 All subsoil drains shall be periodically examined for obstruction at the open joints due to the roots of plants or other growths.

4.12 Pumping of Sewage

4.12.1 In the design of sewerage system, it is necessary to collect the sewage of a low lying area at some convenient point from which it shall be lifted by pumps. At the treatment plant also, lifting of sewage may be necessary to provide head for the flow by gravity of sewage.

4.12.2 *Sewage Pump Stations, Sizing of Sumps and Pumps*

They are required as onsite pump stations to cater to sewage from toilets and kitchen. The stations would be located in basement floors and leading the sewage to onsite treatment plants. Submersible centrifugal pumps are used for pumping the sewage. The sump capacity depends on effective holding capacity considering the flow from drainage fixtures. Usually, retention period of 15 min is adopted. The size of sump depends on the availability of space. The size of the discharge pipe shall be one nominal size higher than the design size or the pump outlet, with a velocity of 1 m/s. Pumps are sized for 100 percent design flow.

NOTE — For other details reference to good practice [E-2(13)] shall be made.

4.13 Sewage Treatment Systems

4.13.1 Sewage treatment is the process of removing contaminants from waste water, primarily from domestic sewage. It includes physical, chemical and biological processes to remove these contaminants and produce environmentally safe treated water (or treated effluent). Sewage treatment is normally carried out by aerobic bacteria (aerobic process; *see* Fig. 18) or anaerobic bacteria (anaerobic process; *see* Fig. 19), which metabolize the organic matter, multiply, and are subsequently settled out and disposed of as sludge.

The by-product of sewage treatment is usually a semisolid waste or slurry, called sewage sludge, that has to undergo further treatment before being suitable for disposal or further application.

4.13.2 The main objective of treating waste water is to stabilize decomposable organic matter present in the sewage to produce treated effluent and sludge, which can be disposed of in the environment without causing health hazards or nuisance.

The microbial population in treatment process can be cultured using the following systems:

a) *Suspended growth system* — In this system, microorganisms remain in suspension, and their concentration is related to mixed liquor suspended solids (MLSS);

b) *Attached growth system* — In this system, microorganisms are developed over mobile or immobile solid covered in biomass (slime);

c) *Combined growth system* — In this system, both systems are used to attain the shock loads.

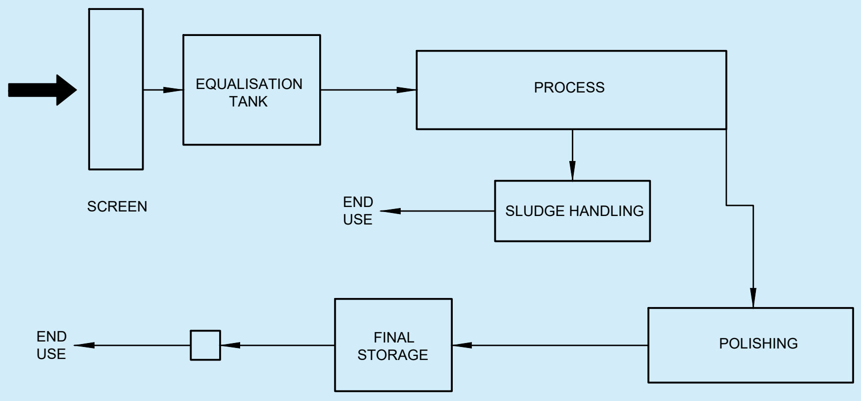

EQUALISATION TANK
PROCESS
SCREEN
END USE
SLUDGE HANDLING
END USE
FINAL STORAGE
POLISHING

FIG. 18 TYPICAL SCHEME FOR SEWAGE TREATMENT (AEROBIC PROCESS)

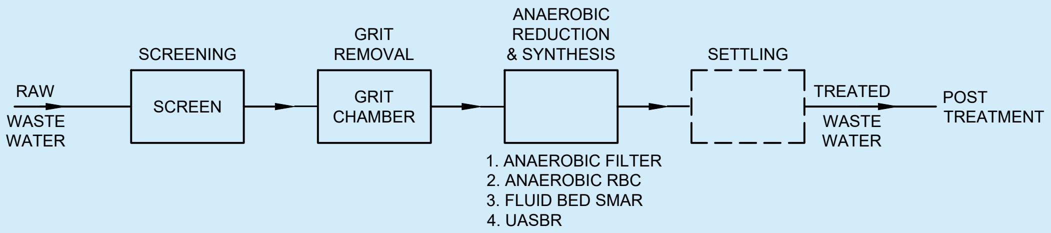

ANAEROBIC REDUCTION & SYNTHESIS
GRIT REMOVAL
SCREENING
SETTLING
RAW WASTE WATER
SCREEN
GRIT CHAMBER
TREATED WASTE WATER
POST TREATMENT
1. ANAEROBIC FILTER
2. ANAEROBIC RBC
3. FLUID BED SMAR
4. UASBR

FIG. 19 TYPICAL SCHEME FOR SEWAGE TREATMENT (ANAEROBIC PROCESS)

4.13.3 *Technologies*

Following technologies for sewage treatment shall be considered based on the requirement:

a) *Extended aeration with activated sludge process* (*EAASP*) — Activated sludge process is the aerobic biological process by which non-settleable substances occurring in dissolved and colloidal forms are converted into settleable sludge which is removed from the liquid carrier (water);

   This process is well suitable for completely populated community and does not require skilled labour for handling the plant. It is time tested and requires more number of units to achieve biological oxygen demand (BOD) less than 10 ppm, like coagulants required for better quality;

b) *Sequential batch reactor* (*SBR*) — It is an activated sludge process designed to operate under non-steady state conditions. An SBR operates in a true batch mode with aeration and sludge settlement both occurring in the same tank. There is a degree of flexibility associated with working in a time rather than in a space sequence;

   Plant for this process requires less space due to batch process, well suitable for modular growth. It can handle smallest flows and the desired quality can be achieved without coagulants. It requires good quality of decanters and skilled labour as the process is timer-based automation;

c) *Membrane bio-reactor* (*MBR*) — It is a continuous process of activated sludge treatment, but solids separation is done through pressurised system or through media. As there is physical barrier for solid separation, quality of treatment is good;

   It is suitable for any type of growth pattern and can handle smaller flows. It requires less space, and skilled labours to handle.

d) *Rotating bio bed reactor* (*RBBR*) — It is combined growth process (aerobic and anaerobic). Bacteria are allowed to grow on media, which is exposed to atmospheric air. It is also known as rotating biological contactor (RBC);

   It is suitable for smaller capacities and does not require skilled labour to handle. The quality of treatment is good.

e) *Fluidized bio bed reactor* (*FBBR*) — In this process, cells are immobilized in small particles which move with the fluid. The small particles create a large surface area for cells to stick and enable a high rate of transfer of oxygen and nutrients to the cells. It is also known as moving bed bio reactor (MBBR). It is suitable for all type of communities, does not require skilled labour and requires less space. It can be installed for all capacities, and the quality of treatment is good;

f) *Submerged aerobic fixed film reactor* (*SAFF*) — It is a combined growth process in which bio-media is fixed and bacteria are allowed to grow on media, which has air supply from below;

   It does not require skilled labour. Supporting structure for media should be anti-corrosive to enable media fixing.

g) *Trickling filters* — It is an attached growth process where media is used to grow bacteria by trickling sewage over the media. It is an old concept and is not now widely used;

h) *Oxidation ponds/lagoons* — Oxidation ponds, also called lagoons or stabilization ponds are large shallow ponds designed to treat waste water through the interaction of sunlight, bacteria and algae;

j) *Packaged sewage treatment plants* (*PSTPs*) — Packaged sewage treatment plants enable on-site treatment of domestic waste water, including grey and black water. These systems are designed as turnkey solutions, catering to the advanced treatment needs of individual communities or decentralized community setups. PSTPs are particularly effective in areas lacking centralized sewerage systems or where such systems are impractical. The design, structural integrity, installation, operation, and maintenance of PSTPs shall comply with the provisions of accepted standard [E-2(23)];

k) *Biodigestor* — Biodigester is a non-sewer on-site human waste treatment system that operates under anaerobic conditions to breakdown organic waste into simpler molecules, water, and biogas. It primarily consists of a specially designed biodigester tank and a bacterial consortium, known as anaerobic microbial inoculum (AMI). The anaerobic digestion process significantly reduces organic matter, minimizes sludge generation, and lowers pathogen transmission. Effluent from biodigesters can also be introduced into centralized sewer systems, reducing the organic load on sewage treatment plants (STPs) and improving their efficiency. The design, construction, installation and effluent standards of biodigester systems shall adhere to good practices specified in [E-2(24)]; and

m) Another option for on-site sanitation (OSS) systems in both urban and rural areas is the use of septic tanks. Septic tanks may be either prefabricated or constructed on site using suitable materials of construction. Precast concrete septic tanks have been in use in the country. Precast concrete septic tank have been is use in the country another type of septic tank is the rotationally moulded polyethylene septic tank (RMPST). RMPST could be single/multiple piece factory made unit, including inlet and outlet level openings which leaves the factory completed, controlled and ready for installation. These tanks are manufactured using rotational moulding technique which is a method for producing hollow plastic objects by placing finely divided plastic powder particles in a hollow mould that is rotated about two axes or given rock and roll type of motion, exposing it to heat and then to cold. RMPST is thus suitable for installation at standard temperature and pressure conditions. These septic tanks shall meet the accepted standards [E-2(25)].

4.14 Treatment of Wastewater and Usage of Recycled Water

See 4.2.4 of Part E ‘Plumbing Services, Section 1 Water Supply’ of this NBCS.

ANNEX A

(*Clause* 3.2.1)

APPLICATION FOR DRAINAGE OF PREMISES

I/We hereby make application to the *………………………………………………………..…………… ……………………………………………… for permission to drain the premises………………Ward No……………………………..…… Street No…………… Road/Street known as……………..……........................

The sanitary arrangement and drains of the said premises are shown in the accompanying plans and a description of the specification of the work/material used is also appended (Annex B).

I/We undertake to carry out the work in accordance with Part E 'Plumbing Services, Section 2 Drainage and Sanitation' of the National Building Construction Standards (NBCS).

………………………………..………...	……………………………………
Signature of the licensed/registered plumber	Signature of the owner
Name and address of the	Name and address…………………
……………………………………………	…………………………………….
……………………………………………	…………………………………….
Date…………..…	Date……..………

NOTE — The application should be signed by the owner of the premises and shall be countersigned by the licensed/registered plumber.

---

* Insert the name of the Authority.

ANNEX B

(*Clause* 3.2.3.2 *and* *Annex* A)

FORM FOR DETAILED DESCRIPTION OF WORK AND SPECIFICATION OF MATERIALS

a) Separation of rainwater and foul water…………………………………………

b) Rainwater drains, curbs and points of discharge……………………………..

c) Rainwater gutters, pipes or spouts where discharging……………………….

d) Open-full-water drains, materials, sizes, curbs and other means places, verandahs, latrines

e) Silt-catcher and grating, size and position………………………………………

f) Drains…………………………………………………………………………….

1) Main sewage drains: Fall …………………………………………………..
Size…………………………………………………….
2) Branch drains : Fall …………………………………………………..
Size……………………………………………………
3) Materials…………………………………………………………………
4) Method of jointing……………………………………………………………

g) Bedding of pipes:

1) Method of bedding………………………………………………………..
2) Thickness and width of beds of concrete…………………………………
3) Thickness of concrete round pipes………………………………………..

h) Protection of drain laid under wall………………………………………………

j) Traps, description and intercepter:

1) Lavatory waste pipes……………………………………………………….
2) Bath waste pipes…………………………………………………………….
3) Sink……………………………………………………………………………
4) Gully-traps…………………………………………………………………….
5) Water closet traps…………………………………………………………
6) Grease traps…………………………………………………………………
7) Slop sink……………………………………………………………………..
8) Urinal………………………………………………………………………...
9) Others………………………………………………………………………….

k) Manholes and inspection chambers:

1) Thickness of walls……………………………………………………….
2) Description of bricks………………………………………………………..
3) Description of rendering……………………………………………………
4) Description of invert channels……………………………………………….

5) Depth of chambers…………………………………………………………

6) Size and description of cover and manner of fixing……………………….

m) Ventilation of drain:

1) Position – Height above nearest ground level……………………………..

2) Outlet shaft position of terminal at top………………………………………

n) Soil pipe, waste pipe and ventilating pipe connections:

1) Lead and iron pipes………………………………………………………..

2) Lead pipe of trap with cast iron pipe……………………………………..

3) Stoneware pipe or trap with lead pipe………………………………………

4) Lead soil pipe or trap with stoneware pipe or trap…………………………

5) Cast iron pipe with stoneware drain…………………………………………

6) Stoneware trap with cast iron soil pipe……………………………………..

p) Ventilation of water closet trap sink, lavatory and other traps material and supports.

q) Water closets (apartments):

1)

i) At or above ground level………………………………………………..

ii) Approached from………………………………………………………

iii) Floor material…………………………………………………………..

iv) Floor fall towards door…………………………………………………

v) Size of window opening in wall made to open…………………………

vi) Position of same……………………………………………………….

vii) Means of constant ventilation…………………………………………

viii) Position of same……………………………………………………..

2) Water closet apparatus:

i) Description of pan, basin, etc…………………………………………

ii) Kind………………………………...

iii) Flushing cistern……………………….

iv) Material of flushing pipe……………………………………………….

v) Internal diameter……………………………………………………….

vi) Union with basin……………………………………………………….

r) Sanitary fittings, water storage tank, etc:

1) Number and description of sanitary fittings in room and rooms in which they are to be installed……………………………………………….

2) Capacity and position of water storage tanks……………………..…………….

3) Size and number of draw off taps and whether taken off storage tanks or direct from main supply……………………………………………………...

4) Details of draw off taps, that is, whether they are of plain screw down pattern or ‘waste not’ and description of any other sanitary work to be carried out not included under above headings……………………………………..

s) Depth of sewer below surface of street…………………………………………...

t) Level of invert of house drain at point of junction:

   1) With sewer……………………………………………………………………….
   2) Level of invert of sewer at point of junction with house drain……………..
   3) Distance of nearest manhole on sewer from the point at which the drain leaves the premises…………………………………………………………

u) Schedule of pipes:

Sl No.	*Description of Pipe/Drain*	*Materials*	*Diameter*	*Weight*	*Method of Jointing*
(1)	(2)	(3)	(4)	(5)	(6)
i)	Subsoil drains				
ii)	Main sewage drains				
iii)	Branch sewag drains				
iv)	Soil pipes				
v)	Ventilating pipes other than soil pipes				
vi)	Waste pipes				
vii)	Rainwater pipes				
viii)	Anti-syphon pipes				

Signature of the licensed/registered plumber……………………………………..…

Name and address of the licensed/registered plumber………….…………………...

……………………………………………………………………………………....

……………………………………………………………………………………....

…………………………………………………………………………………….…..

Date…………………………………………………...………………………..

ANNEX C

(*Clause* 3.2.5)

FORM FOR LICENSED/REGISTERED PLUMBER'S COMPLETION CERTIFICATE

Certified that I/we have completed the plumbing work of drainage and sanitation system for the premises as detailed below. This may be inspected, approved and connection given.

Ward No…………………………………………….….

Street………………………………………….….…..

Locality……………………………..…………..…

Block No…………………………..……………..

House No…………………………………………

Details of work…………………………………………...……………………………………………. ……… ………

The work was sanctioned by the Authority*
vide

…………………..…………………….	……..……………………………………
Signature of the owner	Signature of the licensed/registered plumber
Name and address……………………	Name and address ……………….……………
………………………………………….	………………………………………………..

Date…………………

The Authority's Report

Certified that the plumbing work of drainage and sanitation system for the premises, have been laid, applied, executed in accordance with Part E 'Plumbing Services, Section 2 Drainage and Sanitation' of the National Building Construction Standards (NBCS).

Drainage Connection to the main sewer will be made on…………………………………………………………

Date……………………… The Authority………………………..…

---

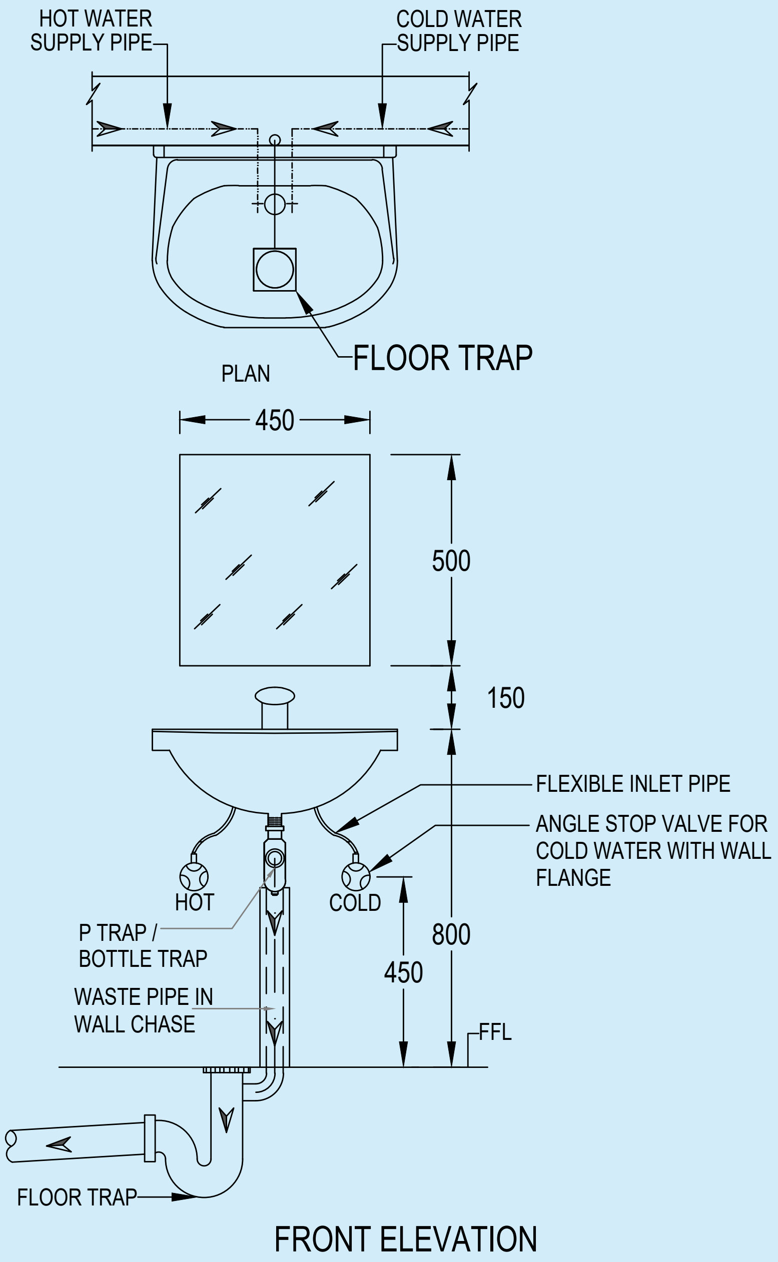
* Insert the name of the Authority

ANNEX D

(*Clause* 4.5.1.4)

TYPICAL MOUNTING ARRANGEMENTS FOR VARIOUS PLUMBING FIXTURES, INCLUDING DRAINAGE SYSTEMS AND VENTILATION

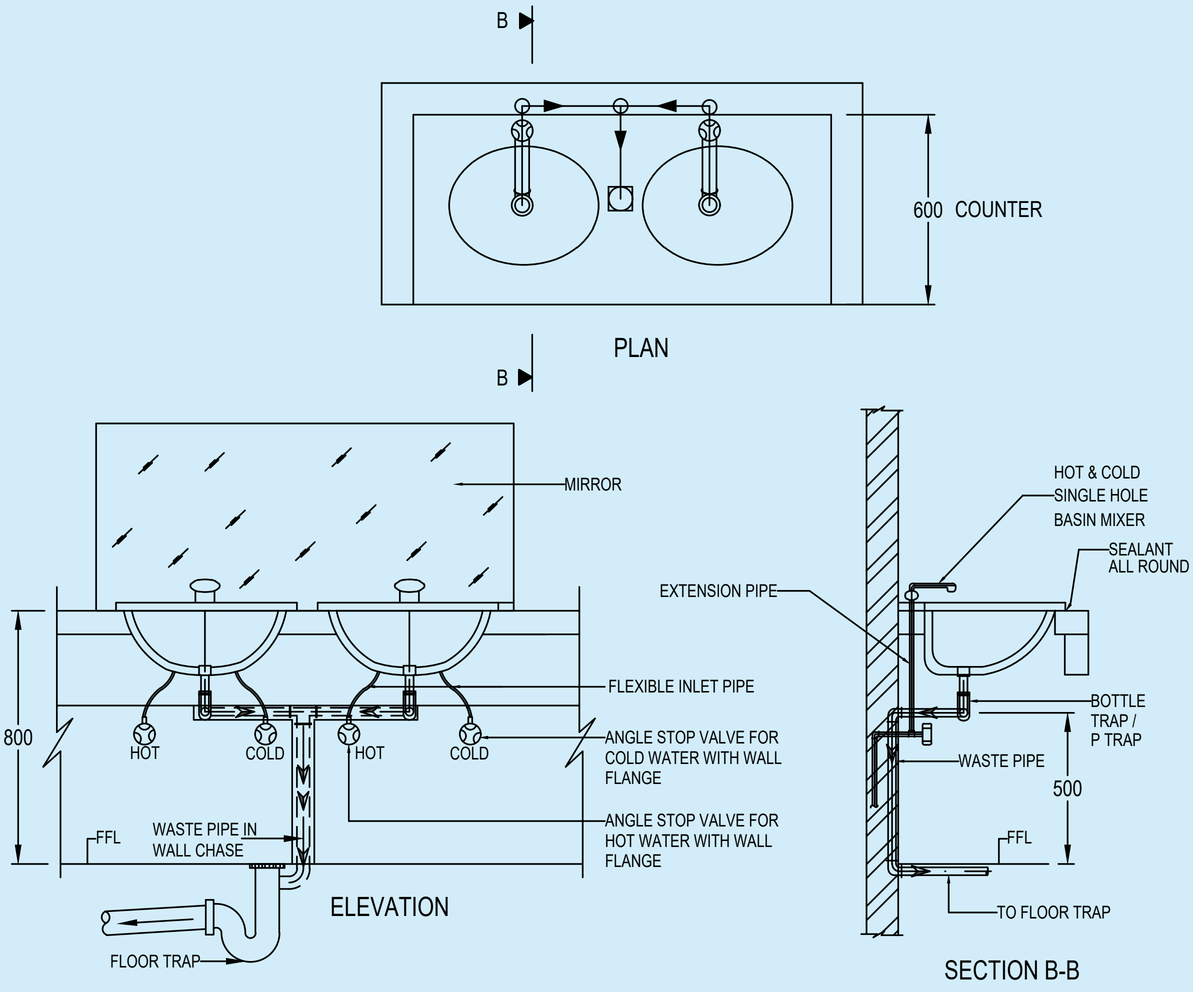
D-1 ARRANGEMENT FOR RECTANGULAR WASH BASIN — *See* Fig. 20


HOT WATER SUPPLY PIPE
COLD WATER SUPPLY PIPE
FLOOR TRAP
PLAN
450
500
150
FLEXIBLE INLET PIPE
ANGLE STOP VALVE FOR COLD WATER WITH WALL FLANGE
HOT
COLD
P TRAP / BOTTLE TRAP
WASTE PIPE IN WALL CHASE
800
450
FFL
FLOOR TRAP
FRONT ELEVATION

All dimensions in millimetres.

FIG. 20 RECTANGULAR WASH BASIN

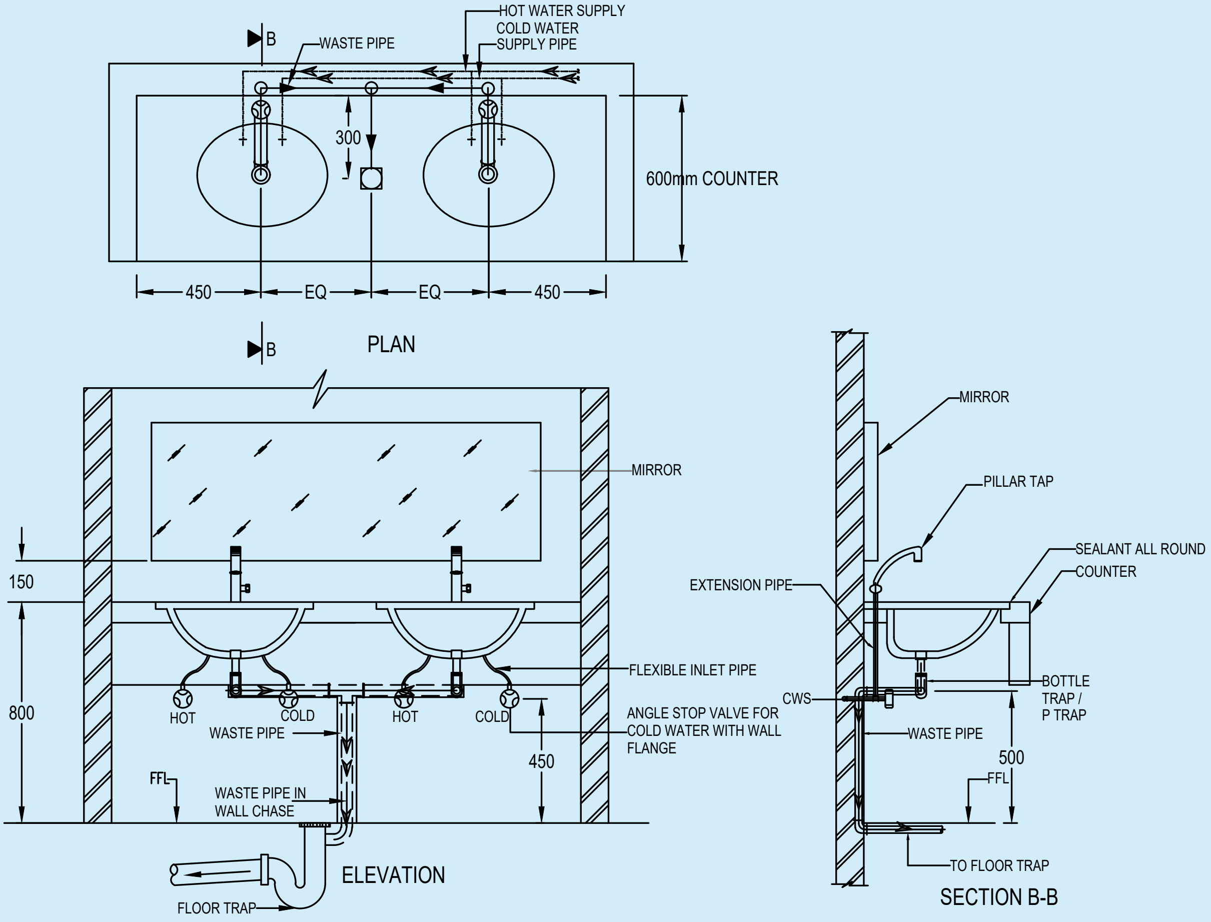
D-2 ARRANGEMENT FOR OVAL WASH BASIN (ABOVE COUNTER) — *See* Fig. 21


B
B
600 COUNTER
PLAN
MIRROR
800
HOT
COLD
HOT
COLD
FLEXIBLE INLET PIPE
ANGLE STOP VALVE FOR COLD WATER WITH WALL FLANGE
ANGLE STOP VALVE FOR HOT WATER WITH WALL FLANGE
FFL
WASTE PIPE IN WALL CHASE
FLOOR TRAP
ELEVATION
EXTENSION PIPE
HOT & COLD SINGLE HOLE BASIN MIXER
SEALANT ALL ROUND
BOTTLE TRAP / P TRAP
WASTE PIPE
500
FFL
TO FLOOR TRAP
SECTION B-B

All dimensions in millimetres.

FIG. 21 OVAL WASH BASIN (ABOVE COUNTER)

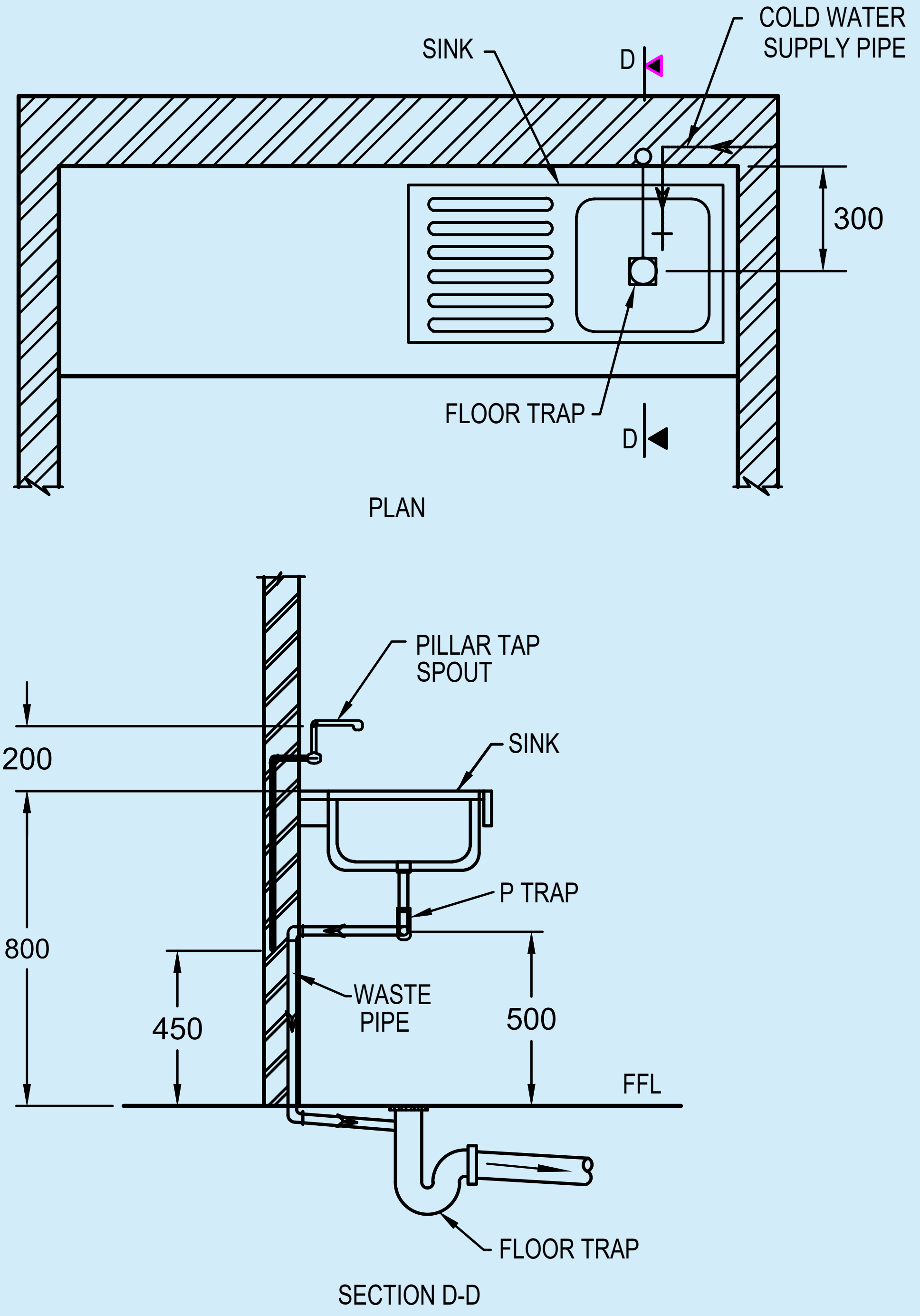
D-3 ARRANGEMENT FOR OVAL WASH BASIN (BELOW COUNTER) — *See* Fig. 22


B
WASTE PIPE
HOT WATER SUPPLY
COLD WATER
SUPPLY PIPE
300
600mm COUNTER
450
EQ
EQ
450
B
PLAN
MIRROR
150
800
HOT
COLD
HOT
COLD
WASTE PIPE
FLEXIBLE INLET PIPE
ANGLE STOP VALVE FOR
COLD WATER WITH WALL
FLANGE
450
FFL
WASTE PIPE IN
WALL CHASE
FLOOR TRAP
ELEVATION
MIRROR
PILLAR TAP
SEALANT ALL ROUND
COUNTER
EXTENSION PIPE
CWS
BOTTLE
TRAP /
P TRAP
WASTE PIPE
500
FFL
TO FLOOR TRAP
SECTION B-B

All dimensions in millimetres.

FIG. 22 OVAL WASH BASIN (BELOW COUNTER)

D-4 ARRANGEMENT FOR SINK — *See* Fig. 23

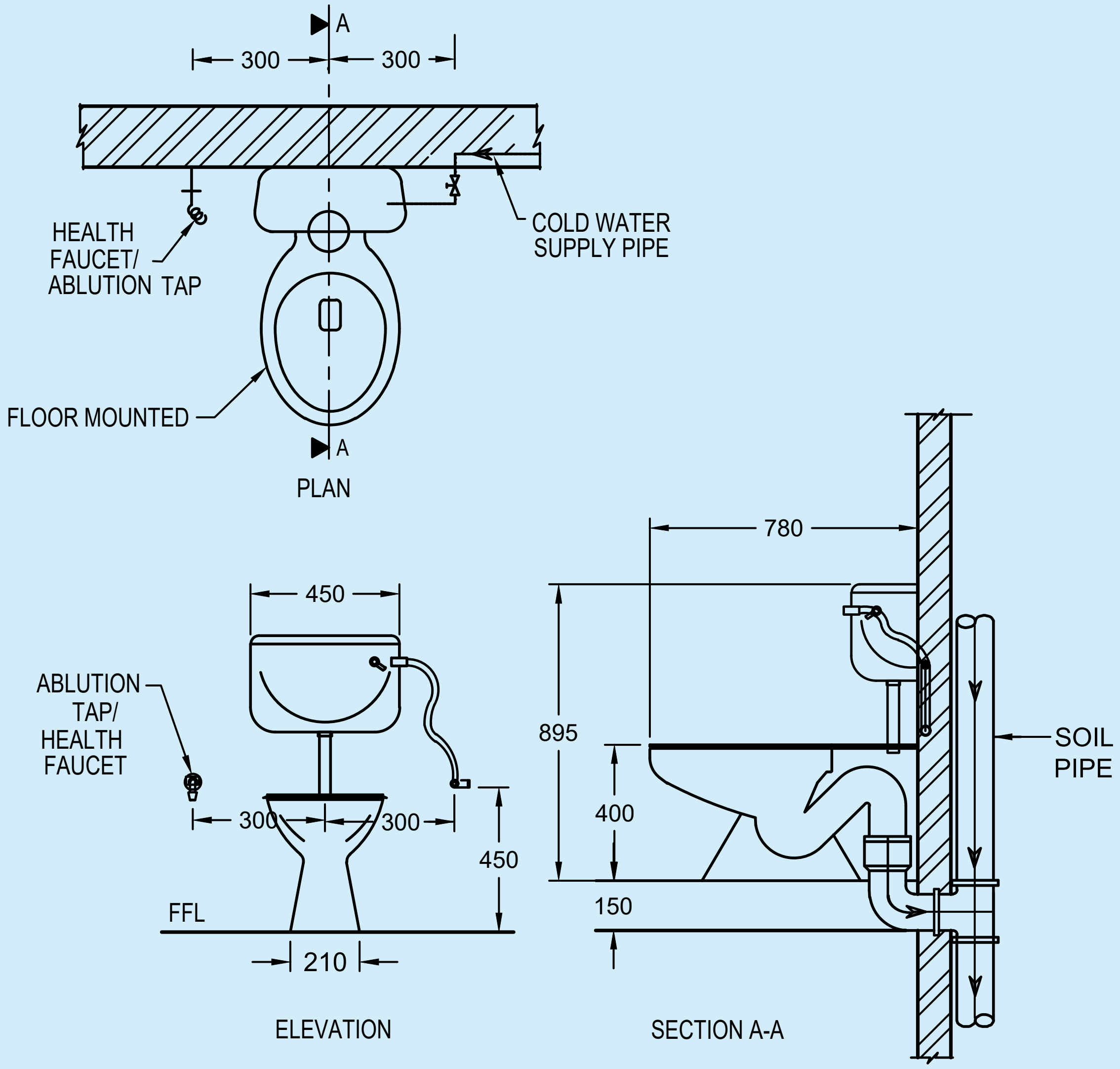


COLD WATER SUPPLY PIPE
SINK
D
300
FLOOR TRAP
D
PLAN
PILLAR TAP SPOUT
SINK
200
P TRAP
800
WASTE PIPE
450
500
FFL
FLOOR TRAP
SECTION D-D

All dimensions in millimetres.

FIG. 23 SINK

D-5 ARRANGEMENT FOR EUROPEAN WATER CLOSET (FLOOR MOUNTED WITH FLUSH TANK AND S-TRAP) — *See* Fig. 24

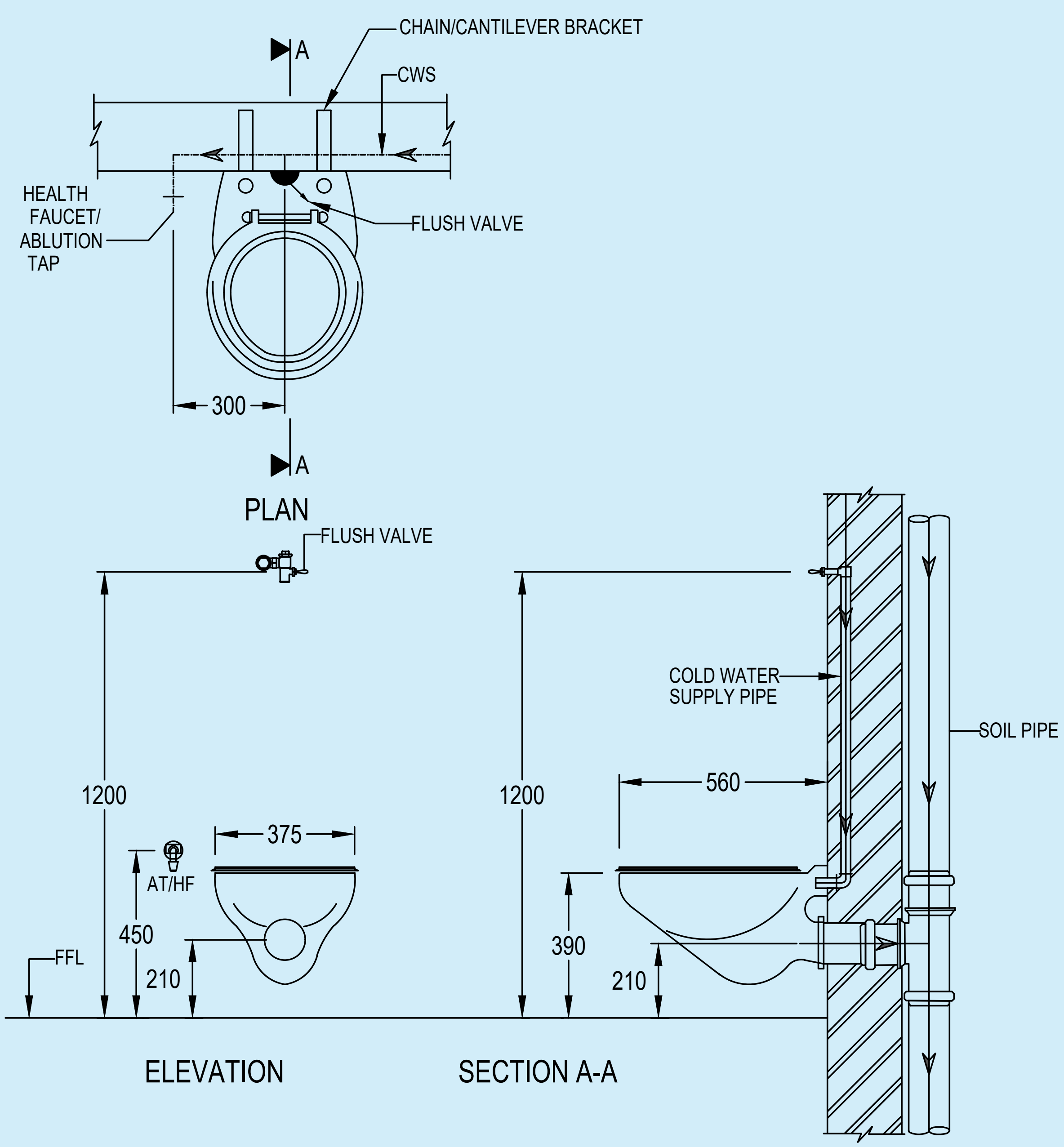


A
300
300
HEALTH
FAUCET/
ABLUTION TAP
COLD WATER
SUPPLY PIPE
FLOOR MOUNTED
A
PLAN
780
450
ABLUTION
TAP/
HEALTH
FAUCET
895
SOIL
PIPE
400
300
300
450
FFL
150
210
ELEVATION
SECTION A-A

All dimensions in millimetres.

FIG. 24 EUROPEAN WATER CLOSET
(FLOOR MOUNTED WITH FLUSH TANK AND S-TRAP)

D-6 ARRANGEMENT FOR EUROPEAN WATER CLOSET (WALL HUNG WITH FLUSH VALVE) — *See* Fig. 25

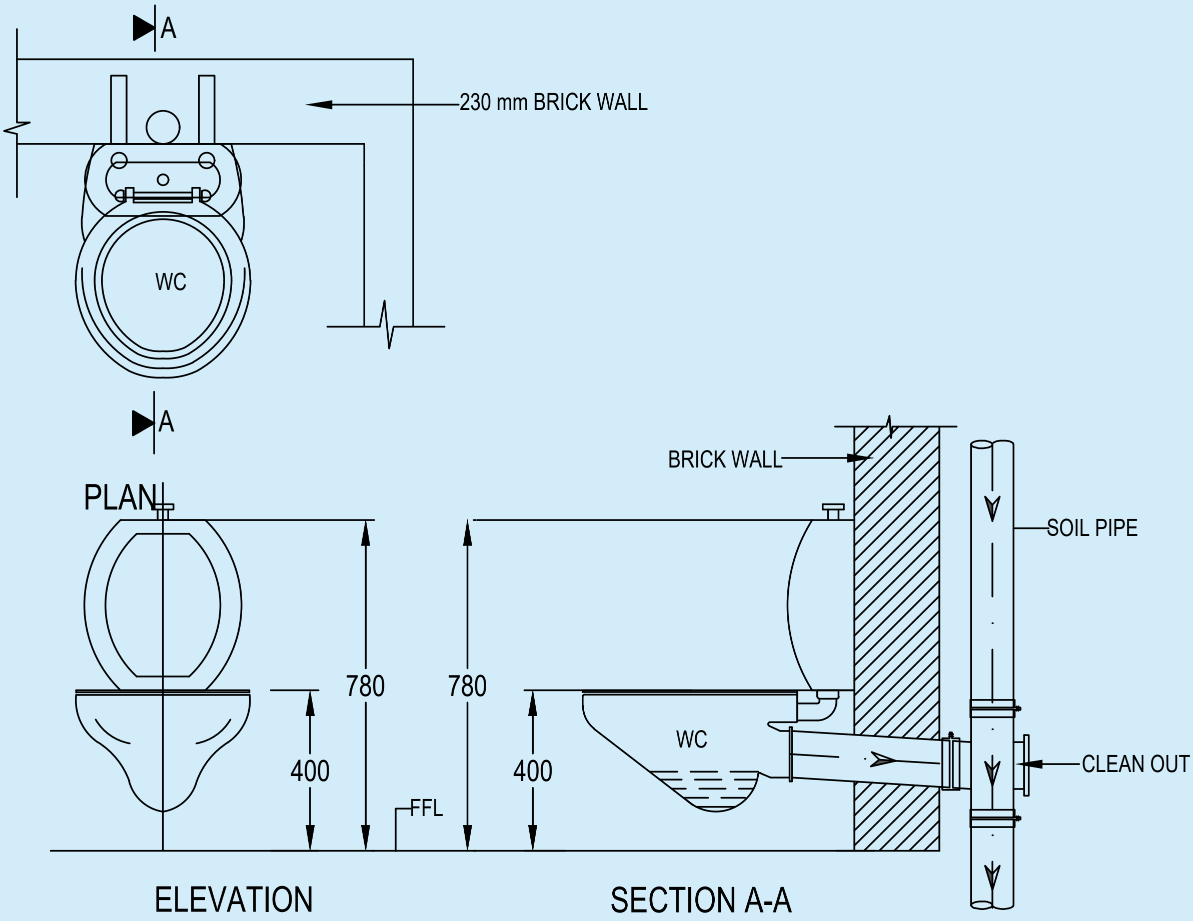


CHAIN/CANTILEVER BRACKET
A
CWS
HEALTH FAUCET/ ABLUTION TAP
FLUSH VALVE
300
A
PLAN
FLUSH VALVE
1200
375
AT/HF
450
210
FFL
ELEVATION
1200
COLD WATER SUPPLY PIPE
SOIL PIPE
560
390
210
SECTION A-A

All dimensions in millimetres.

FIG. 25 EUROPEAN WATER CLOSET (WALL HUNG WITH FLUSH VALVE)

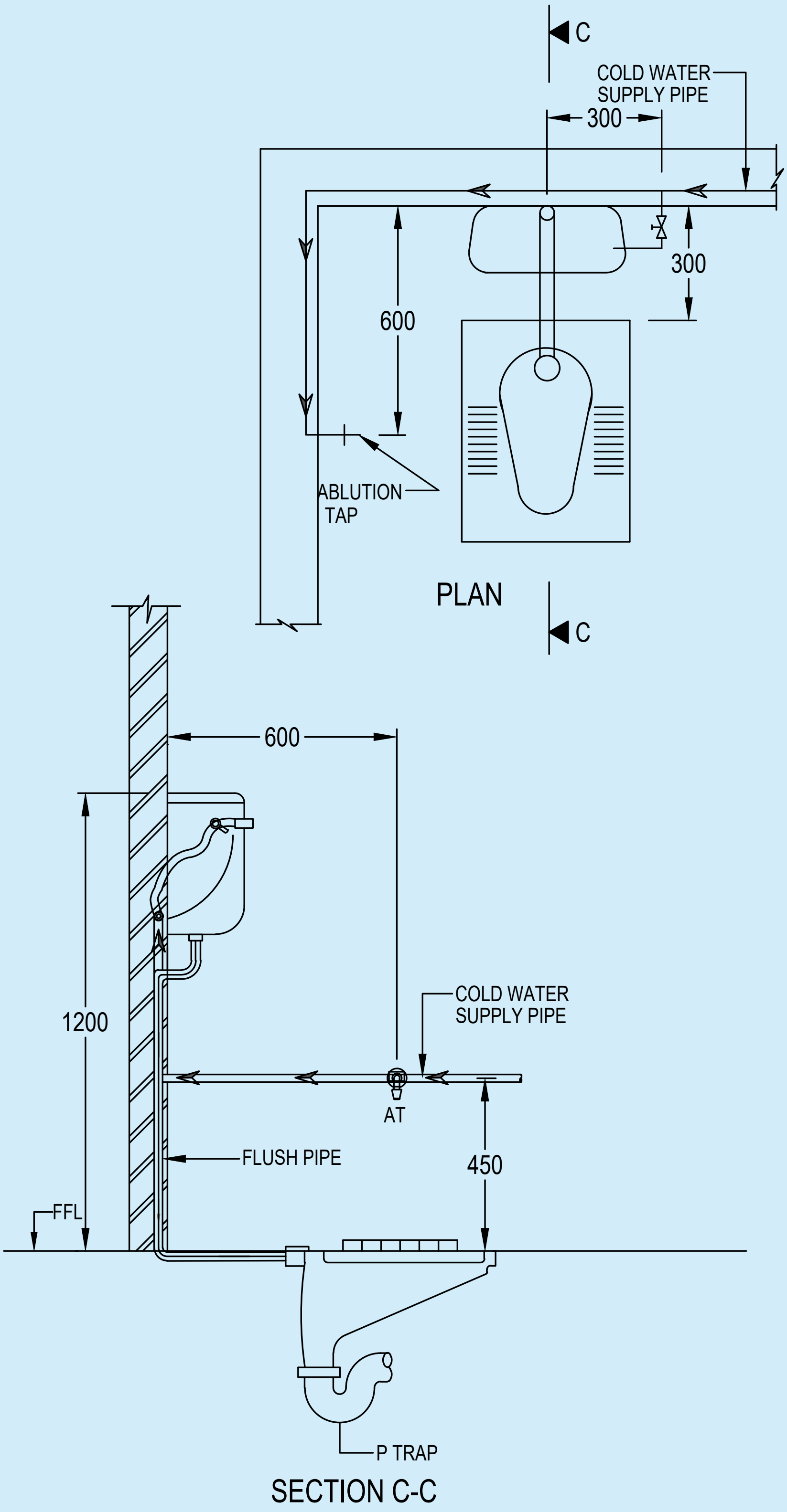
D-7 ARRANGEMENT FOR EUROPEAN WATER CLOSET (WALL HUNG WITH FLUSHING CISTERN) — *See* Fig. 26


A
230 mm BRICK WALL
WC
A
PLAN
BRICK WALL
SOIL PIPE
780
780
WC
400
400
CLEAN OUT
FFL
ELEVATION
SECTION A-A

All dimensions in millimetres.

FIG. 26 EUROPEAN WATER CLOSET
(WALL HUNG WITH FLUSHING CISTERN)

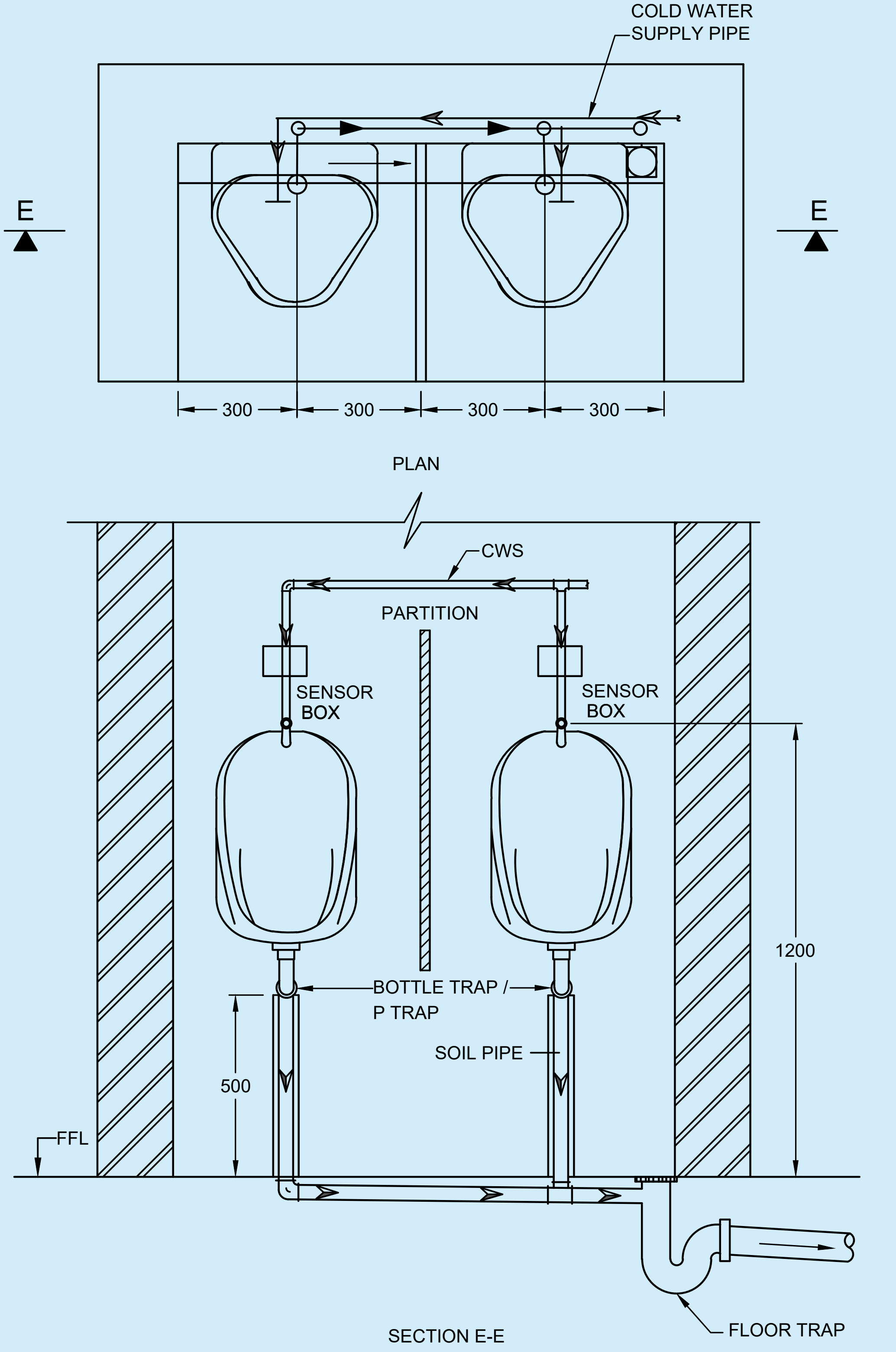
D-8 ARRANGEMENT FOR ORISSA PAN INDIAN WATER CLOSET — *See* Fig. 27


C
COLD WATER SUPPLY PIPE
300
300
600
ABLUTION TAP
PLAN
C
600
1200
COLD WATER SUPPLY PIPE
AT
FLUSH PIPE
450
FFL
P TRAP
SECTION C-C

All dimensions in millimetres.

FIG. 27 ORISSA PAN INDIAN WATER CLOSET

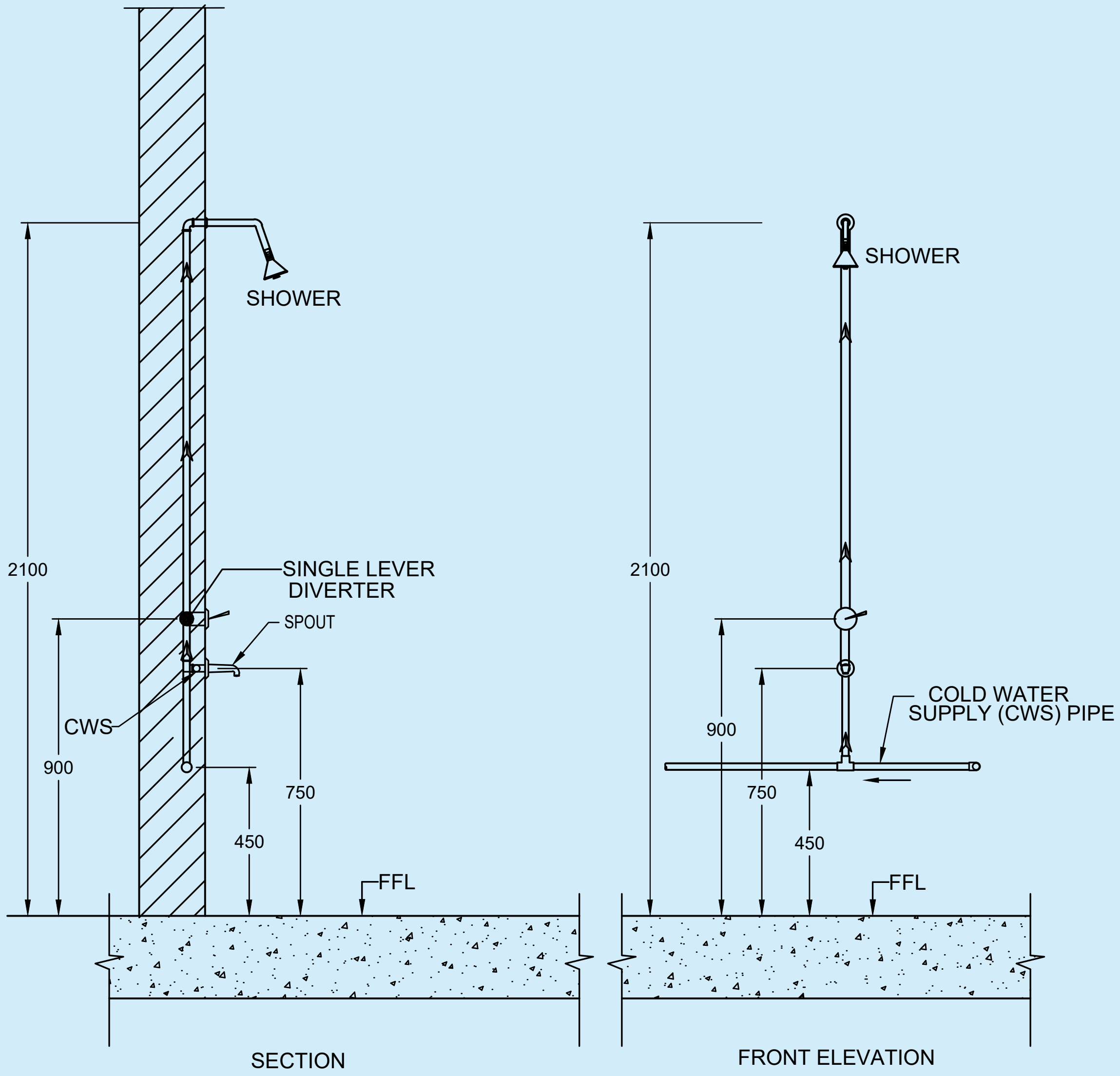
D-9 ARRANGEMENT FOR URINAL — *See* Fig. 28


COLD WATER
SUPPLY PIPE
E
E
300
300
300
300
PLAN
CWS
PARTITION
SENSOR
BOX
SENSOR
BOX
1200
BOTTLE TRAP /
P TRAP
SOIL PIPE
500
FFL
SECTION E-E
FLOOR TRAP

All dimensions in millimetres.

FIG. 28 URINAL

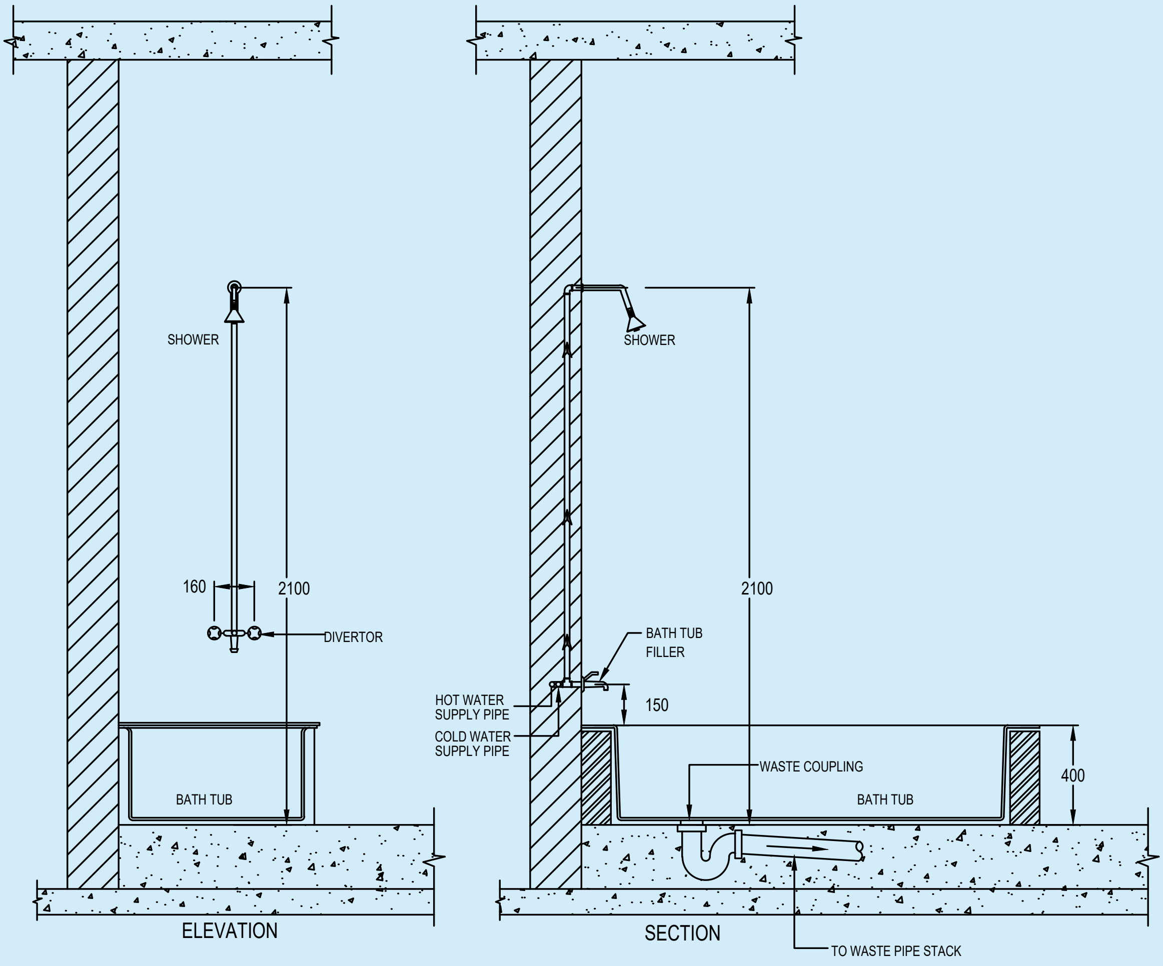
D-10 ARRANGEMENT FOR SHOWER — *See* Fig. 29


SHOWER
SINGLE LEVER DIVERTER
SPOUT
CWS
2100
900
750
450
FFL
SECTION
SHOWER
COLD WATER SUPPLY (CWS) PIPE
2100
900
750
450
FFL
FRONT ELEVATION

All dimensions in millimetres.

FIG. 29 SHOWER

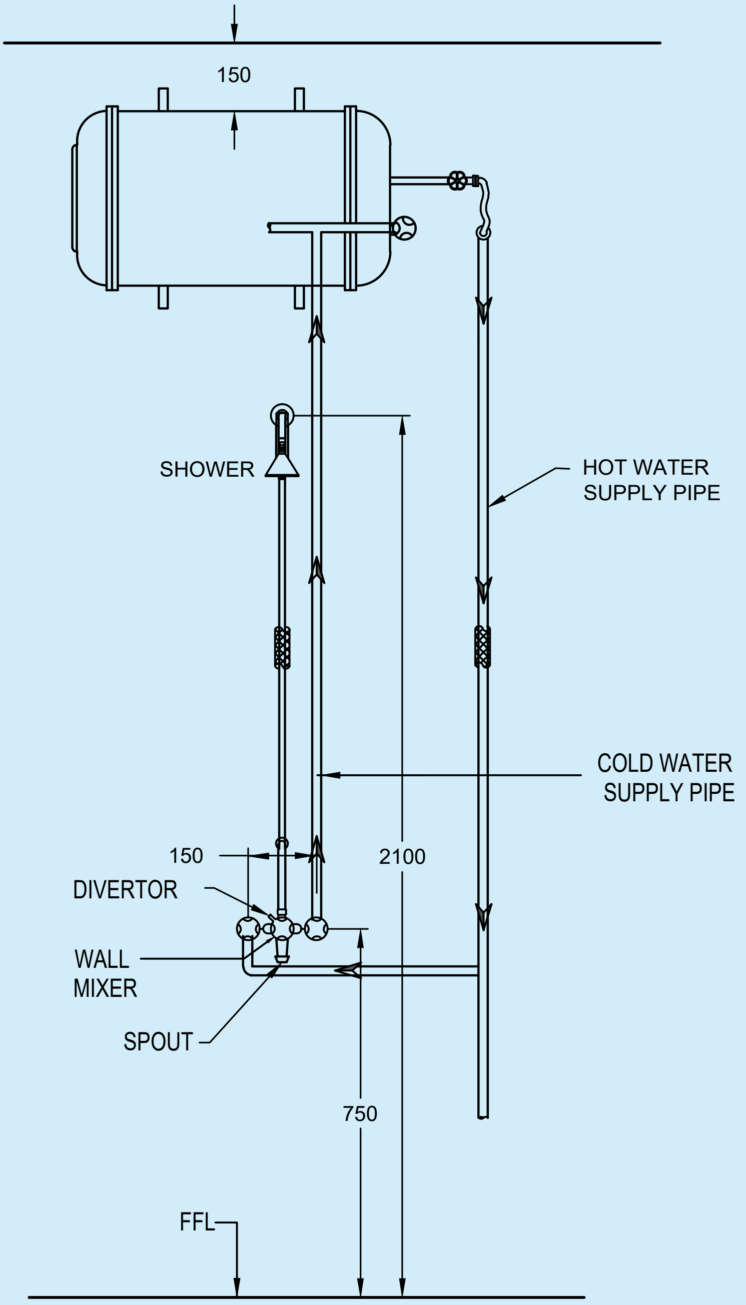
D-11 ARRANGEMENT FOR BATH TUB/SHOWER — *See* Fig. 30


SHOWER
160
2100
DIVERTOR
BATH TUB
ELEVATION
SHOWER
2100
BATH TUB
FILLER
HOT WATER
SUPPLY PIPE
COLD WATER
SUPPLY PIPE
150
WASTE COUPLING
400
BATH TUB
SECTION
TO WASTE PIPE STACK

All dimensions in millimetres.

FIG. 30 BATH TUB/SHOWER

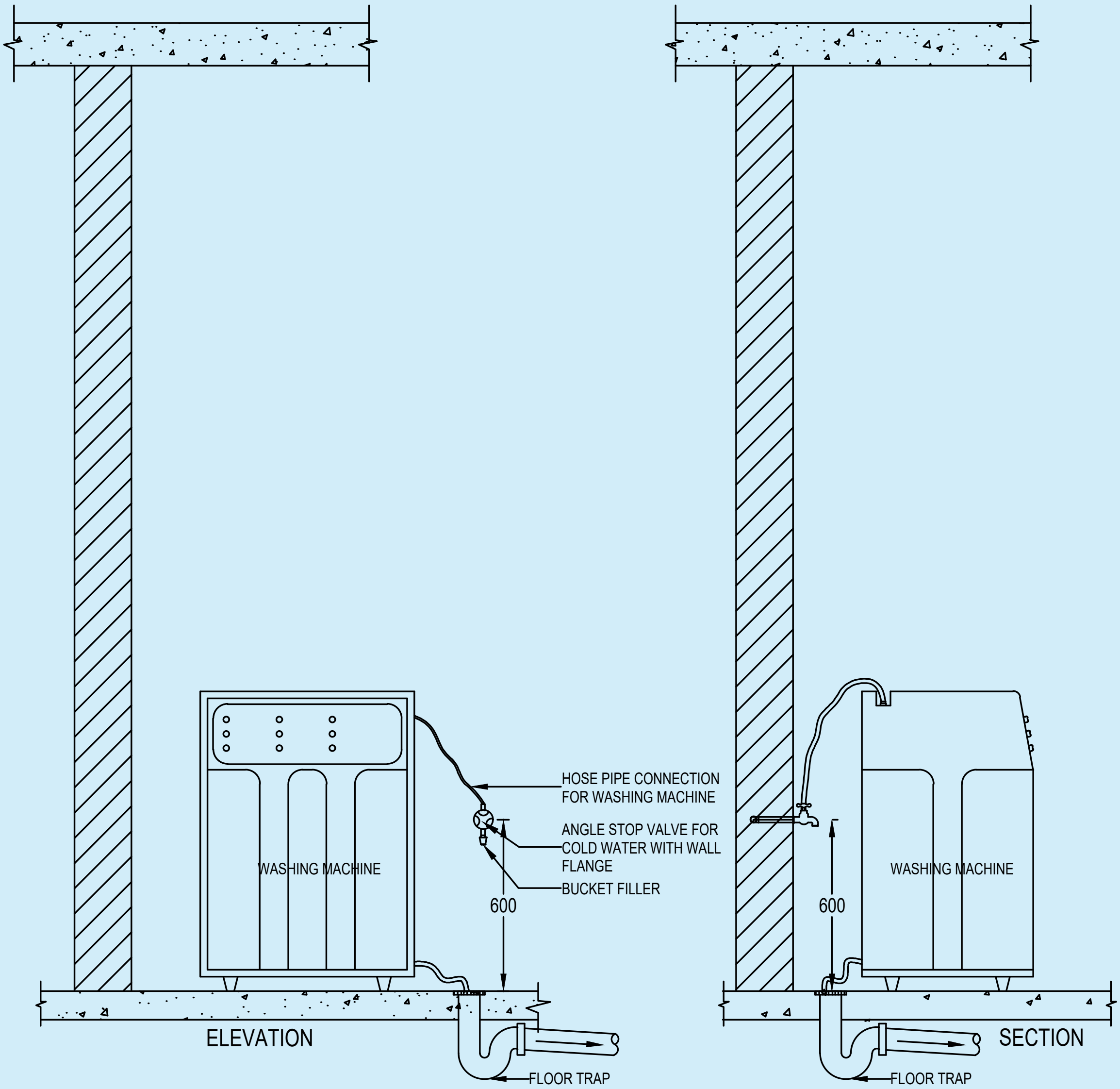
D-12 ARRANGEMENT FOR SHOWER AND ELECTRIC WATER HEATER (HORIZONTAL MOUNTED TYPE) — *See* Fig. 31


150
SHOWER
HOT WATER
SUPPLY PIPE
COLD WATER
SUPPLY PIPE
150
2100
DIVERTOR
WALL
MIXER
SPOUT
750
FFL

All dimensions in millimetres.

FIG. 31 SHOWER AND ELECTRIC WATER HEATER (HORIZONTAL MOUNTED TYPE)

D-13 ARRANGEMENT FOR WASHING MACHINE — *See* Fig. 32

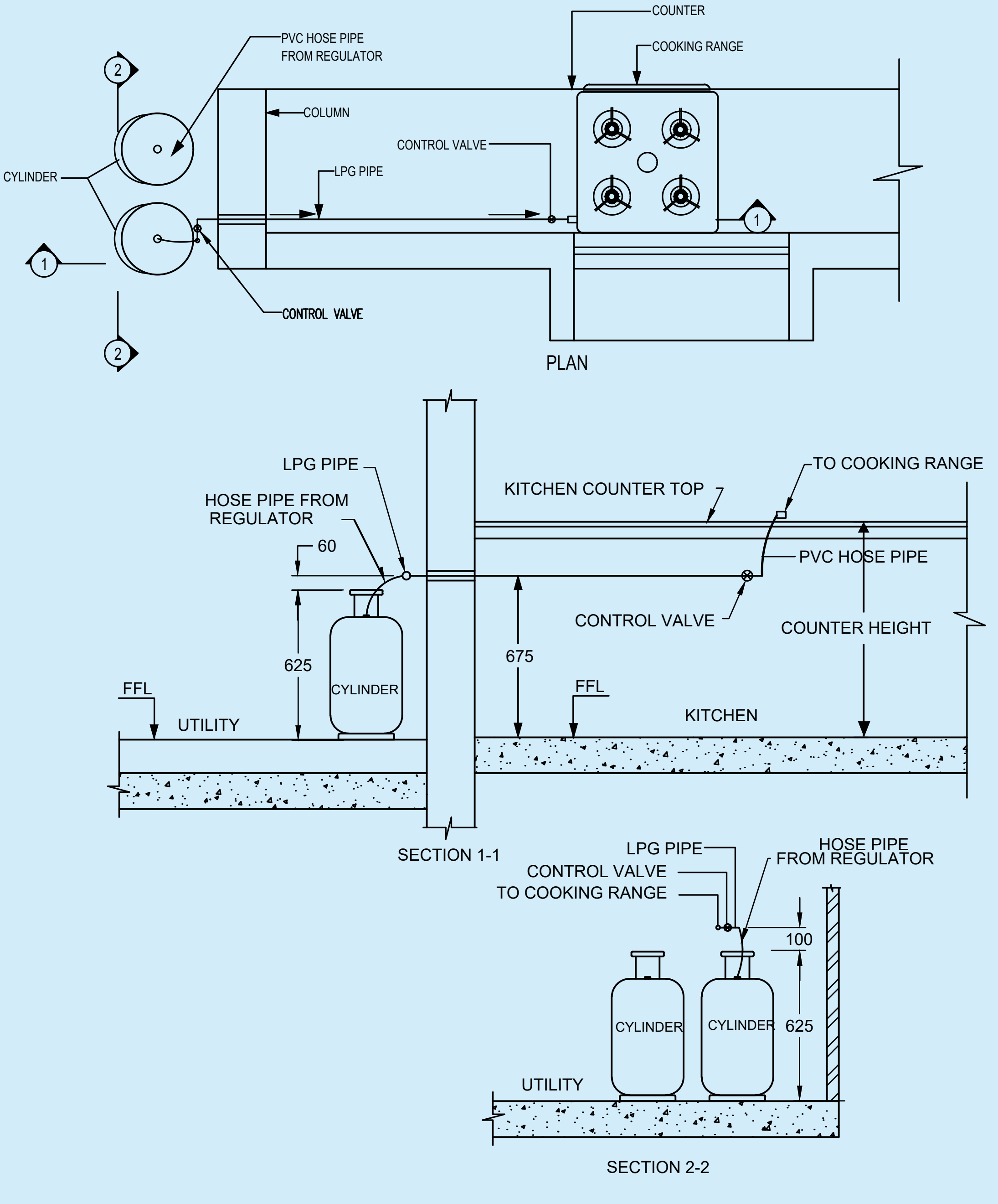

WASHING MACHINE
HOSE PIPE CONNECTION FOR WASHING MACHINE
ANGLE STOP VALVE FOR COLD WATER WITH WALL FLANGE
BUCKET FILLER
600
ELEVATION
FLOOR TRAP
WASHING MACHINE
600
SECTION
FLOOR TRAP

NOTE – Manual type washing machine : waste lead into floor trap.
Automatic type washing machine : waste outlet should be 300 mm above FFL (and as per manufacturer's technical specifications).

All dimensions in millimetres.

FIG. 32 WASHING MACHINE

D-14 ARRANGEMENT FOR LPG PIPING — *See* Fig. 33


COUNTER
COOKING RANGE
PVC HOSE PIPE FROM REGULATOR
2
COLUMN
CONTROL VALVE
LPG PIPE
CYLINDER
1
1
CONTROL VALVE
2
PLAN
LPG PIPE
HOSE PIPE FROM REGULATOR
60
TO COOKING RANGE
KITCHEN COUNTER TOP
PVC HOSE PIPE
CONTROL VALVE
COUNTER HEIGHT
625
675
CYLINDER
FFL
FFL
UTILITY
KITCHEN
SECTION 1-1
LPG PIPE
CONTROL VALVE
TO COOKING RANGE
HOSE PIPE FROM REGULATOR
100
CYLINDER
CYLINDER
625
UTILITY
SECTION 2-2

All dimensions in millimetres.

FIG. 33 LPG PIPING

LIST OF STANDARDS

The following list records those standards which are acceptable as ‘good practice’ and ‘accepted standards’ in the fulfillment of the requirements of this NBCS. The latest version of a standard shall be adopted at the time of enforcement of this NBCS. The standards listed may be used as a guide in conformance with the requirements of the referred clauses in this NBCS.

	IS No.	*Title*
(1)	IS 10446 : 1983	Glossary of terms relating to water supply and sanitation
(2)	IS 4963 : 2025	Accessibility in built environment for older adults and persons with disabilities — Requirements (*second revision*)
(3)	IS 11208 : 1985	Guidelines for registration of plumbers
(4)	IS 774 : 2021	Ceramic (vitreous china) flushing cisterns for water closets and urinals — Specification (*sixth revision*)
	IS 2548	Plastic seats and covers for water-closets — Specification:
	(Part 1) : 1996	Thermoset seats and covers (*fifth revision*)
	(Part 2) : 1996	Thermo plastic seats and covers (*fifth revision*)
	IS 2556	Vitreous china sanitary appliances — Specification:
	(Part 1) : 2021	General requirements (*fourth revision*)
	(Part 2) : 2024	Specific requirements of washdown water closets (*sixth revision*)
	(Part 3) : 2024	Specific requirements of squatting pans (*sixth revision*)
	(Part 4) : 2004	Specific requirements of wash basins (*fourth* revision)
	(Part 5) : 1994	Specific requirements of laboratory sinks (*third revision*)
	(Part 6) : 2021	Specific requirements of urinals and partition plates (*fifth revision*)
	(Part 7) : 1995	Specific requirements of accessories for sanitary appliances (*third revision*)
	(Part 8) : 2021	Specific requirements of close-coupled and one-piece pedestal washdown and syphonic water closets (*sixth revision*)
	(Part 9) : 2004	Specific requirements of pedestal type bidets (*fifth revision*)
	(Part 14) : 2024	Specific requirements of integrated squatting pans (*second revision*)
	(Part 15) : 2024	Specific requirements of universal water closets (*third revision*)
	(Part 16) : 2024	Specific requirements of washdown wall mounted water closets (*first revision*)
	(Part 17) : 2001	Specific requirements for wall mounted bidets
	IS 6411 : 1985	Specification for gel-coated glass fibre reinforced polyester resin bath tubs (*first revision*)
	IS 7231 : 2021	Plastic flushing cisterns for water closets and urinals — Specification (*third revision*)
	IS 11246 : 1992	Glass fibre reinforced polyester resins (GRP) squatting pans — Specification (*first revision*)
	IS 13983 : 1994	Stainless steel sinks for domestic purposes — Specification
(5)	IS 651 : 2007	Glazed stoneware pipes and fittings — Specification (*sixth revision*)
	IS 3006 : 1979	Specification for chemically resistant glazed stoneware pipes and fittings (*first revision*)

	IS No.	*Title*
(6)	IS 458 : 2021	Precast concrete pipes (with and without reinforcement) — Specification (*fifth revision*)
	IS 784 : 2019	Prestressed concrete pipes (including specials) — Specification (*third revision*)
	IS 1916 : 2018	Steel cylinder pipes with concrete lining and coating (*second revision*) — Specification
	IS 4350 : 1967	Specification for concrete porous pipes for under drainage
	IS 7319 : 1974	Specification for perforated concrete pipes
(7)	IS 1536 : 2023	Centrifugally cast (spun) iron pressure pipes for water, gas and sewage — Specification (*fifth revision*)
	IS 1537 : 1976	Specification for vertically cast iron pressure pipes for water, gas and sewage (*first revision*)
	IS 1538 : 1993	Cast iron fittings for pressure pipes for water, gas and sewage — Specification (*third revision*)
	IS 3989 : 2024	Centrifugally cast (spun) spigot and socket pipes, fittings and accessories — Specification (*fourth revision*)
	IS 7181 : 1986	Specification for horizontally cast iron double flanged pipes for water, gas and sewage (*first revision*)
(8)	IS 1592 : 2003	Asbestos cement pressure pipes and joints — Specification (*fourth revision*)
	IS 1626	Asbestos cement building pipes and pipe fittings, gutters and gutter fittings, and roofing fittings — Specification:
	(Part 1) : 1994	Pipes and pipe fittings (*second revision*)
	(Part 2) : 1994	Gutters and gutter fittings (*second revision*)
	(Part 3) : 1994	Roofing fittings (*second revision*)
	IS 6908 : 1991	Asbestos cement pipes and fittings for sewerage and drainage — Specification (*first revision*)
(9)	IS 13592 : 2013	Unplasticized polyvinyl chloride (PVC-U) pipes for soil and waste discharge system for inside and outside buildings including ventilation and rain water Ssystem — Specification (*first revision*)
	IS 14333 : 2022	Polyethylene pipes for sewerage and industrial chemicals and effluent — Specification (*first revision*)
	IS 14735 : 1999	Unplasticized polyvinyl chloride (UPVC) injection moulded fittings for soil and waste discharge system for inside and outside buildings including ventilation and rain water system — Specification
	IS 15328 : 2003	Unplasticized non-pressure polyvinyl chloride (PVC-U) pipes for use in underground drainage and sewerage systems — Specification
(10)	IS 2470	Code of practice for installation of septic tanks:
	(Part 1) : 1985	Design criteria and construction (*second revision*)
	(Part 2) : 1985	Secondary treatment and disposal of septic tank effluent (*second revision*)
(11)	IS 1536 : 2023	Centrifugally cast (spun) iron pressure pipes for water, gas and sewage — (*fifth revision*)
(12)	IS 5329 : 1983	Code of practice for sanitary pipe work above ground for buildings (*first revision*)
(13)	SP 35 : 1987	Handbook on water supply and drainage with special emphasis on plumbing

	IS No.	*Title*
(14)	IS 2212 : 1991	Brick works — Code of practice (*first revision*)
(15)	IS 5455 : 1969	Specification for cast iron steps for manholes
(16)	IS 1726 : 1991	Cast iron manhole covers and frames — Specification (*third revision*)
	IS 12592 : 2002	Precast concrete manhole covers and frames — Specification (*first revision*)
(17)	IS 4111 (Part 1) : 1986	Code of practice for ancillary structures in sewerage system : Part 1 Manholes (*first revision*)
(18)	IS 15792 : 2008	Artificial recharge to ground water — Guidelines
(19)	IS 14961 : 2024	Surface water management in hilly areas (including rainwater harvesting) — Guidelines (*first revision*)
	IS 15797 : 2008	Roof top rainwater harvesting — Guidelines
(20)	IS 783 : 1985	Code of practice for laying of concrete pipes (*first revision*)
	IS 1742 : 1983	Code of practice for building drainage (*second revision*)
	IS 3114 : 1994	Code of practice for laying of cast iron pipes (*second revision*)
	IS 4127 : 2023	Laying of glazed stoneware pipes — Code of practice (*second revision*)
	IS 6530 : 1972	Code of practice for laying of asbestos cement pressure pipes
(21)	IS 2527 : 1984	Code of practice for fixing rainwater gutters and downpipes for roof drainage (*first revision*)
	IS 1729 : 2023	Sand cast iron spigot and socket pipes, fittings and accessories — Specification (*third revision*)
	IS 1626 (Part 1) : 1994	Asbestos cement building pipes and pipe fittings, gutters and gutter fittings and roofing fittings: Part 1 Pipe and pipe fittings (*second revision*)
	IS 1239 (Part 1) : 2004	Steel tubes, tubulars and other wrought steel fittings: Part 1 Steel tubes — Specification (*sixth revision*)
	IS 13592 : 2013	Unplasticized polyvinyl chloride (PVC-U) pipes for soil and waste discharge systems inside buildings including ventilation and rainwater system — Specification (*first revision*)
(22)	IS 2064 : 1993	Selection, installation and maintenance of sanitary appliances — Code of practice (*second revision*)
(23)	IS 18797 : 2024	Packaged sewage treatment plant — Specification
(24)	IS 18150 : 2023	Non-sewered on-site santitation system — Design, fabrication and installation of biodigesters for human waste decomposition — Code of practice
(25)	IS 9872 : 1981	Specification for precast concrete septic tanks
	IS 18666 : 2024	Rotationally moulded polyethylene septic tanks — Specification

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART E PLUMBING SERVICES (INCLUDING SOLID WASTE MANAGEMENT)

SECTION 3 SOLID WASTE MANAGEMENT

BUREAU OF INDIAN STANDARDS

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National Building Code Sectional Committee, CED 46

FOREWORD

This NBCS (Part E/Section 3) covers the solid waste management systems, assessment of per solid waste quantities and treatment of solid waste within the building, building complexes and their built environments.

In the first version of the Code formulated in 1970, as part of the National Building Code of India, three separate sections of this Part on 'Plumbing Services', were brought out, namely, Section 1 Water Supply, Section 2 Drainage and Sanitation, and Section 3 Gas Supply. These sections were subsequently revised in 1983 and in 2005.

In the second revision in 2005, the Part 9 was renamed as 'Plumbing Services (Including solid waste management)' and provisions on solid waste management were included for the first time under Section 1 which contained in it, Water supply, drainage and sanitation including solid waste management. Gas Supply was covered in Section 2 of Part 9 of the Code.

In the third revision in 2016, to comprehensively address the various and distinct features related to the plumbing aspects, this Part 9 was rearranged as follows:

Section 1 Water supply

Section 2 Drainage and sanitation

Section 3 Solid waste management

Section 4 Gas supply

The significant changes included in the 2016 version of NBC included: Elaborative provisions on solid waste management systems; inclusions of the provisions for persons with disabilities towards operation of refuse chutes; recommendation of electrically operated dumb waiters for 5 storied (and above); inclusion of assessment of per capita waste quantity; referencing the latest statutory rules and regulations; inclusion of detailed provisions on treatment methods; inclusion of annexes namely Annex A on municipal solid waste generation, Annex B on treatment of food wastes; and review of terminology.

In this revision, this publication has been renamed as National Building Construction Standards (NBCS).

The significant changes incorporated in this revision include:

a) References to the latest rules and regulations have been made;

b) Terminology clause has been reviewed and updated;

c) Circularity aspects of solid waste management has been included;

d) Domestic waste now covers all the remaining types of wastes generated;

e) Caution with respect to plastic waste by avoiding their down cycling is included;

f) Primary segregation and secondary segregation have been detailed in sorting at source;

g) Additional options towards efficient use of refuse chutes are included;

h) Treatment options namely aerobic processes, vermi-composting have been updated taking care of the best practices in these activities;

j) Provisions for the colour coding of waste bins have been incorporated to ensure proper segregation of solid waste;

k) Provisions have been incorporated for the treatment of biodegradable waste by household and commercial facilities; and

m) References to all the concerned Indian Standards have been updated.

Reference may also be made to the Municipal Solid Waste Management Manual — Part I — An Overview and Part II — The Manual, 2016, CPHEEO, Ministry of Urban Development, Government of India.

All Indian Standards, cross-referred to in the main text of this Section, are subject to revision. The parties to agreement based on this Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

As the regulation of land development and buildings is a State subject and is dealt by the States and local bodies such as urban local bodies within their jurisdiction through building regulatory documents like building regulations, building byelaws, and fire regulations, this document is voluntary in nature and is non-binding. The implementation depends on adoption by concerned parties or stipulations in a contract or by appropriate adoption by the concerned authorities.

For the purpose of deciding whether a particular requirement of this Section is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 'Rules for rounding off numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this Section.

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Important Explanatory Note for Users of this NBCS

In any Part/Section of this NBCS, where reference is made to **'good practice'** in relation to design, constructional procedures or other related information, and where reference is made to **'accepted standard'** in relation to material specification, testing, or other related information, the Indian Standards listed at the end of the Part/Section shall be used as a guide to the interpretation.

At the time of publication, the editions indicated in the standards were valid. All standards are subject to revision and parties to agreements based on any Part/Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

In the list of standards given at the end of a Part/Section, the number appearing within parentheses in the first column indicates the number of the reference of the standard in the Part/Section. For example:

a) Good practice [E-3(1)] refers to the Indian Standard(s) given at serial number (1) of the list of standards given at the end of this Part E/Section 3, that is, IS 9569 : 2022 'Solid waste management — Glossary (*first revision*)'.

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART E PLUMBING SERVICES (INCLUDING SOLID WASTE MANAGEMENT)

SECTION 3 SOLID WASTE MANAGEMENT

1 SCOPE

This NBCS (Part E/Section 3) covers the solid waste management systems, assessment of per capita solid waste quantities and treatment of solid waste within the building, building complexes and their built environments.

2 TERMINOLOGY

For the purpose of this Section, the following definitions shall apply, and for other terms those given in the accepted standard [E-3(1)] shall apply.

2.1 Anaerobic Digestion — A controlled process involving microbial decomposition of organic matter in the absence of oxygen.

2.2 Authorization — The consent given by the State Pollution Control Board or Pollution Control Committee, as the case may be, to the operator of a facility.

2.3 Biodegradable Substance — A substance that can be degraded by microorganisms into simpler stable compounds.

2.4 Biomethanation — A process which entails enzymatic decomposition of the organic matter by microbial action to produce methane rich biogas.

2.5 Collection — Lifting and removal of solid wastes from door step, collection points or any other designated position in segregated manner as per *Solid Waste Management Rules*/local bylaws.

2.6 Composting — A controlled process involving microbial decomposition of organic matter.

2.7 Construction and Demolition Waste — Wastes from building materials debris and rubble resulting from construction, re-modelling, repair and demolition operation.

2.8 Disposal — Final disposal of non-biodegradable and non-recyclable part of municipal solid wastes in accordance with the specified measures to prevent contamination of groundwater, surface water and ambient air quality.

2.9 Generator of Wastes — Persons or establishments generating municipal solid wastes.

2.10 Landfilling — Disposal of residual solid wastes on land in a facility designated and with protective measures against pollution of groundwater, surface water and air fugitive dust, wind-blown litter, bad odour, fire hazard, bird menace, pests or rodents, greenhouse gas emissions, slope instability and erosion.

2.11 Leachate — Liquid that seeps through solid wastes or other medium and has extracts of dissolved or suspended material from it.

2.12 Municipal Authority — Municipal Corporation, Municipality, Nagar Palika, Nagar Nigam, Nagar Panchayat, Municipal Council including notified area committee (NAC) or any other local body constituted under the relevant statutes and, where the management and handling of municipal solid waste is entrusted to such agency.

2.13 Municipal Solid Waste — Commercial and residential wastes generated in municipal or notified areas in either solid or semi-solid form, excluding industrial hazardous wastes and construction and demolition waste but including treated bio- medical wastes.

2.14 Operator of a Facility — A person who owns or operates a facility for collection, segregation, storage, transportation, processing and disposal of municipal solid wastes and also includes any other agency appointed as such by the municipal authority for the management and handling of municipal solid wastes in the respective areas.

2.15 Pelletization — A process whereby pellet are prepared which are small cubes or cylindrical pieces made out of solid wastes and includes fuel pellets which are also referred as refuse derived fuel.

2.16 Processing — The process by which solid wastes are transformed into new or recycled products.

2.17 Recycling — The process of transforming segregated solid wastes into raw materials for producing new products, which may or may not be similar to the original products.

2.18 Segregation — To separate the municipal solid wastes into the groups of bio-degradable, recyclables, hazardous and inert wastes.

2.19 Storage — The temporary containment of municipal solid wastes at a designated place in a manner so as to prevent littering, attraction to vectors, stray animals and excessive foul odour.

2.20 Transportation — Conveyance of municipal solid wastes from place to place hygienically and covered through specially designed transport system so as to prevent foul odour, littering, unsightly conditions and accessibility to vectors.

2.21 Vermi-composting — A process of using earthworms for conversion of biodegradable wastes into compost.

3 GENERAL

3.1 Solid waste is generated from various human activities and is normally disposed as useless and unwanted by the primary user because of end-of-life condition.

Broadly, depending upon the type of building and built environment, it includes solid or semi-solid domestic waste, such as sanitary waste, commercial waste, office waste, catering and market waste and other non-residential wastes, street sweepings, silt removed or collected from the surface drains, horticulture waste and construction and demolition waste. Further, there may be industrial hazardous waste, bio-medical waste and e-waste.

The primary objective of solid waste management is to collect, treat and dispose of solid wastes in an environmentally and socially satisfactory manner using the most economical means available. Ideally, solid waste should not contain faecal matter or urine but despite all precautions, some pathogens and chemical residues inevitably may be present in the waste. Uncontrolled or poorly managed intermediate decomposition of organic components of solid waste can contaminate air, water and soil resources. Implementation of integrated solid waste management practices benefits substantially, both the public health and the quality of the environment. It is also an integral part of an efficient solid waste management (SWM) system to create circularity by ensuring the maximum recycling and recovery of solid waste generated and avoiding/reducing of landfillable waste and dumping.

3.2 Based on source of generation, solid waste can be broadly categorized as follows:

a) *Domestic waste* — It is generated in residential units, commercial and educational entities; and consists of food wastes, paper, cardboard, plastics, textiles, leather, yard wastes, wood, glass, metals, ashes, special wastes (for example, bulky items, consumer electronics, white goods, batteries, oil and tyres), and household hazardous wastes including domestic sanitary, expired/discarded household usage chemicals, paints, automobiles batteries, household cleaners, swimming pool chemicals, and domestic e-waste;

b) *Industrial waste* — It is generated in manufacturing units, fabrication plants, construction sites, power and chemical plants; and consists of packaging, hazardous wastes, ashes, special wastes, wood, steel, concrete, dirt, etc;

c) *Institutional and commercial waste* — It is generated in schools, hospitals, prisons, government centers, stores, hotels, restaurants, markets, office buildings, etc; and consists of domestic wastes, paper, cardboard, plastics, wood, glass, metals, special wastes and hazardous wastes; and

d) *Horticulture waste* — It is generated in landscaping, parks, orchards, dairies, and consists of street sweepings; landscape and tree trimmings; etc.

3.3 Based on suitability for handling and disposal, solid waste can also be categorized as follows:

a) *Garbage* — Garbage is the term applied to animal and vegetable waste resulting from the handling, storage, sale, cooking and serving food. Such wastes contain putrescible organic matter, which produces strong odours and therefore attracts rats, flies and other vermin. It requires immediate attention in its storage, handling and disposal;

b) *Municipal waste* — Municipal waste includes waste resulting from municipal activities and services such as street wastes, dead animals, market wastes and abandoned vehicles. However, the term is commonly applied in a wider sense to incorporate domestic wastes and commercial wastes;

c) *Hazardous wastes* — Hazardous wastes may be defined as wastes of industrial, institutional or consumer origin which because of their physical, chemical or biological characteristics are potentially dangerous to human and the environment. It includes any waste that exhibits one of the hazardous characteristics, such as ignitability, corrosivity, reactivity, or toxicity, whether alone or when in contact with other wastes or substances. In some cases although the active agents may be liquid or gaseous, they are classified as solid waste because they are confined in solid containers. Typical examples are solvents, paints and pesticides whose spent containers are frequently mixed with municipal wastes. Good waste management should ensure that hazardous wastes are stored, collected, transported and disposed of separately, preferably after suitable treatment to render them innocuous;

A sub-category of household hazardous waste, is post-consumer utilization waste which qualifies as hazardous waste when discarded. It includes household chemicals and other consumer products used in home care, personal care, automotive care, pest control, etc. These products exhibit characteristics of reactivity, ignitability, corrosivity, toxicity, or persistence;

d) *Bio-medical waste* — Bio-medical waste is any waste, which is generated during the diagnosis, treatment or immunization of human beings or animals or in research activities pertaining thereto or in the production or testing of biologicals. This waste is highly infectious and can be a serious threat to human health if not managed in a scientific and discriminate manner. It may include wastes like sharps, soiled waste, disposables, anatomical waste, cultures, discarded medicines, chemical wastes, etc. It has been estimated that hospitals generate total waste at a rate of 1.5 kg per bed per day, out of which approximately 25 percent is bio-medical waste. Generally, these wastes are handed over to common bio-medical treatment and disposal facilities for suitable treatment and final disposal.

Biological means any preparation made from organisms or microorganisms or product of metabolism and biochemical reactions intended for use in the diagnosis, immunization or the treatment of human beings or animals or in research activities pertaining thereto.

Bio-medical waste treatment facility means any facility wherein treatment, disposal of bio-medical waste or processes incidental to such treatment and disposal is carried out, and includes common treatment facilities. The common bio-medical treatment facilities are set up based on the need for ensuring environmentally sound management of bio-medical waste keeping in view the techno-economic feasibility and viable operation of the facility with minimal impacts on human health and environment.

All healthcare establishments including hospitals, research facilities and laboratories generate solid waste in course of performing their intended functions. 75 percent to 90 percent of such solid waste is non-risk healthcare waste, comparable to domestic waste. It requires minimal treatment and is safely handled by housekeeping staff. The remaining 10 percent to 25 percent of healthcare waste is designated as bio-hazardous waste and is designated bio-medical waste. It carries a variety of health risks in its handling and disposal. It is handled by trained staff and many safety devices and apparels are deployed. In addition, bio-medical waste includes the waste originating from minor or scattered sources, such as that produced in the course of healthcare undertaken in the home (dialysis, insulin injections, etc);

e) *Plastics* — Plastics, due to their non-biodegradable nature, versatility in use and impact on environment, can be grouped under a different category of solid waste. Significant quantity of the plastic waste generated in our country is recycled and used in the manufacture of various plastic products. Careless disposal of plastic in various forms chokes drains, blocks the porosity of the soil, causes problems for groundwater recharge, disturbs the soil microbe activity, contaminates foodstuff and when ingested by animals, it can kill them; apart from impacting the marine life when they end up in river/water bodies. Down cycling of plastics degrades their quality in each cycle and hence the same should be least preferred; and

f) *E-waste* — It refers to discarded electrical and electronic equipment and their components that are no longer in use or functional. It encompasses a wide range of household appliances, office equipment, and related devices. E-waste contains hazardous substances such as lead, mercury, cadmium and beryllium, which can contaminate soil, water and air, thereby adversely affecting ecosystems and human health. Proper e-waste management through formal recycling processes enables recovery of valuable materials, reduces environmental pollution, and minimizes health hazards.

3.4 Efficient collection and disposal of domestic garbage from a building or activity area is of significant importance to public health and environmental sanitation and, therefore, an essential part of the built environment. Notwithstanding the provisions given herein, the solid waste management shall have to comply with relevant statutory Rules and Regulations in force from time-to-time. The provisions of the following shall, as amended from time to time, govern the procedures for handling, treatment, etc, of solid wastes as applicable to the concerned building occupancy:

a) *The Environment* (*Protection*) *Act*, 1986;

b) *The Solid Waste Management Rules*, 2016;

c) *The Bio-Medical Waste Management Rules*, 2016;

d) *The E-Waste* (*Management*) *Rules*, 2022;

e) *The Battery Waste Management Rules*, 2022;

f) *The Hazardous and Other Wastes* (*Management and Transboundary Movement*) *Rules*, 2016;

g) *Plastic Waste Management* (*Amendment*) *Rules,* 2024; and

h) *Environment* (*Construction and Demolition*) *Waste Management Rules,* 2025.

NOTE — Radioactive wastes are covered under the provisions of *The Atomic Energy Act*, 1962 and rules made thereunder and the enforcement agency for these is Atomic Energy Regulatory Commission (AERC).

3.5 The provisions relating to solid waste management given in 4 are applicable to municipal solid waste and specifically exclude the hazardous chemical wastes, bio- medical waste and radioactive waste.

4 SOLID WASTE MANAGEMENT SYSTEMS

4.1 ln designing a system dealing with collection of domestic garbage for a built premises/community/environment, the aim shall be to provide speedy and efficient conveyance as an essential objective for design of the system. The various available systems may be employed in accordance with 4.2 to 4.4, which may be adopted individually or in combination as appropriate in specific situations.

4.1.1 The basic stages of the municipal solid waste management system include the following:

a) Waste sorting at source, collection and transportation;

b) Resource recovery through centralized sorting and recycling;

c) Resource recovery through waste processing, that is, recovery of energy; and

d) Waste transformation without recovery.

4.1.2 The functional elements of municipal solid waste management system include the following:

a) *Waste generation* — Activity in which the waste gets generated as material no longer having any value to the primary consumer;

b) *Waste handling, sorting, storage and processing at site* — Waste handling and sorting involves the activities associated with management of waste until they are placed in storage container for collection;

c) *Collection* — Gathering of solid wastes in segregated form including transportation; and

d) *Transfer and transport* — Transfer of waste from smaller collection vehicle to larger transport equipment and subsequent transport of wastes over long distances to a designated processing or disposal site.

4.2 Sorting at Source

Sorting shall be planned based on the existing markets for recyclable materials. It is preferable to have coloured-bin system based on the usage of the facility and the types of the waste likely to be generated in the facility. Colour code for bins/bags-shall be as follows:

a) Green — for bio-degradable waste;

b) White or Blue — for dry waste (excluding biomedical waste/hazardous waste); and

c) Red — for bio-medical waste and rejects.

All bins shall be covered with lid. Reference shall be made to good practice [E-3(2)]_for detailed provisions on the colour coding of bins.

Common sorting methods involve sorting into;

a) dry recyclable materials, for example, glass, paper, plastics, metals, etc;

b) bio-waste and garden waste;

c) bulky waste;

d) hazardous material in household waste;

e) construction and demolition waste; and

f) mingled MSW (mixed waste).

In case of sorting not done at source, it is required to plan centralized sorting. The types of sorting that may be adopted, are:

a) Hand sorting from a raised picking belt; and

b) Mechanized sorting facilities using magnetic and electric field separation, density separation, etc.

Sorting at source (also known as primary segregation) normally recovers most of the recyclable materials for reuse. However, a small fraction of such materials may escape the sorting process. Sorting may therefore be also undertaken just prior to waste processing (secondary segregation), waste transformation or landfilling to recover such recyclable materials.

Wherever manual sorting is adopted, care shall be taken to ensure that sorters are protected from all disease pathways and work in hygienic and safe conditions using necessary safety gear including aprons, protective mask, gloves and boots/shoes. The movement of waste shall be planned by suitable mechanism and building shall be planned for easy movement of waste by means of garbage/material lift, ramps, etc, meeting the good engineering practices and minimum handling of waste as well as no contact with ground during the whole process or littering.

4.3 Refuse Chute System

4.3.1 *General*

Refuse chute system is a convenient and safe mode of transportation and collection of domestic solid wastes from buildings exceeding 5 storeys from floors at different heights. The refuse is received from the successive floor through the inlets located on the vertical system of pipes that convey refuse through it and discharge it into the collecting chamber, located at ground level, from where the refuse is cleared at suitable intervals. This system has got four functionally important components, namely, the chutes, the inlet hopper, the collection chamber and the cleaning and disinfecting arrangements.

The chute may be carried through service shafts meant for carrying drainage pipes. However, the location shall be mostly determined by the position of the inlet hopper and the collecting chamber that is most convenient for the user. It should also be considered to locate the chute away from living rooms in order to avoid noise and smell nuisance. The internal diameter of the chute shall be at least 300 mm.

In individual chute system, the inlet hopper shall be located in the passage near the kitchen and in the common chute system towards the end of the common passage. Natural ventilation should be adequate to prevent any possible odour nuisance. There should be adequate lighting at this location. For ground floor (floor 1), the inlet hoppers may be placed at a higher level, but should be easily accessible. The access to the refuse chute shall be provided from well ventilated and well illuminated common corridor or lobby and preferably it should not be located opposite or adjacent to entry of individual flats or lift.

4.3.2 *Opening for Feeding of Refuse Chute*

Opening, with top or bottom hinged shutters with appropriate lockable latch, shall be provided for convenient accessing of the refuse chute by users. It facilitates total building garbage collection at one single point and provides separate collection for dry and wet garbage. The opening of the refuse chute may have separate receptacles for both wet and dry waste. Mixed waste disposal may not be allowed. For wet waste, there should be a provision for collection of leachate. Chute system shall have the following features:

a) Sanitation system for internal cleaning of chutes, with sprinklers at every floor intake level, with disinfectant cleaning, which may preferably be automatic in operation;

b) Exhaust system with 25 to 35 air changes per hour;

c) Discharge end fire resistant door;

d) Chute may be of masonry, R.C.C pipe, asbestos cement pipe or suitable non- corrosive material, preferably stainless steel. It should be rigid with smooth internal finish, high ductility and alkali/acid resistant properties {*see also* good practice [E-3(3)]};

e) For fire rating, reference should be made to relevant clauses of Part F ‘Fire and Life Safety’ of this NBCS;

f) Fire sprinklers shall be provided inside chute;

g) Vent shall be installed at roof level to remove foul smell and gases generated;

h) Chute should discharge to trolley directly;

j) Necessary automation of the system may be planned to avoid malfunction by manual operation; and

k) All care shall be taken for ensuring accessibility to the chute for persons with disabilities. The opening of the chute shall not be higher than 700 mm and there shall be a clear space of minimum 1 500 mm × 1 500 mm in front of the chute opening to gain easy access even for persons using wheelchairs. There may be high colour contrast provided around the chute opening to make it easy to identify it. The flooring in front of the chute opening may be texturally highly different from the rest of the floor.

4.3.3 *Refuse Collection Chamber*

The collection chamber may be located in ground floor or basement level, provided appropriate arrangement is made for drainage of the collection pit by gravity flow to ensure its dryness, an appropriate ramp access is provided for convenient removal of garbage from the collection pit, and satisfactory ventilation is provided for escape of gas and odour.

The floor of the chamber shall be provided with drainage through a 100 mm diameter trap and screen to prevent any solid matters flowing into the drain and the drain shall be connected to the sewer line. The floor shall be finished with smooth hard surface for convenient cleaning.

The height of the collection chamber and vertical clearance under the bottom level of garbage chute shall be such that the garbage trolley can be conveniently placed.

The collection chamber shall be provided with appropriate shutter to prevent access of scavenging animals like cattle, dogs, cats and rats.

Building owners and associations should be encouraged about proper usage of this system which otherwise can be clogged and malfunction. They may also be encouraged to have a single agent/person for door to door collection having effective segregation at source and ensuring hygienic conditions and authorizing only such agent/person operate the chute. This system is quite effective in industrial and commercial buildings which are professionally controlled all the time and also typically having one type of waste or largely dry waste only.

4.3.4 *Refuse Collection Room*

The refuse collection room should be planned in ground or basement level with appropriate ventilation and proper drainage. The room should have access for vehicle or trolley transfer of garbage.

4.3.5 *See also* accepted standards [E-3(4)].

4.4 Dumb-Waiter or Service Lift

In high rise buildings with more than 5 storeys, electrically operated dumb-waiters may be used for carrying domestic garbage in packets or closed containers. For handling of garbage by dumb-waiters in a building, a garbage chamber shall have to be provided either at ground floor or basement level and the provisions of garbage collection chamber for chute as given in 4.3 shall apply.

5 ASSESSMENT OF PER CAPITA WASTE QUANTITY

5.1 For purposes of this Section, the following municipal refuse generation rates are recommended:

a) Residential refuse : 0.3 kg/capita/day to 0.6 kg/capita/day
b) Commercial refuse : 0.2 kg/capita/day to 0.6 kg/capita/day
c) Street sweepings : 0.34 kg/capita/day to 0.7 kg/capita/day
d) Institutional refuse : 0.25 kg/capita/day to 0.6 kg/capita/day

Out of the total solid waste generated, 40 percent may be considered inorganic waste, which includes a proportion of inert waste, and 60 percent as organic waste. The knowledge of chemical characteristics of waste is important for selecting and designing the waste processing and disposal facilities.

5.2 These generation rates are subject to considerable site-specific factors, such as degree of urbanization, economic level, geographical terrain and other site-specific factors and are required to be supported by field data studies. The waste contains a high percentage of ash and fine earth. The calorific value of Indian solid waste generally varies between 800 kcal/kg and 1 000 kcal/kg and the density varies between 300 kg/m^3 and 500 kg/m^3.

5.3 Other than municipal solid waste, the following types of waste may also be generated in urban centres:

a) *Industrial waste* — Hazardous and non-hazardous waste from industrial areas within municipal limits;

b) *Bio-medical waste* — Waste from hospitals, slaughter houses, etc;

c) *Thermal power plant waste* — Fly ash from coal-based electricity generating plant within municipal limits;

d) *Effluent treatment plant waste* — Sludge from sewage treatment plants and industrial effluent treatment plants;

e) *Construction and demolition waste* — Generated from demolition, remodelling of existing buildings and new construction; and

f) *Other wastes* — Special wastes from non-conforming areas or special units.

All waste streams shall be managed by their own waste management system.

6 TREATMENT

6.1 Garbage collected at one location may be treated for organic portion, and inorganic portion shall be handed over to vendors carrying out recycling. Organic waste generated in building/premises/community/environment may be treated and reused as manure and as per *The Solid Waste Management Rules*, 2016, preferably should be recycled at source site itself for bulk waste generators. The norms prescribed by the pollution board authorities shall be followed, keeping hygiene and safe operation for the working/operating people.

Biological or thermal treatment of waste can result in recovery of useful products such as compost or energy.

6.2 Biological Processes

Biological treatment involves using microorganisms to decompose the biodegradable components of waste. The following two types of processes may be typically used, the former being used more commonly:

a) *Aerobic processes* — It may comprise composting, aerated static pile composting and in-vessel composting; vermi-culture, etc. In the aerobic process the utilizable product is compost and high microbial liquid drained out which can be recollected and used as liquid manure after dilution or as for sprinkling over new manure to quicken the process as bioenzyme;

b) *Anaerobic processes* — It may comprise low-solids anaerobic digestion (wet process), high solids anaerobic digestion (dry process) and combined processes. In the anaerobic process the utilizable product is methane gas (for energy recovery).

6.2.1 *Composting*

Decomposition and stabilization of organic waste matter is a natural phenomenon. Composting is an organized method of producing compost manure by adopting this natural phenomenon.

a) *Manual composting* — It is an anaerobic method conventionally carried out in pits. Initially the waste is anaerobically stabilized in pits where alternate layers of solid waste and night soil are laid. The pit is completely filled and a final soil layer is laid to prevent fly breeding, entry of rain water into the pit and for conservation of the released energy. The material is allowed to decompose for 4 to 6 months after which the stabilized material is taken out and used as compost;

b) *Mechanical composting* — Mechanical processes are preferred where higher labour costs and limitations of space exist. It is the process using a combination of aerobic and anaerobic decomposition in enclosed containers. Organic wet waste composter is used where raw refuse is composted in large vessel, which are turned at intervals by mobile pedals or plates. Several other processes have now been developed, using different methods of processing of solid waste, using different designs of digester.

   Latest technology uses electrically operated rapid processing organic waste convertor with different capacities as mechanical composters. The organic wet and dry waste is separated and shredder is used to homogenize the materials and blenders are used under controlled temperature and bio-enzyme addition in closed containers. These output manure may be used for horticultural/agriculture works; and

c) *Vermi-composting* — Vermi-compost treatment shall be provided to the organic wastes in composting pits located in shade. The pits shall be used to receive the garbage in a predetermined (periodic) cyclic order (for example, 5 pits to receive garbage in 5 days and these 5 pits together accepting daily load of garbage). The gross area of the composting pits may be about 0.1 m^2 per person.

   The site for vermi-composting shall be enclosed from all sides with appropriate fencing (for keeping scavenging animals away) and provided with a small door for accessing the enclosed premises.

   Composting pits shall be constructed either under the shade of trees (except Neem tree) or created under sheeting or shade-net, so as to keep the pits under shade. The pits shall be easily accessible for convenience of receiving of garbage through trolleys.

   The composting pits shall be made in a manner that the pits do not have the risk of inundation by water. This may be achieved by appropriately raising the base level of the pit and providing weep holes from sides. Height of side walls of compost pits shall be 0.6 m to 0.75 m high. However, the same can be lined to avoid any contamination of ground waste or ground by providing proper slope and drainage arrangement; optionally, empty green coconuts (after the removal of coconut water) is used as bottom layer considering their long life and ability to decompose at a very slow pace.

   Initiation of composting pits shall be done by providing a 75 mm thick layer of cow dung (fresh or partially decomposed), spreading 1 kg of vermi-compost and covering it with 75 mm to 100 mm thick layer of dry leaves/grass, etc, and sprinkling of water and allowing to decompose naturally for about 10 to 15 days.

Sorted garbage free from inert and toxic matters shall be applied in the composting pit in layers of 75 mm and spread, and covered with a layer of 75 mm thick dry leaves, followed by sprinkling of water or, by sprinkling cow urine or cow dung plus water slurring or bioenzymes prepared by mixing cow waste and jaggery and kept covered for a few days for fermentation. Apart from these, microbial culture application may also be considered for odour control and rapid biodegradation.

The compost may be removed from the bottom of the compost pit after intervals of 3 months to 6 months. The compost so made needs to be taken out and aired for 1 to 2 days post that it stabilizes fully and is ready to be used after sieving it. May be used in appropriate horticultural and related applications.

See also accepted standard [E-3(5)] for manure grade municipal solid waste compost.

6.3 Thermal Processes

Thermal treatment involves conversion of waste into gaseous, liquid and solid conversion products with concurrent or subsequent release of heat energy.

Three types of systems can be adopted, namely:

a) *Combustion Systems* (*Incinerators*) — Thermal processing with excess amounts of air;
b) *Pyrolysis Systems* — Thermal processing in complete absence of oxygen (low temperature); and
c) *Gasification Systems* — Thermal processing with less amount of air (high temperature).

6.4 Land Filling

6.4.1 Disposal of waste on lands identified for the purpose is typical of this method of waste disposal. The depth of filling depends upon the site topography and location and varies from deep to shallow filling. A municipal solid waste landfill plant is an engineered facility used for disposal of solid waste. Landfills in which municipal waste is placed are designated as 'MSW landfills'.

The main considerations in respect of landfill sites are:

a) Specifications for landfill sites;
b) Site selection;
c) Facilities at site; and
d) Specification of land filling.

6.4.2 Improper landfill generally impacts the environment in the following ways:

a) Ground water contamination by the leachate generated by the waste dump;
b) Surface water contamination by the run-off from the waste dump;
c) Bad odour, pests, rodents and wind-blown litter in and around the waste dump;
d) Generation of inflammable gas (for example, methane) within the waste dump;
e) Bird menace above the waste dump which affects flight of aircraft;
f) Fires within the waste dump;
g) Erosion and stability problems relating to slopes of the waste dump;
h) Epidemics through stray animals;
j) Acidity to surrounding soil; and
k) Release of greenhouse gas.

6.5 Some recycling/treatment methods for food waste are given in Annex B for guidance.

6.6 *See also* accepted standards [E-3(6)] for solid waste management, and for analysis and testing of solid wastes.

6.7 Households and communities shall be highly encouraged to practice various methods such as home composting, bio-methanation, etc, listed in Annex C of good practice [E-3(7)] for treatment of bio-degradable waste. In case of treatment of bio-degradable waste at community level, conventional facilities/ modern technologies such as composting, biogas plants, biomethanation facilities, etc, as provided by Urban Local Bodies/Regulatory Authorities shall be used.

6.8 Commercial facilities like markets, malls, where group of wet waste generators are clustered, shall be highly encouraged to practice various methods such as community composting/bio-methanation etc, listed in Annex B of good practice [E-3(8)] for treatment of bio-degradable waste. In case of treatment of bio-degradable waste at local level, conventional facilities/modern technologies such as composting, biogas plants, bio-methanation facilities or any other suitable technology as provided by urban local bodies/regulatory authorities shall be used.

6.9 Other/special wastes shall be dealt with in accordance with the statutory provisions in respect of the same (*see* **3.4**). See various other good practice [E-3(9)] for segregation, collection and treatment of different types of wastes.

ANNEX A

(*Foreword*)

MUNICIPAL SOLID WASTE GENERATION

A-1 WASTE GENERATION

A-1.1 The typical type of wastes generated may be as follows:

Sl No. (1)	*Types of Solid Waste* (2)	*Description* (3)	*Sources* (4)
i)	Food waste (garbage)	Wastes from the preparation, cooking, and serving of food. Market refuse, waste from the handling, storage, and sale of produce and meats and vegetable	Households, institutions and commercial such as hotels, stores, restaurants, markets, etc
ii)	Rubbish	a) *Combustible* (*primary organic*) — Paper, cardboard, cartons wood, boxes, plastics, rags, cloth, bedding, leather, rubber, grass, leaves, yard trimmings b) *Non-combustible* (*primary inorganic*) — Metals, tin cans, metal foils dirt, stones, bricks, ceramics, crockery, glass bottles, other mineral refuse	-do-
iii)	Ashes and residues	Residue from fires used for cooking and for heating buildings, cinders, clinkers, thermal power plants	-do-
iv)	Bulky waste	Large auto parts, tyres, stoves refrigerators, others large, appliances, furniture, large crates, trees, branches, palm fronts, stumps	-do-
v)	Street waste	Street sweepings, dirt, leaves, catch basin dirt, animal droppings, contents of litter receptacles, dead animals	Streets, sidewalks, alleys, vacant lots, etc
vi)	Dead animals	*Small animals* — Cats, dogs, poultry, etc *Large animals* — Horses, cows, etc	-do-
vii)	Construction and demolition waste	Lumber, roofing and sheathing scraps, crop residues, rubble, broken concrete, plaster, conduit pipe, wire, insulation, etc	Construction and demolition sites, remodelling, repairing sites
viii)	Industrial waste and sludge	Solid wastes resulting from industry processes and manufacturing operations, such as food processing wastes and boiler House cinders, wood, plastic and metal scraps and shaving, etc. Effluent treatment plant sludge of industries and sewage treatment plant sledges, coarse screening, grit and septic tank	Factories, power plants, treatment plants, etc
ix)	Hazardous wastes	Pathological waste, explosives, radioactive material, toxic waste, etc	Households, hospitals, institution, stores, industry, etc
x)	Horticulture wastes	Tree-trimmings, leaves, waste from parks and gardens, etc	Parks, gardens, roadside trees, etc

A-1.2 The typical quantity of waste generated measured per capita in urban areas may be as follows:

Sl No. (1)	*Population Range Million* (2)	*Average Per Capita Value* kg/capita/day (3)
i)	0.1 to 0.5	0.21
ii)	0.5 to 1.0	0.25
iii)	1.0 to 2.0	0.27
iv)	2.0 to 5.0	0.35
v)	More than 5.0	0.50

A-2 INDUSTRIAL WASTE

The major generators are thermal power plants, integrated iron and steel mills, non- ferrous industries, pulp and paper industries and fertilizer and allied industries. Following are the source and quantum of generation of some major industrial wastes.

Sl No. (1)	*Name of Industry* (2)	*Quantity Million tonne per annum* (3)
i)	Steel and blast	35.0
ii)	Brine mud	0.02
iii)	Copper slag	0.016 4
iv)	Fly ash	30.0
v)	Kiln dust	1.6
vi)	Lime sludge	3.0
vii)	Mica scraper waste	0.005
viii)	Phospho-gypsum	4.5
ix)	Red mud/bauxite	3.0

A-3 SLAUGHTER HOUSE WASTE

Slaughtering of animals generates waste consisting of non-edible offal (lungs, large intestines, etc), stomach/intestinal contents, dung, sludge from waste water and bones, etc. These have to be disposed of by methods like rendering/controlled incineration/burial/composting/anaerobic digestion, etc. The estimated waste generation may be as per the following:

Sl No. (1)	*Type of Slaughter House* (2)	*Annual Capacity* (3)	*Dry Waste Generated* (tonne per day) (4)
i)	Large	Large animals more than 40 000 Small animals more than 600 000	6 to 7
ii)	Medium	Large animals — 10 001 to 40 000 Small animals — 100 001 to 600 000	2 to 6
iii)	Small	Large animals up to 10 000 Small animals up to 100 000	0.5 to 1.0

NOTES

1 Animals are commonly classified as 'large' or 'small' according to species, which affects handling, processing, and facility requirements.

2 Large animals typically include bovines such as cattle and buffalo, as well as horses and camels.

3 Small animals generally refer to species like sheep, goats, and calves. Processing these animals is less equipment-intensive than processing large animals.

A-4 BIO-MEDICAL WASTE

The waste generated from medical activities can be hazardous, toxic and even lethal because of their high potential for disease transmission.

The components of bio-medical waste include:

a) Human anatomical waste (tissues, organs, body parts, etc);

b) Animal waste (as above, generated during research/experimentation, from veterinary hospitals, etc);

c) Microbiology and biotechnology waste, such as, laboratory cultures, microorganisms, human and animal cell cultures, toxins, etc;

d) Waste sharps, such as hypodermic needles, syringes, scalpels, broken glass, etc;

e) Discarded medicines and cyto-toxic drugs;

f) Soiled waste, such as dressing, bandages, plastercasts, material contaminated with blood, etc;

g) Solid waste (disposable items like tubes, catheters, etc, excluding sharps);

h) Liquid waste generated from any of the infected areas;

j) Incineration ash; and

k) Chemical waste.

The estimated generation of total waste is 1.5 kg/bed and the estimated generation of bio-medical waste at 25 percent of total waste generation.

ANNEX B

(*Foreword and Clause* 6.5)

TREATMENT OF FOOD WASTE

B-1 FOOD WASTE

Food waste represents a large percentage of the solid waste. For establishments that serve food, the waste generated per meal varies significantly; however, on average, 60 g of food waste is generated per meal served when both pre-service and post-service waste is considered. The organic nature of food waste makes it unsuitable for disposal by landfills, though it is bio-degradable.

In order to use the nutrient and calorific value of the food waste, it is collected, stored and then recycled. When collecting, it should be ensured that food waste does not enter the drainage system. When providing temporary storage, the risk of physical contamination of kitchen working areas should be avoided. It should be a separate ventilated room with 6 total air changes per hour. In hot climates, it shall be cooled to a temperature of 24 °C to minimize odour generation. The storage area should be cleaned at least once every day.

A brief overview of some of the ways of food waste recycling/treatment is given in **B-2** to **B-4**. Before recycling/treatment, it requires non-organic materials to be removed from food waste.

B-2 FEEDING ANIMALS

Food discards can be made available for feeding animals. This may involve provisions for farmers, zoos, piggeries (very common) and many other applications. Converting food discards to animal feed and pet food is common and a suitable option for recycling food scraps. Vegetable market waste to cow shelters, slaughter house waste to dog shelters, food waste from events, weddings, etc to piggeries, fish market waste to ducks, etc are suggested aiding to circularity.

B-3 INDUSTRIAL USES

Food waste can be used in the rendering industry for converting these materials to soaps, cosmetics and biodiesel fuel.

B-4 ANAEROBIC DIGESTION

This process involves breaking down organic matter in an oxygen-free environment in order to generate biogas, which is a combination of methane and carbon dioxide. The methane is burned for energy. The material that remains after digestion (digestate) should then be composted aerobically to complete the process and produce a valuable soil amendment.

Food waste drying system can provide a fast, simple and user friendly onsite process for decomposing and dehydrating food scraps into rich soil sediments. These systems do not require microorganisms, enzymes, fresh water or other additives.

Food cycler sterilizes, deodorizes and turns potentially harmful food scraps into safe, sterilized compost that can be reused as a soil amendment. It is a multi-phase, onsite organic food waste recycling machine that dehydrates and converts daily food waste into a sterile biomass. The sterilization process takes place at 82 °C and reduces the waste volume by 85 percent to 93 percent. After sterilization, the food waste is converted into compostable humus-rich, high-carbon organic particles. The by-products of the process can be reused as soil amendment, compost accelerant, biofuels, animal feed, pet food, etc. Further benefits can be obtained by mixing the water produced from the food cycler units with potable or non-potable supplies to reduce the amount of water used from mains for use in gardens and landscaping.

LIST OF STANDARDS

The following list records those standards which are acceptable as ‘good practice’ and ‘accepted standards’ in the fulfillment of the requirements of this NBCS. The latest version of a standard shall be adopted at the time of enforcement of this NBCS. The standards listed may be used for conformance with the requirements of the referred clauses in this NBCS.

	IS No.	*Title*
(1)	IS 9569 : 2022	Solid waste management — Glossary (*first revision*)
(2)	IS 16557 : 2016	Solid waste management — Segregation, collection and utilization at household/community level — Guidelines
	IS18520 : 2024	Solid waste management — Segregation, collection and utilization at commercial facilities (shops, markets, malls etc) — Guidelines
(3)	IS 6924 : 1973	Code of practice for the construction of refuse chutes in multi-storeyed buildings
(4)	IS 12402	Specification for mobile containers for solid waste:
	(Part 1) : 1988	General characteristics
	(Part 2) : 1988	Methods of test
	IS 12647 : 2021	Solid waste management system collection equipment – Requirements and Guidelines (*first revision*)
	IS 12662	Guidelines for use of vehicles for collection and transportation of solid wastes:
	(Part 1) : 2021	Selection of vehicles (*first revision*)
	(Part 2) : 2025	Guidelines for maintenance (*first revision*)
(5)	IS 16556 : 2016	Specification for municipal solid waste compost, manure grade
(6)	IS 9234	Methods of sampling and test for solid waste:
	(Part 1) : 2021	Preparation of samples for analysis (*first revision*)
	(Part 2) : 2021	Determination of moisture content (excluding industrial solid wastes) (*first revision*)
	(Part 3) : 2023	Chemical analysis (excluding industrial solid wastes) (*first revision*)
	IS 16557 : 2016	Solid waste management — Segregation, collection and utilization at household/community level — Guidelines
	IS 18520 : 2024	Solid waste management — Segregation, collection and utilization at commercial facilities (shops, markets, malls etc) — Guidelines
(7)	IS 16557 : 2016	Solid waste management — Segregation, collection and utilization at household/community level — Guidelines
(8)	IS 18520 : 2024	Solid waste management — Segregation, collection and utilization at commercial facilities (shops, markets, malls etc) — Guidelines
(9)	IS 17862 : 2022	Storage, collection, dismantling and recycling of E-waste — Guidelines
	IS 14534 : 2023	Plastics — Recovery and recycling of plastics waste — Guidelines (*second revision*)

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NATIONAL BUILDING CONSTRUCTION STANDARDS

PART E PLUMBING SERVICES (INCLUDING SOLID WASTE MANAGEMENT)

SECTION 4 GAS SUPPLY

BUREAU OF INDIAN STANDARDS

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National Building Code Sectional Committee, CED 46

FOREWORD

This NBCS (Part E/Section 4) covers the safe use of gases for purposes like fuel, lighting and medical in buildings.

The use of gases for fuel and lighting purposes in buildings is becoming more and more common in different parts of the country, and with the advent of new petroleum complexes and piped gas system, community gas supply is bound to become one of the important services like electricity and water supply in buildings.

The use of liquefied petroleum gas supplied in containers and cylinders is already quite popular. On release of pressure, by opening the valve, they readily convert into the gaseous phase. In this state they present a hazard comparable to any inflammable natural or manufactured gas, except that being heavier than air, low level ventilation is necessary to avoid inflammable concentration of gas. Similarly, a series of precautions and regulations are necessary for laying of natural gas pipelines from city gas distribution entity to building premises and finally in the use location. Of late, the use of medical gases in hospitals through pipelines has become quite prevalent due to associated advantages; however, this needs to be supplemented with required care and precautions.

A minimum set of safety provisions are, therefore, laid down to safeguard the gas piping installation and the mode of operation in the interest of public safety.

In the first version formulated in 1970, as part of the National Building Code of India, three separate sections of this Part on 'Plumbing Services' were brought out, namely, Section 1 Water Supply, Section 2 Drainage and Sanitation, and Section 3 Gas Supply. These sections were subsequently revised in 1983.

In the first revision of the Code, in 1983, the safe distance between gas piping and electrical wiring system was modified as well as between gas piping and steam piping was incorporated. Additional information regarding the handling, use, storage and transportation of LPG in cylinders exceeding 500 ml water capacity were included. Provisions relating to LPG cylinders, installations regarding some aspects, such as jointing compound used at joints, painting of gas piping, details of fire extinguishers, total quantity of LPG at stationary and portable installations in proportion to the floor area were added. Also, some provisions of LPG bulk storage installations were introduced.

In the second revision of the Code in 2005, the Part 9 was renamed as 'Plumbing Services (Including Solid Waste Management)' and provisions on solid waste management were included for the first In the second revision, provisions with regard to pressure regulations were modified; in the provision of service l shut-off valves, number of additional shut-off valves were specified; in the provision of installation of gas pipe, new materials for pipes were mentioned; the minimum diameter for gas pipe was reduced to 8 mm; the colour for pipe line for supplying natural gas was specified; the provisions regarding protection against the corrosion were modified; the process of installation of meters were clarified; and additional method for detection of leakage of gas was recommended.

In the third revision of the Code in 2016, to comprehensively address the various and distinct features related to the plumbing aspects, this Part 9 was rearranged as follows:

Section 1 Water supply

Section 2 Drainage and sanitation

Section 3 Solid waste management

Section 4 Gas supply

In the revision in 2016, in Section 4, several key updates were made to enhance the safety and clarity of the guidelines. Certain terminologies were included and updated to reflect current practices, while a provision for the use of fire stops/sleeves at openings was introduced to ensure better fire safety. The clause on the use of liquefied petroleum gas was completely revised for improved accuracy, and a new detailed clause on the use of piped natural gas was added to address emerging needs. Additionally, a new clause on the medical gas pipeline system was included to ensure proper installation and safety measures in healthcare facilities. Further, cross-referenced standards were updated to align with the latest industry practices and regulations.

In this revision, this publication has been renamed as National Building Construction Standards (NBCS).

Based on the experience gained in the use of this Section, the provisions have been modified in this revision. The significant changes incorporated in this revision include the following:

a) New provisions have been introduced for the installation of sloped piping and drips to prevent gas system blockages, ensure proper condensate drainage, and facilitate cleaning, especially in systems handling wet gas.

b) Comprehensive guidelines for the installation of shutoff valves have been added to ensure proper control, easy accessibility, and maintenance, with specific provisions for individual shutoff valves for each meter and tenant in multi-tenant buildings.

c) The inclusion of over-pressure protection devices for gas systems has been mandated to ensure safe operation and prevent appliance damage due to excessive pressure.

d) Detailed provisions for the installation and safe operation of equipment powered by internal combustion engines and gas turbines have been added, with guidelines for flexible gas supply connections to prevent system stress from equipment movement.

e) References to all the concerned Indian Standards have been updated.

It may also be noted that the following Indian Standards have also been formulated on design and installation of natural gas pipelines:

IS 15663	Code of practice for design and installation of natural gas pipelines:
(Part 1) : 2006	Laying of pipelines
(Part 2) : 2006	Laying of pipelines in crossings
(Part 3) : 2006	Pre-commissioning and commissioning of pipelines

While implementing this NBCS, compliance with statutory regulations shall be ensured.

The information regarding the use of liquefied petroleum gas has been largely based on the following Indian Standards:

IS 6044	Liquefied petroleum gas storage installations — Code of practice:
(Part 1) : 2018	Residential, commercial and industrial cylinder installations (*third revision*)
(Part 2) : 2021	Commercial, industrial and domestic bulk storage installations (*second revision*)

All standards, whether given herein above or cross-referred to in the main text of this Section, are subject to revision. The parties to agreement based on this Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

As the regulation of land development and buildings is a State subject and is dealt by the States and local bodies such as urban local bodies within their jurisdiction through building regulatory documents like building regulations, building byelaws, and fire regulations, this document is voluntary in nature and is non-binding. The implementation depends on adoption by concerned parties or stipulations in a contract or by appropriate adoption by the concerned authorities.

For the purpose of deciding whether a particular requirement of this Section is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 'Rules for rounding off numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this Section.

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Important Explanatory Note for Users of this NBCS

In any Part/Section of this NBCS, where reference is made to **'good practice'** in relation to design, constructional procedures or other related information, and where reference is made to **"accepted standard"** in relation to material specification, testing, or other related information, the Indian Standards listed at the end of the Part/Section shall be used as a guide to the interpretation.

At the time of publication, the editions indicated in the standards were valid. All standards are subject to revision and parties to agreements based on any Part/ Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

In the list of standards given at the end of a Part/Section, the number appearing within parentheses in the first column indicates the number of the reference of the standard in the Part/Section. For example:

Accepted standards [E-4(1)] refers to the Indian Standard(s) given at serial number (1) of the list of standards given at the end of this Part E/Section 4, that is, IS 14885 : 2022 'Specification for polyethylene pipe for the supply of gaseous fuel' (*first revision*) and IS 17544 : 2022 Multilayer (PE-AL-PE) plastic piping system for indoor gas installations with a maximum operating pressure up to and including 500 kPA (5 bar) — Specification.

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART E PLUMBING SERVICES (INCLUDING SOLID WASTE MANAGEMENT)

SECTION 4 GAS SUPPLY

1 SCOPE

This NBCS (Part E/Section 4) covers the requirements regarding safety of persons and property for all piping uses and for all types of gases for purposes like fuel, lighting and medical in buildings.

1.2 This Section does not cover safety rules for gas burning appliances.

2 TERMINOLOGY

For the purpose of this Section, the following definitions shall apply.

2.1 Appliance Valve — A device that will shut-off the gas supply to the burner(s).

2.2 Approved Agency — Person or agency or a corporate body approved by competent authority or distribution company to execute the job of designing, erection and maintenance of multi cylinder installation.

2.3 Authority Having Jurisdiction — The authority which has been created by a statute and which, for the purpose of administering this NBCS /Part, may authorize a committee or an official to act on its behalf; hereinafter called the 'Authority'.

2.4 Competent Authority — The Authority designated or otherwise recognized under *Gas Cylinder Rules*, 2004 for approving LPG cylinders, valves and regulators.

2.5 Customer's/Consumer's Connection — Piping tapped on riser to supply each individual customer/consumer.

2.6 Distribution/Distributing Company — The company which is in the field of marketing LPG and PNG, and is the owner of LPG cylinders.

2.7 Gas Fitter — A qualified personnel of the authorized gas supplying organization.

2.8 Installation — A designated premise in an establishment where the complete multi-cylinder-system comprising cylinder, piping manifold, vaporizers, etc, is installed.

2.9 Manifold — A pipe header provided with several opening to which the cylinders are connected by using suitable pipe fittings.

2.10 Pilot — A small flame which is utilized to ignite the gas at the main burner(s).

2.11 Pressure Regulator — A device designed to lower the pressure of gas coming from the distribution main and to maintain it practically constants downstream. This normal operation pressure shall be practically in all cases that of the gas appliances used.

2.12 Purge — To free a gas conduit of air or gas or a mixture of gas and air.

2.13 Qualified Installing Agency — An individual, firm or agency which either in person or through a representative is engaged in and is responsible for the installation or replacement of gas piping on the outlet side of the gas meter, or the connection, installation or repair of gas supply piping and appliances within a building, and who is experienced in such work, familiar with all precautions required, and who has complied with all the requirements as to qualification, registration, licensing, etc, of the Authority.

2.14 Riser — Piping usually vertical on most of its length that supplies gas from the service to the various storeys of the building.

2.15 Service Pipe — Pipe that runs between the distribution main in the street and the riser in the case of multistoried building or the meter in the case of an individual house.

2.16 Service Shut-Off Valve (Isolation Valve) — A device installed outside the premises to cut-off the main supply of gas from pipeline by the supplier.

2.17 Vent Pipe — A safety device to which certain regulators are connected to evacuate outside gas that may escape from the normal circuit when some part of system gets damaged or malfunctions or a safety valve is open.

3 PRESSURE REGULATIONS

3.1 Pressure regulation is required to economize the sizing of piping system. Where the pressure of gas supplied to domestic system or other low pressure gas piping system in buildings is in excess of the pressure to be used in the appliance, a gas pressure regulator of suitable specification shall be installed in service pipe of each system to prevent excess pressure reaching the appliance. The pressure regulators to be used can be from 400 kN/m^2 upstream pressure to 2.1 kN/m^2 for domestic consumers and 10 kN/m^2, 30 kN/m^2, 200 kN/m^2 for commercial consumers, as the case may be.

3.1.1 In some place the reduction of pressure from main distribution source of 400 kN/m^2 to intermediate pressure (say 7 kN/m^2) and then to operating pressure of 2.1 kN/m^2 is achieved.

3.1.2 Whereas in most of the other places the reduction of pressure from main distribution source of 400 kN/m^2 to directly operating pressure (say 2.1 kN/m^2, 10 kN/m^2, 30 kN/m^2, 200 kN/m^2) is achieved in single stage pressure reduction.

3.2 If located inside a building, the required regulator shall comply with the following:

a) If any of the diaphragms of the regulator ruptures, the gas shall be sent to an outlet vent pipe made of brass or plastic in order to ventilate or drain the gas out of the building. The vent pipe will, however, lead to outer air about 1 m above the topmost storey of the building. Means shall be employed to prevent water from entering this pipe and also to prevent stoppage of it by insects or other foreign bodies;

b) If the gas pressure at the outlet of the regulator falls below 50 percent of the operating gas pressure or rises above twice the operating gas pressure, the gas input to the pressure regulator shall be cut off; and

c) In the event of malfunctioning of this safety device, a supplementary device shall connect the low pressure circuit to the outlet circuit (vent pipe) as soon as the exit pressure reaches 7 kN/m^2.

3.3 It shall also be ensured by the supply authority that the calorific value and supply pressure of gas shall not exceed the values for the type of gas used.

4 SERVICE SHUT-OFF VALVES

4.1 Service shut-off valves shall be installed on all new services including replacements in a readily accessible location.

4.2 Service shut-off valves shall be located upstream of the meter if there is no regulator or upstream of the regulator, if there is one.

4.2.1 Service shut-off valves shall be located in the upstream of the meter, if a single regulator is supplying more than one consumer and each such stream shall have one additional shut-off valve upstream of regulator.

4.3 All gas services operating at pressure greater than 7 kN/m^2 shall be equipped with an approved service shut-off valve located on the service pipe outside the building.

4.4 Underground shut-off valves shall be located in a covered durable curb box, manhole, vault or stand pipe which is designed to permit ready operation of the valve and the covers of which shall be clearly marked ‘Gas’.

5 EXISTING WORK

Nothing herein shall prohibit the continued use of existing system of the gas piping without further inspection or test, unless the Authority has reason to believe that defects which make the system dangerous to life or property exist.

6 RULES FOR TURNING GAS ON

6.1 No person, unless is the employ of the gas company or having permission from the gas company, shall turn on the gas at a service shut-off valve or at any valve that controls the supply of gas to more than one consumer.

6.2 Gas shall not be turned on at any meter valve without specific permission from the gas company or other authority if any of the following conditions exists:

a) If the gas piping appliances or meter supply through the meter valve are known to leak or otherwise to be defective (*see* **10**);

b) If required inspection of the piping or appliance has not been made;

c) If the gas company or other authority has requested that the gas be left turned off; and

d) If the meter valve is found shut-off for some reason not known to the gas fitter.

The gas shall not be turned on in the event of fire.

6.3 Gas shall not be turned on at any branch line valve if any of the conditions specified in **6.2** prevails. Where a branch line valve is found closed, a gas fitter shall again turn the gas on at such valve only if proper precautions to prevent leakage are taken and no other unsafe conditions are created thereby.

6.4 Gas shall not be turned on at either the meter valve or service line unless all gas keys or valves provided on all outlets in the piping system are closed or all outlets in the piping system are capped or plugged.

7 RULES FOR SHUTTING OFF THE GAS

7.1 The gas fitter shall put the gas off to any appliance, pipe or piping system and shall leave the gas turned off, until the causes for interrupting the supply has been removed in any one of the following cases:

a) If ordered to do so by the Authority;

b) If leakage of gas is noted, which appears to be sufficient to cause fire, explosion or asphyxiation;

c) If an installation of some gas appliance is found to be such as to cause a serious hazard to persons or property; and

d) If any condition exists which threatens interruption of gas supply which may cause burner outage or otherwise prove dangerous.

7.2 It shall be the duty of the installing agency when the gas supply is to be turned off to notify all affected consumers.

7.3 Before turning off the gas at the meter, for the purpose of installation, repair, replacement or maintenance of piping or appliance, all burner and pilot valves on the premises supplied with gas through the meter shall be turned off and the meter test hand observed for a sufficient length of time to ascertain that there is no gas passing through the meter. Where there is more than one meter on the premises, precaution shall be exercised to ensure that the concerned meter is turned off.

8 INSTALLATION OF GAS PIPES

8.1 Installation, repair and replacement of gas piping or appliances shall be performed only by a qualified installing agency.

8.2 Piping

8.2.1 Piping shall be of wrought iron, steel, copper, stainless steel or cast iron when the gas pressure is less than 7 kN/m^2; with higher gas pressure use of cast iron shall be prohibited.

8.2.1.1 SS 316/304/321 and flexible PE coated flexible pipe in rolls shall be permitted in low pressure system provided the pipe meets the required standard, to avoid the bends, fittings and leakages from the joint which are potential leakage points. Also, reference may be made to accepted standards [E-4(1)]. Heavy rubber flexible tube shall be permitted only as direct connection to burner from appliance valve.

8.2.1.2 For details regarding medical gas pipeline systems, a reference may be made to good practice [E-4(2)].

8.2.2 *Size of Gas Piping*

Gas piping shall be of such size and so installed as to provide supply of gas sufficient to meet the maximum demand without undue loss of pressure between the meter or service regulator when a meter is not provided, and the appliance(s).

8.2.2.1 The size of gas piping depends upon the following factors:

a) Allowable loss in pressure from meter or service regulator, when a meter is not provided, to appliance;

b) Maximum consumption to be provided;

c) Length of piping and number of fittings; and

d) Specific gravity of gas.

8.2.2.2 No gas pipe smaller than 8 mm shall be used.

8.2.3 As far as possible, straight lengths of piping should be used. Where there are bends in the pipe line, these should have a radius of at least five times the diameter of the pipe.

8.2.4 For any thread joint proper sealant shall be used on male threads only.

8.3 The gas piping shall be of the colour stipulated by explosive authority to distinguish it from other piping and the piping shall be painted silver grey with red band of 150 mm width. The gas pipeline shall be painted canary yellow in case of natural gas.

8.4 Piping Underground

8.4.1 *Protection of Piping*

Piping shall be buried to a minimum depth of 1 m or covered in a manner so as to protect the piping from physical damage.

8.4.2 *Protection Against Corrosion*

Generally, all the piping within the premises where it has to run on the wall shall be exposed and should not be in contact with wall to ensure that no corrosion takes place. Epoxy sealant or polyethylene conduit shall be used to ensure no contact of pipe with the wall in the situation of pipe crossing the wall. Underground or concealed gas pipeline in contact with earth or other materials which may corrode the piping shall be protected against corrosion by application of adequate corrosion resistant coating backed up by cathodic protection system.

8.5 The building shall not be weakened by the installation of any gas piping.

8.6 Gas piping in building shall be supported with pipe hooks, metal pipe straps, bonds or hangers suitable for the size of piping and of adequate strength and quality and located at proper intervals so that the piping may not be moved accidentally from the installed position.

8.7 Pipe Entrance to Buildings

Where gas pipe enters a building through a wall or floor of masonry or concrete, any gas piping or other piping entering the walls or floors shall be suitably sealed against the entrance of water/moisture or gas.

The openings or imperfection of fit or design are also source of possible fire and smoke passing through them. Fire stops shall be provided to fill the openings around penetrating items such as gas pipes, etc, through the wall or floor openings. Non-combustible sleeving may also be used as an alternative to proprietary seals for penetration of pipes of lead, aluminium, aluminium alloy, fibre cement or uPVC up to a specified nominal internal diameter. Proprietary fire stopping and sealing systems which have been shown by test to maintain the fire resistance of the wall or other elements, are available and may be used. Other fire stopping materials include cement mortar; gypsum-based plaster; cement or gypsum vermiculite/perlite mixes; glass fibre, crushed rock, blast furnace slag, or ceramic based products (with or without resin binders), and intumescent mastics. These may be used in situations appropriate to the particular material. Not all of them will be suitable in every situation. When sleeving is used, its length should be greater than the thickness of wall or floor. The sleeve shall be properly grouted to maintain fire/smoke separation.

Regarding protection of openings in walls or floors, from fire, reference may be made to Part F ‘Fire and Life Safety’ of this NBCS.

8.7.1 *Piping in Floors*

Piping in solid floors, such as concrete, shall be laid in channels in the floor suitably covered to permit access to the piping with a minimum damage to the building.

8.7.2 Single pipe without joint shall be used for wall crossing in any building.

8.8 Gas pipe shall not be bent. Fittings shall be used when making turns in gas pipe.

8.9 Generally concealed piping shall not be allowed. However, if it is necessary then it shall be under the **8.4** of underground piping and all protection such as coating, cathodic protection shall be done.

8.10 A drip shall be provided in the gas distribution system, if the moisture contents in the gas is likely to reach saturation point at any stretch of pipe line in the system; a drip shall, however, be provided at any suitable point in the line of the pipe where condensate may collect and from where it can be easily removed. This drip should be so installed as to constitute a trap where in an accumulation of condensate will shut-off the flow of gas before it will run back into the meter.

8.10.1 Drip has to be provided in the case of gas consisting moisture content.

8.11 Prohibited Devices

No device shall be placed inside the gas piping or fittings that will reduce the cross- sectional area or otherwise obstruct the free flow of gas.

8.12 Piping shall be electrically continuous throughout its length and properly earthed except in stretches where cathodic protection system is used for protection against corrosion. It shall not, however, be used to earth any electrical equipment.

8.12.1 The distance between gas piping and electrical wiring system shall be at least 60 mm and, where necessary, they shall be securely fixed to prevent contact due to movement. The gas piping should run above the electrical wiring. In this type of installation in the event of any leakage of natural gas, the gas would move up (natural gas being lighter than air) and would not come directly in contact with the electrical wiring. If the gas to be supplied is heavier than the air then the gas piping should run below the electrical wiring.

8.13 The distance between the gas piping and steam piping, if running parallel, shall be at least 150 mm. The gas piping should preferably run below the steam piping.

8.14 Piping installation shall be thoroughly gastight.

8.15 Smoking shall not be permitted when working on piping which contains or has contaminated gas.

8.16 Meters shall be installed in such a way that there shall be no load transfer from the pipeline to the inlet/outlet of the meter and shall be easily accessible.

8.17 Sloped Piping and Drips

Piping systems designed for gas flow, particularly those handling wet gas, should include provisions to ensure the smooth and safe operation of the system by adhering to the guidelines given in **8.17.1 to 8.17.3.**

8.17.1 *Slopes*

Pipes shall be installed with a slope of not less than 1/6.3 mm per 4 572 mm to prevent the formation of traps.

8.17.2 *Drips*

Where conditions involve wet gas, drips shall be installed at points where condensate may accumulate, such as the outlet of meters, to act as traps. These traps should allow for the collection of condensate and prevent its backflow into the meter or other critical components. Drips shall be located in accessible areas to facilitate cleaning or removal of condensate, and they shall be positioned to avoid freezing conditions that may compromise functionality.

8.17.3 *Sediment Trap*

Where a sediment trap is not incorporated as part of the appliance, a sediment trap shall be installed down-stream of the appliance shutoff valve as close to the inlet of the appliance as practical. The sediment trap shall be either a tee fitting having a capped nipple of any length installed vertically in the bottommost opening of the tee as illustrated in Fig. 1 or other device approved as an effective sediment trap. Illuminating appliances, ranges, clothes dryers, decorative vented appliances for installation in vented fireplaces, gas fireplaces and outdoor grills need not be so equipped.

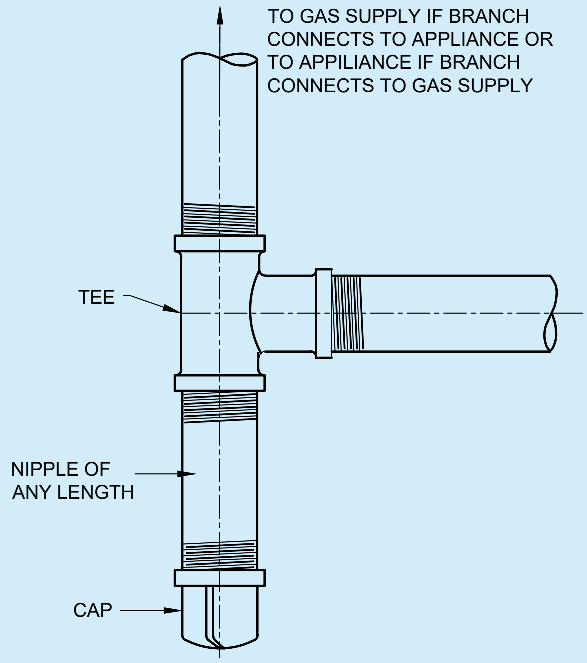
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FIG. 1 METHOD OF INSTALLING A TEE FITTING SEDIMENT TRAP

8.18 Shutoff Valves

Piping systems shall be equipped with shutoff valves to ensure proper control and isolation of the system as required. The following guidelines shall be followed for the installation and use of shutoff valves in piping systems:

a) Shutoff valves shall be of a suitable type and constructed from materials that are compatible with the piping system. They shall meet the necessary standards for the pressure and specific application of the system;

b) Shutoff valves shall not be installed in concealed spaces, furnace plenums, or locations where access may be hindered;

c) Shutoff valves shall be installed in locations that allow easy access for operation. They should also be protected from potential damage;

d) Each meter installation shall include a shutoff valve on the supply side of the meter to allow isolation of the gas supply;

e) For systems supplying gas to multiple buildings or tenants from a single meter, each building or tenant shall have an individual shutoff valve;

f) In buildings with multiple tenants, a shutoff valve shall be provided for each tenant, ensuring they have access to the valve controlling their space;

g) Each shutoff valve serving a house line shall be clearly marked with an identification tag to facilitate easy identification of the systems it controls;

h) Each appliance shall be equipped with a shutoff valve installed in close proximity, allowing easy isolation of the appliance;

j) Laboratories with multiple fuel gas outlets shall be provided with a dedicated shutoff valve. This valve shall be readily accessible, located within the laboratory, and clearly identified with signage; and

k) Valves installed in tubing systems shall be securely supported independently of the tubing to maintain system integrity.

8.19 Over-pressure Protection Devices

Over-pressure protection devices are essential for ensuring the safe operation of gas systems by preventing excessive pressure that could damage appliances or pose safety risks. The guidelines cover when and where these devices are required, their pressure limitation capabilities, and the materials and construction standards to ensure reliable performance. Proper installation and maintenance of over-pressure protection devices are critical to ensure compliance with safety standards and protect both equipment and personnel.

The following steps and guidelines shall be followed for the installation and use of over-pressure protection devices in gas piping systems:

a) Over-pressure protection devices shall be installed in piping systems serving appliances designed to operate at a gas pressure of 3.5 kPa or less, when the serving gas supplier delivers gas at a pressure greater than 13.8 kPa. Piping systems serving equipment with higher inlet pressures shall also be equipped with over-pressure protection devices as specified by the appliance manufacturer.

b) The pressure limitation for over-pressure protection devices shall comply with the relevant guidelines for systems designed to operate at specific gas supply pressures, as follows:

    1) *Pressure under* 3.5 kPa — Over-pressure protection devices shall limit the gas pressure to 13.8 kPa or less when the line pressure regulator fails;

    2) *Pressure over* 3.5 kPa — Over-pressure protection devices shall limit the gas pressure to the requirements specified by the appliance manufacturer's installation instructions when the system operates with pressures above 3.5 kPa;

    3) *Device capability* — Over-pressure protection devices shall be capable of independently limiting the gas pressure to the appliances as required, without relying on other pressure control equipment in the system; and

    4) *Failure detection* — Systems requiring over-pressure protection shall be designed so that any failure of the primary pressure control device is easily detectable. If a relief valve is used for over-pressure protection, it shall maintain pressure within safe limits under all failure conditions, including the failure of the line pressure regulator.

c) *Types of Over-Pressure Protection Devices* — The over-pressure protection device shall be one of the following:

    1) Pressure relief valve;

    2) Monitoring regulator;

    3) Series regulator; and

4) Automatic shutoff device.

These devices shall either be integrated with the service or line pressure regulator or installed separately, in compliance with the relevant guidelines.

i) *Construction and installation* — Over-pressure protection devices shall be constructed from materials that prevent impairment due to corrosion and shall be designed for easy operation, testing, and examination for leakage when closed;

ii) *External control piping* — Control piping shall be installed to avoid damage that could render both the regulator and the over-pressure protection device inoperative;

iii) *Setting* — The over-pressure protection devices shall be set to ensure the gas pressure supplied to connected appliances does not exceed the limits established by the relevant pressure guidelines;

iv) *Unauthorized operation* — Measures shall be taken to prevent unauthorized operation of shutoff valves that could disable the over-pressure protection device. This may include locking the valve in the open position or installing duplicate relief valves;

v) *Vents* — Discharge stacks, vents, and outlets of over-pressure protection devices shall be directed outdoors, designed to prevent blockages, and sized to match the outlet of the relieving device; and

vi) *Size of fittings, pipe, and openings* — All fittings, pipes, and openings between the protected system and the over-pressure device shall be properly sized to prevent hammering and ensure adequate relief capacity.

8.20 Engine and Gas Turbine Powered Equipment

The requirements for the installation and operation of equipment powered by internal combustion engines and gas turbines shall be followed towards reducing fire hazards both during installation and operation. Proper installation is essential to ensure safe operation, minimize risks, and enhance the equipment's performance and longevity. The following guidelines cover the installation practices and considerations necessary for integrating these systems safely into the overall setup.

a) *Powered Equipment* — Permanently installed equipment powered by internal combustion engines and turbines shall be installed according to the manufacturer's instructions. This ensures that the equipment operates as intended, with all safety and operational specifications followed.

b) *Gas Supply Connection* — Equipment powered by internal combustion engines and turbines shall not be rigidly connected to the gas supply piping. Flexible connections shall be used to prevent stress or strain on the piping system caused by movement or vibration of the equipment, ensuring safe and reliable operation.

9 INSPECTION OF SERVICES

9.1 No person shall use or permit the use of a new system or an extension of an old system of gas piping in a building or structure before the same has been inspected and tested to ensure the tightness of the system, and a certificate has been issued by the Authority.

9.1.1 *Test of Piping for Tightness*

Before any system of gas piping is finally put in service, it shall be carefully tested to ensure that it is gastight. Where any part of the system is to be enclosed or concealed, this test should precede the work of closing in. To test for tightness, the piping may be filled with city gas, air or inert gas but not with any other gas or liquid. In no case shall oxygen be used. The piping shall stand a pressure of at least 20 kN/m^2 measured with a manometer or slope gauge, for a period of not less than 10 min without showing any drop in pressure.

9.1.2 When the gas pressure exceeds 7 kN/m^2, the piping shall withstand a pressure of 0.6 MN/m^2 for 4 h (this test is for piping designed for working pressure less than 0.4 MN/m^2).

9.2 The Authority shall, within a reasonable time after being requested to do so, inspect and test a system of gas piping that is ready for such inspection and test, and if the work is found satisfactory and test requirements are complied with, it shall issue the certificate.

10 LEAKAGE CHECK

10.1 Before turning gas under pressure into any piping, all openings from which gas may escape shall be closed.

10.2 Checking for Gas Leakage

No matches, flame or other sources of ignition shall be employed to check for gas leakage from meters, piping or appliances. Checking for gas leakage with soap and water solution is recommended.

10.3 Use of Lights

Artificial illumination used in connection with a search of gas leakage shall be restricted to electric hand flash lights (preferably of the safety type) or approved safety lamps. In searching for leaks, electric switches should not be operated. If electric lights are already turned on, they should not be turned off.

10.4 Checking for Leakage with Meter

Immediately after turning gas into the piping, the system shall be checked to ascertain that no gas is escaping. This may be done by carefully watching the test dial of the meter to determine whether gas is passing through the meter. In no case should a leakage test be made using a gas meter unless immediately prior to the test it has been determined that the meter is in operating condition.

10.5 Checking of Leakage Without Using a Meter

This may be done by attaching to an appliance, orifice or a manometer or equivalent device and momentarily turning on the gas supply and deserving the gauging device for pressure drop with the gas supply shut-off. No discernible drop in pressure shall occur during a period of 3 min.

10.6 After piping has been checked, all gas piping shall be fully purged. Piping shall not be purged into the combustion chamber of an appliance. A suggested method for purging the gas piping to an appliance is to disconnect the pilot piping at the outlet of the pilot valve.

10.7 After the gas piping has been effectively purged, all appliances shall be purged and the pilots lighted.

10.8 In addition to the checking of gas leakage with soap and water solution, a suitable gas detector is also recommended for use.

11 USE OF LIQUEFIED PETROLEUM GAS (LPG)

11.1 The cylinders used for the storage and transportation of liquefied petroleum gas (LPG) shall conform to accepted standards [E-4(3)] approved by the statutory authority.

11.2 The handing, use, storage and transportation of liquefied petroleum gas in cylinders exceeding 500 ml water capacity shall be done in accordance with good practice [E-4(4)].

11.3 LPG Cylinder Installation

The following recommendations apply to installation in commercial, industrial, educational and institutional premises.

11.3.1 *General Recommendations*

11.3.1.1 Those responsible for the installation of cylinders, equipment and piping should understand the characteristics of LPG and be trained in good practice of handling, installing and maintaining installations.

11.3.1.2 The jointing compound used at different joints in the system shall be decided by the Qualified Installing Agency. Hemp and similar materials shall not be used at the joint. In any joint in which the thread provides a gastight seal, jointing compound shall be used only on the male thread.

11.3.1.3 Fire extinguishers of dry powder type or carbon dioxide type conforming to accepted standard [E-4(5)] shall be provided in places where LPG cylinder installations are situated and shall be located near such installations. Two buckets filled with sand and two with water shall also be installed nearby. The number, type and size of the fire extinguishers shall be as follows:

		Number	*Type*	*Capacity*
a)	For installations with LPG 40 kg to 200 kg	2	Dry powder	9 kg
b)	For installations with LPG more than 200 kg and up to 320 kg	3	Dry powder	9 kg
c)	For installations with LPG more than 320 kg and up to 1 000 kg	4	Dry powder	9 kg

NOTE — For electrical installations, one number CO_2 fire extinguisher (4.5 kg capacity) shall be provided.

11.3.1.4 Liquefied petroleum gas shall not be transferred from the cylinders in which it is received to any other container.

11.3.2 *Cylinder Location*

11.3.2.1 *Stationary installations*

a) Stationary installation not exceeding 50 kg of LPG may be installed indoors on any floor. It is recommended to have a minimum floor area of 5 m^2 for such an installation.

b) Stationary installations each not exceeding 50 kg of LPG may be installed indoors on any floor and within the same workspace provided the minimum distance between two such installations is 3 m, the proportion of such installations to floor area is one installation per 5 m^2 and the aggregate quantity of gas of all such installations does not exceed 200 kg.

c) Stationary installation not exceeding 100 kg of LPG may be installed indoors on any floor provided the floor area for such an installation is not less than 12 m^2.

d) Stationary installations each not exceeding 100 kg of LPG may be installed indoors on any floor and within the same workspace provided the minimum distance between two such installations is 3 m, the proportion of such installations to floor area is one installation per 12 m^2 and the aggregate quantity of gas of all such installations does not exceed 200 kg.

e) Stationary installation not exceeding 400 kg of LPG may be installed indoors in an enclosed section of a building or a room reserved exclusively for this purpose and ventilated at low level directly to the outside air.

f) Stationary installations above 400 kg [200 kg in case provision as in (e) is not possible] but not exceeding 1 000 kg shall be installed outdoors on ground floor level only. A minimum distance of 3 m shall be maintained between an installation and any building, public place, roadways, and other surroundings. The installation shall be protected from excessive weathering by sun, rain, etc, and from tampering by unauthorized persons. A lean-to roof with expanded metal on angle-iron framework on the sides is considered suitable for this purpose. In any case, adequate ventilation at ground level to the outside air shall be provided.

g) If the storage per installation is more than 1 000 kg, installations in multiples of 1 000 kg with manifold, safety devices, change over mechanism may be provided with minimum inter distance of 3 m from all sides. Total number of such installations shall not exceed 4 including stand by installation. If more than two installations are used, then number of cylinders per installations should not exceed 30.

h) For storage installations of 1 000 kg or installations in multiple of 1 000 kg the number of cylinders to be connected per manifold shall not exceed 15 and for each 1 000 kg installation two such manifolds shall be provided.

j) Cylinders shall be installed upright with the valves uppermost.

k) Cylinder containing more than 20 kg of gas shall not be located on floors above ground level.

m) Cylinders shall be located on a concrete or brick floor, preferably raised in case of outdoor installations.

n) In order to prevent the hazardous collection of gas, cylinders shall be placed at least 1 m away from culverts, depressions, or openings leading to below ground level compartment and drains.

p) Cylinders which have safety relief valves or similar devices incorporated in them shall be so positioned so that if the relief device operates, escaping gas is not hazardous;.

q) Cylinder installation for commercial/industrial/domestic/residential complexes, etc, or at any public place shall meet the following requirements:

  1) For commercial and industrial cylinder installation for any public places like mall, buildings, industries, hotels, etc, the sum total of all stationery installations inside the building shall not exceed 400 kg of LPG in any case. In case sum total of net weight of all the cylinders installed indoors exceed 400 kg provision for outdoor installations shall be made. For installations where the sum total is less than 400 kg of LPG provisions of (b) to (e) shall apply;

  2) For commercial and industrial cylinder installation for any public place, industry, etc, if the net weight of all the cylinders installed is more than 400 kg but less than 1 000 kg, than the installation shall be provided outdoors in line with (f). The cylinder installation shall be provided in a covered industrial shed but open from all sides for proper ventilation. In case the installed capacity increases more than 1 000 kg, than the installation shall be provided in line with (g). Two separate installations shall be provided and distance between each of the installations shall be minimum 3 m (this distance shall be between the outer edge of the two sheds);

  3) For multistoried buildings, flats housing society the reticulated installation of any capacity shall be provided at a safe place especially earmarked for this purpose. The installation shall not be provided by the side of road where there is continuous movement of vehicles or is approachable to residents especially children. The installation should be secured and should be provided in a covered shed open from all sides for ventilation. The area shall be demarcated by 1.5 m high chain link fencing having one gate. There should be minimum 3 m clear space all around the fencing and the space between the fencing and the edge of the shed should be minimum 2 m all around;

  4) If the requirement is more than 1 000 kg, installations in multiples of 1 000 kg with manifold, safety devices, change over mechanism, not exceeding 4 such installations (including stand by) may be provided with minimum distance of 3 m from all sides. The number of cylinders per installations should not exceed 30; and

  5) Location of cylinder bank:

    i) The site for LPG cylinder manifold shall be located away from the kitchen/LPG utility area/residential building. Installation shall be slightly raised minimum 100 mm from surrounding ground level;

    ii) Cylinders installation should not be located in inaccessible location, under a stairway, basements, cellars, where air movement across cylinders is very low/not present, to prevent the cylinders from getting inadequate latent heat and unapproachable during emergency;

    iii) Cylinders installation should not be close to steam pipes, boilers, transformers, DG sets, etc, to prevent cylinders from getting affected due to radiant heat;

    iv) Cylinders shall not be installed at a place where they are likely to cause obstruction, suffer damage or be exposed to conditions likely to affect safety;

    v) Cylinders installation should not be located along the drive way. Under unavoidable conditions, minimum distance of 3 m from drive way shall be maintained. Brick masonry (minimum 230 mm thick)/concrete (minimum 100 mm thick) walls or metallic shields/barriers (minimum 1.63 mm sheet) and of minimum 2 m height should be erected between drive way and cylinder installation for the safety and security of the installation;

    vi) Cylinders shall be located on a concrete or brick floor that is firm, at level, smooth, drained in case of outdoor installation; and

    vii) The cylinder shall be installed in upright position with the valve pointing upwards and minimum 1 m away from any combustible materials.

r) Cylinder storage room:

  1) The cylinder storage room shall be made out of non-flammable material that is concrete (minimum 100 mm thick) or brick masonry walls (minimum 230 mm thick) or steel structures made out of minimum 5 mm thick MS angle iron structure and 1.63 mm MS wire mesh of size minimum 11;

2) Since LPG is heavier than air, ventilation shall be provided at floor level, that is 100 mm above inside cylinder bank room, open to atmosphere. The ventilators shall be provided with 2 layers' copper or non-corroding metal wire mesh not less than 11 to the linear centimetre. The size of the ventilators should be minimum 500 mm long and 300 mm height;

3) The storage room shall be well ventilated, that is openings/ventilators shall be provided in the walls of cylinder storage covering minimum 25 percent of wall area. It should also have adequate lighting. Both exteriors and interiors should be painted with weather proof paints. FLP fittings, approved by statutory authorities shall be provided for electrical use;

4) The doors of the room where cylinders are installed shall open outwards and shall have louvers/wire mesh to ensure visibility and ventilation; and

5) Flammable materials like wood and plastic shall not be used. The cylinder bank storage room shall not use for storing any other materials.

11.3.2.2 *Portable installations*

When portability of cylinders is necessary, the following requirements shall be fulfilled:

a) The sum total of capacity of the cylinders connected to each manifold shall not exceed 100 kg of LPG. The total quantity of gas thus installed in a workspace shall not exceed 200 kg.

b) If cylinders are mounted on a trolley, the trolley shall be stable. Where necessary, the cylinders shall be secured to prevent them from falling.

c) The regulator shall be connected directly to the cylinder valve or to a manifold which shall be connected to the cylinder valves by means of rigid connections to give adequate support to the regulator. The only exception to this requirement is where cylinders are mounted on a trolley and the manifold is rigidly supported on the trolley. In such a case flexible or semi-flexible connections may be used between the cylinder valves and the manifold but not between the manifold and the regulator.

d) Anytime the total quantity of gas at portable installations shall be in proportion to the floor area as specified in 11.3.2.1 **(a)** to **(f)**.

e) At any time, the provisions at 11.3.2.1 **(a)** to **(r)** shall be ensured for all installations.

11.3.3 *Cylinder Manifolds*

11.3.3.1 All materials, fittings, etc, used in cylinder manifold systems shall comply with the statutory provisions or relevant Indian Standards. In absence of any such provisions or Indian Standards, equivalent international norms shall be followed.

11.3.3.2 The individual component parts of manifolds, that is piping, fittings, pigtails, etc, which are subject to cylinder pressure shall be capable of withstanding a test pressure without bursting of 2.5 N/mm^2 or one and a half times the developed pressure at 65 °C, whichever is more.

11.3.3.3 Where cylinder installations are made up with service and reserve batteries of cylinders, suitable change-over devices or valves shall be incorporated in the manifold header to prevent undue escape of the gas when cylinders are changed.

11.3.3.4 In case pressure regulators, manifold headers and automatic change-over devices are connected to cylinder by semi-flexible connectors, these shall be rigidly supported. Copper tube pigtails are considered to be semi-flexible for this purpose.

11.3.3.5 It is recommended that joints in manifold headers which do not have to be broken in normal use should be welded or brazed using a material which shall have a melting point of at least 540 °C.

11.3.3.6 All joints between manifold headers and cylinder connectors shall be readily accessible.

11.3.3.7 All joints in the manifold should be welded (except for valve fixation) and be easily accessible for inspection/repairs, etc.

11.3.3.8 Each manifold arm shall be fabricated in such a way that minimum joints are provided. Only seamless pipes are recommended for use in manifolds. There should be a minimum gap of 300 mm between the manifold and valve protection ring of the LPG cylinders.

11.3.3.9 The cylinders connected to a manifold shall be safely spaced for easy and safe replacement of cylinder when empty. A minimum distance of 400 mm shall be maintained between two nipples provided on the manifold for connecting the cylinders to the manifold. In case the diameter of the cylinder is higher than 400 mm then the distance between the two nipples shall be diameter of the cylinder plus 100 mm.

11.3.3.10 A pressure gauge of 100 mm dial shall be provided in the manifold to indicate the gas pressure in the manifold. The pressure gauge shall be suitable for a pressure range 0 to 1.0 N/mm^2.

11.3.4 *Pressure Regulators*

11.3.4.1 Pressure regulators and other devices used to control the gas shall comply with the distributing company's stipulations and accepted standards [E-4(6)].

11.3.4.2 Pressure regulator fitted with a safety valve shall be either,

a) Installed in the open air; or
b) Vented to the open by means of a metal vent pipe connected to the safety valve outlet.

11.3.4.3 Care shall be taken that safety valve outlets do not become choked with dust or other foreign matter.

11.3.4.4 If the regulator is fitted with a relief valve, care should be taken in positioning the regulator to avoid unnecessary hazards if the relief valve functions.

11.3.4.5 Pressure regulators and other control devices shall be adequately supported.

11.3.5 *Instructions to Consumers*

Consumers shall be instructed by the distribution company on the following, through appropriate written instructions:

a) Operation of the whole system;
b) How to recognize gas leaks;
c) Action to be taken in case of leakage;
d) Action to be taken in case of fire; and
e) Action to be taken in case of damage to, or failure of, any part of the installation.

11.3.6 For detailed information regarding installation of LPG cylinders in commercial, industrial, educational and institutional premises, reference may be made to good practice [E-4(7)].

11.4 LPG Bulk Storage Installations

The following recommendations apply to LPG bulk storage installations where storage tanks over 450 ℓ water capacity are used at industrial, commercial and domestic consumers' premises.

The maximum capacity of an individual tank and group of tanks at industrial, commercial and domestic premises shall be as follows:

Sl No. (1)	*Premises* (2)	*Maximum Water Capacity of an Individual Tank* ℓ (3)	*Maximum Water Capacity of Group of Tanks* ℓ (4)
i)	Industrial	130 000	260 000
ii)	Commercial	40 000	80 000
iii)	Domestic	20 000	80 000

11.4.1 *Location and Spacing of Storage Tanks*

11.4.1.1 Storage tanks shall be located outside the buildings and shall not be installed one above the other.

11.4.1.2 Each individual tank shall be located with respect to the nearest important building or group of buildings or line of adjoining property which may be built in accordance with Table 1. The distances given refer to the horizontal distance in plan between the nearest point of the storage tank and building/property line.

11.4.1.3 In heavily populated or congested areas the authority may determine the need for other reasonable protective methods to be taken, such as provision of fire walls, etc. If fire walls are to be provided, the authority may determine the extent to which the safety distances for above ground tanks may be reduced.

11.4.1.4 No LPG tank(s) shall be located within the bonded enclosures of any petroleum installation. The minimum distance of separation between LPG storage tanks and any petroleum installation shall be as prescribed under the *Petroleum Rules*, 1976 or as specified in Table 1, whichever is more.

11.4.1.5 The number of storage tanks in one storage installation shall not exceed six. In case there are more than one storage installations, the safety distance between two installations shall be the same as the distance between the tanks and the property line in accordance with Table 1.

Table 1 Minimum Safety Distances

(*Clauses* 11.4.1.2, 11.4.1.4 *and* 11.4.1.5)

Sl No.	**LPG Storage Water Capacity of Individual Tank**	**Distance from Building/ Property Line**		**Distance between Tanks**	
		Above Ground	Under Ground	Above Ground	Under Ground
	ℓ	m	m	m	m
(1)	(2)	(3)	(4)	(5)	(6)
i)	Up to 2 000	5	5	1	1.5
ii)	Above 2 000 and up to 10 000	10	7.5	1	1.5
iii)	Above 10 000 and up to 20 000	15	10	1.5	1.5
iv)	Above 20 000 and up to 40 000 adjacent	20	15	2	0.25 × diameter of vessel or 1.5 m (*Min*)
v)	Above 40 000 and above adjacent	30	15	2	0.25 × diameter of vessel or 1.5 m (*Min*)

NOTE — If the aggregate water capacity of a multi-tank installation is 40 000 ℓ or greater, the above minimum safety distances shall apply to the aggregate storage capacity rather than the capacity per individual storage tank.

11.4.2 *Bunding*

Since LPG is heavier than air, storage tank shall not be enclosed within bund walls. The accumulation of flammable liquid under LPG tanks shall be prevented by suitably slopping the ground.

11.4.3 *Protection*

11.4.3.1 To prevent trespassing or tampering, the area which includes tanks, direct fired vaporizers, pumping equipment and loading and unloading facilities shall be closed by an industrial type fence at least 2 m high along the perimeter of the safety zone. Any fence shall have at least two means of exit. Gates shall open outwards and shall not be self-locking.

11.4.3.2 When damage to LPG systems from the LPG tank lorry is a possibility, precautions against such damage shall be taken.

11.4.3.3 Underground tanks shall be protected from above ground loading by providing a suitable kerb to prevent a possible accidental damage to the tank and its fittings by LPG tank lorry.

11.4.4 *Grass and Weed Removal*

Road ignitable material, such as weeds, long grass or any combustible material shall be removed from an area within 3 m from the shell of any LPG tank of up to 2 000 litre water capacity, and within 6 m from the shell of larger tanks. If weed killers are used, chemicals which are a potential source of fire hazard shall not be selected for this purpose.

11.4.5 *Warning Signs*

No smoking or naked flames shall be permitted within the safety zone of the installation. Prominent notices to this effect shall be posted at access point. From accessibility point of view, the signs shall be in accordance with good practice [E-4(8)].

11.4.6 *Fire Protection*

The possibility of a major fire outbreak, leading to direct flame impingement of the storage tank, shall be minimized by sound engineering in plant design and layout, good operating practice, and proper education and training of personnel on both routine operations and on action to be taken in an emergency.

11.4.6.1 *Water supply*

Provision shall be made for an adequate supply of water and fire protection in the storage area according to the local hoses and mobile equipment, fixed monitors or by fixed spray systems which may be automatic. Control of water flow should be possible from outside any danger area.

11.4.6.2 *Fire extinguishers*

At least two dry chemical powder type fire extinguishers of 9 kg capacity each, conforming to the quality requirements in accordance with the accepted standard [E-4(5)], shall be installed at points of access to the storage installations. The fire extinguishers should be mounted keeping in view the ease of accessibility in accordance with good practice [E-4(9)] and Part F ‘Fire and Life Safety’ of this NBCS.

11.4.7 For detailed information regarding LPG bulk storage installations, reference may be made to good practice [E-4(10)].

12 USE OF PIPED NATURAL GAS (PNG)

12.1 The PNG infrastructure shall be in complete compliance with all the requirements of *Petroleum and Natural Gas Regulatory Board* (*Technical Standards and Specifications including Safety Standards for City or Local Natural Gas Distribution Network*) *Regulations*, 2008.

12.1.1 The user-group/housing society concerned (referred hereinafter in these clauses as ‘society’) should contact the local city gas distribution (CGD) entity at the stage of the design of the building. This ensures that all the adequate provisions are incorporated in the design itself, as also the compliance with all the safety standards stipulated/required by the regulations/gas entities, as applicable from time-to-time. This ensures avoidance/mitigation of any rework at a later stage, or even situations where incorporation of any changes may become impractical or not possible, thereby rendering the building devoid of PNG infrastructure.

12.1.2 The entire gas pipeline infrastructure proposed to be laid in the premises of the society shall be easily accessible in future by the representatives of the CGD entity. Provision should be made by the builder for the same. Builder/society should ensure communication of the same to the future customer and should incorporate it in their agreements with the customer.

12.1.3 No permanent/temporary structure shall be erected on the ground along the paths where gas pipeline exists underground.

12.2 The PNG infrastructure inside the premises of societies primarily comprises the following:

a) Underground medium pressure (MP) pipeline networks, comprising mainly polyethylene pipes and fittings;

b) Underground low pressure (LP) pipeline networks, comprising mainly polyethylene (PE) pipes and fittings;

c) Service regulator modules;

d) Above ground riser and lateral system, comprising mainly electric resistance welded GI pipes and fittings; and

e) Pipeline inside premise and/or kitchen of individual customer, comprising various components like meter regulator, diaphragm gas meter, copper pipe, brass fittings, brass valves, etc.

The guidelines mentioned under **12.3** to **12.6** give the minimum requirements to be complied with.

12.3 Guidelines for MP and LP Pipeline Networks

12.3.1 Gas pipelines are required to be laid at a minimum top cover of 1 m from the finished surface level. Underground PE pipeline shall not be laid through the basement.

12.3.2 A minimum clearance of at least 300 mm is required to be maintained between the gas pipelines and any other obstacles/services.

12.3.3 Gas pipelines should not be laid closer to properties than as stipulated below:

Sl No. (1)	*Pressure* (2)	*Minimum Proximity* (3)
i)	Up to 0.01 N/mm^2	0.25 m
ii)	Up to 0.4 N/mm^2	3.00 m

12.3.4 Laying of underground natural gas pipelines within the premises of society shall be in accordance with *Petroleum and Natural Gas Regulatory Board* (*Technical Standards and Specifications including Safety Standards for City or Local Natural Gas Distribution Network) Regulations*, 2008.

12.3.5 A dedicated utility corridor may be provided in the society for natural gas pipelines. However, if provision of dedicated utility corridor for natural gas pipeline is not feasible inside the society premises due to space constraints, then, provisions pertaining to safety inter-distances of natural gas pipelines with other utilities as mentioned in *Petroleum and Natural Gas Regulatory Board* (*Technical Standards and Specifications including Safety Standards for City or Local Natural Gas Distribution Network*) *Regulations*, 2008 shall be followed.

12.3.6 In case of contradiction between the provisions of this NBCS and *Petroleum and Natural Gas Regulatory Board* (*Technical Standards and Specifications including Safety Standards for City or Local Natural Gas Distribution Network) Regulations*, 2008, then, provision of *Petroleum and Natural Gas Regulatory Board* (*Technical Standards and Specifications including Safety Standards for City or Local Natural Gas Distribution Network*) *Regulations*, 2008 shall prevail.

12.4 Guidelines for Service Regulator Modules

The user-group/society should provide adequate open spaces in the premises for installation of gas equipment like regulating stations, which will be required to facilitate supply of PNG to the residents of the building/premise.

The identified location shall be such that it does not obstruct any vehicular movement and is at a safe location in the premise.

12.5 Guidelines for Above Ground Riser and Lateral System

12.5.1 The riser and lateral system supplying gas to multistoried residential buildings shall be in compliance with the requirements of the PNGRB regulations.

12.5.2 Multi-occupancy buildings having eight floors or more should have purpose- built utility shafts/ducts for accommodating riser and lateral system, which should be preferred route for constructing/locating the riser.

12.5.3 Provision shall be made for safe access to the riser and lateral system by the representatives of the CGD entity for future maintenance and repair. In the case of a continuous shaft, a concrete slab or similar flooring shall be provided for maintenance work at each floor.

12.5.4 *Ventilation*

12.5.4.1 Adequate provision for natural ventilation shall be provided in the building where PNG infrastructure is laid, so as to prevent any potential gas leaks from accumulating in the atmosphere to an unsafe level. Mechanical ventilation shall not be used to achieve the required ventilation levels. The minimum levels of ventilation in riser's ducts/shafts shall be as given below:

Sl No.	*Cross Sectional Area* (*CSA*) *of Riser Duct* m^2	*Minimum Free Area of Each High and Low Level Ventilation* (*Open Ventilator*) m^2	*Typical Air Duct Size* mm	*Typical Ventilator Size* mm
(1)	(2)	(3)	(4)	(5)
i)	Less than 0.01	0.002	Ø50	Ø70
ii)	0.01 to 0.375	0.010	Ø100	100 × 100
iii)	0.375 to 0. 5	0.02	Ø150	100 × 200
iv)	0. 5 to 7. 5	0.05	Ø250	200 × 250
v)	More than 7.5	1 percent CSA of the duct	–	–

12.5.4.2 Where the duct has a single ventilator that is part of the architectural design of the building, the free area of the ventilator to outside area shall be a minimum of 0.04 m^2 or 4 percent of the CSA of the duct, whichever is greatest.

12.5.4.3 Pipe work shall be installed in an unventilated void.

12.5.4.4 The pipe may enter the building to gain access to the riser shaft through a basement or car parking area, provided the area is well ventilated.

12.5.4.5 Any duct containing a riser or lateral shall be ventilated either directly to outside air, or indirectly to outside air *via* an area that is normally occupied and is itself ventilated to outside.

12.5.4.6 The provision of ventilation should be through permanent ventilators within the area/duct containing pipe-work.

12.5.4.7 All flammable release sources shall be at a lower elevation than the bottom of the highest ventilation opening.

12.5.4.8 Pipes may run in the same duct (subject to availability of adequate clearance from other utilities and ventilation) as most other services, including hot and cold water services, heating pipes, electrical conduits and cables and pipes containing other fuels. However, the following services shall not be installed in the same duct as gas pipes:

a) Ventilation ducts and vacuum pipes that operate at sub-atmospheric pressure and that are not of all-welded or all-brazed construction; and

b) Services containing oxidizing or corrosive fluids.

12.5.5 There shall be provision for installing risers and laterals such that a minimum distance of 300 mm is ensured from any electrical equipment or installations and associated excess current control boxes of fuse boxes, and 25 mm is ensured from the electricity supply and distribution cables and other metal piped services.

12.5.6 In case where the gas pipeline is required to cross through a wall, provisions (like core cutting) or holes of adequate size drilled through the wall/building structure, to accommodate an easy passage of the gas pipelines through them, shall be made. The elevation of these provisions/holes shall be near the roof and not near the floor of the room.

12.6 Guidelines for Pipeline Inside Premise and/or Kitchen of Individual Customer

12.6.1 Meters will normally be located inside the property on an outside wall with a minimum length of inlet pipe-work inside the property. Kitchen is the preferred room to locate the meter, thereby minimizing the length of the outlet pipe work.

12.6.2 The gas meter shall be installed in an area with adequate ventilation and at a proper location to facilitate safe and convenient meter reading and maintenance activities in future. A minimum ventilation area of 2 percent of the internal floor area of the room shall be provided in the room where the gas meter is located. The gas pipeline inside the kitchen shall be laid along the walls of the kitchen and in a ventilated area.

12.6.3 In case pipe work is required to be laid in solid floors inside the kitchen, adequate provisions (in the shortest possible route and a minimum of 75 mm screed to provide an approximate cover of at least 50 mm over the gas pipe) shall be provided to protect the pipeline against corrosion and failure caused by movement. This method of construction consists of a base concrete raft foundation onto which a cement screed is subsequently laid in order to obtain a satisfactory surface to accept the floor finish. Provision of preformed ducts with protective covers should be made to facilitate laying of gas pipeline. It is advisable to contact the CGD entity at the designing stage so that adequate provisions are incorporated in the design of the kitchen/floor plan to facilitate easy and safe installation of PNG system.

12.6.4 Installation pipe work shall not be placed within the cavity of a cavity wall. Every pipe passing through a cavity wall shall take the shortest possible practicable route and shall be sleeved.

12.6.5 In case of provision of sleeve, the same should be of a diameter that provides a sliding fit to the pipe allowing normal pipe expansion/contraction.

13 USE OF MEDICAL GAS PIPELINE SYSTEM (MGPS)

13.1 General

A medical gas pipeline system (MGPS) is installed to provide a safe, convenient and cost effective system for the provision of medical gases to the clinical and nursing staff at the point of use. It reduces the problems associated with the use of gas cylinders such as safety, porterage, storage and noise.

MGPS generally handles distribution of oxygen, nitrous oxide, medical air, surgical air, medical vacuum only; and sometimes provides an aesthetic gas scavenging systems. All other gases used in hospitals have low volume use and are provided through cylinders at the point of use.

It is essential to ensure that there is no possibility of a cross-connection between any system and that all parts of each system to which connections can be made by users are gas specific.

Separate installations are provided for pathology, general laboratories and special laboratories. These are designated Laboratory Gases (Pipeline) Supply System (LGSS). LGSS is provided with valve controlled outlets and shall never be provided with medical gas terminal units.

Use and storage of medical gases is governed by *Indian Drugs and Cosmetics Act*, 1940.

13.2 Design and Installation

13.2.1 *Pipelines Systems for Compressed Medical Gases and Vacuum*

The design, installation, performance, documentation, testing and commissioning of pipeline systems for compressed medical gases, gases for driving surgical tools and vacuum in healthcare facilities to ensure continuous delivery of the correct gas and the provision of vacuum from the pipeline system, shall be in accordance with the good practice [E-4(11)]. This is inclusive of the requirements for supply systems, pipeline distribution systems, control systems, monitoring and alarm systems and non-interchangeability between components of different gas systems.

13.2.2 *Anaesthetic Gas Scavenging Disposal Systems*

The design, installation, performance, documentation, testing and commissioning of an aesthetic gas scavenging disposal systems to ensure patient safety and to minimize exposure of the operator and other persons to an aesthetic gases and vapours, shall be in accordance with the good practice [E-4(12)]. This is inclusive of requirements for the power device, pipeline system, performance, non- interchangeability between key components and avoidance of cross connections between an aesthetic gas scavenging (AGS) disposal systems and medical gas and vacuum pipeline systems.

LIST OF STANDARDS

The following list records those standards which are acceptable as ‘good practice’ and ‘accepted standards’ in the fulfillment of the requirements of this NBCS. The latest version of a standard shall be adopted at the time of enforcement of this NBCS. The standards listed may be used for conformance with the requirements of the referred clauses in this NBCS.

	IS No.	*Title*
(1)	IS 14885 : 2022	Polyethylene pipes for the supply of gaseous fuels — Specification (*first revision*)
	IS 17544 : 2022	Multilayer (PE-AL-PE) plastic piping system for indoor gas installations with a maximum operating pressure up to and including 500 kPA (5 bar) — Specification
(2)	IS 18466 (Part 1) : 2024/ ISO 7396-1 : 2016	Medical gas pipeline systems: Part 1 Pipeline systems for compressed medical gases and vacuum (*first revision*)
	IS/ISO 7396-2 : 2007	Medical gas pipeline systems: Part 2 Anaesthetic gas scavenging disposal systems
(3)	IS 3196 (Part 1) : 2013	Welded low carbon steel cylinders exceeding 5 litres water capacity for low pressure liquefiable gases: Part 1 Cylinders for liquefied petroleum gases (LPG) — Specification (*sixth revision*)
	IS 7142 : 2025	Welded low carbon steel cylinders for low pressure liquefiable gases not exceeding 5 litre water capacity — Specification (*second revision*)
(4)	IS 8198 (Part 5) : 2022	Code of practice for steel cylinders for compressed gases: Part 5 Liquefied petroleum gas (LPG) (*second revision*)
(5)	IS 15683 : 2018	Portable fire extinguishers — Performance and construction — Specification (*first revision*)
(6)	IS 9798 : 2013	Low pressure regulators for use with liquefied petroleum gas (LPG) — Specification (*second revision*)
	IS 16280 : 2021	High pressure regulators and adaptors for use with liquefied petroleum gases (LPG) — Specification (*first revision*)
(7)	IS 6044 (Part 1) : 2018	Liquefied petroleum gas storage installations — Code of practice: Part 1 Residential, commercial and industrial cylinder installations (*third revision*)
(8)	IS 4963 : 2025	Accessibility in built environment for older adults and persons with disabilities — Requirements (*second revision*)
(9)	IS 2190 : 2024	Selection, installation and maintenance of first-aid fire extinguishers — Portable and mobile — Code of practice (*fifth revision*)
(10)	IS 6044 (Part 2) : 2021	Liquefied petroleum gas storage installations — Code of practice: Part 2 Commercial, industrial and domestic bulk storage installations (*second revision*)
(11)	IS 18466 (Part 1) : 2024/ ISO 7396-1 : 2016	Medical gas pipeline systems: Part 1 Pipeline systems for compressed medical gases and vacuum (*first revision*)
(12)	IS/ISO 7396-2 : 2007	Medical gas pipeline systems: Part 2 Anaesthetic gas scavenging disposal systems

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART F FIRE AND LIFE SAFETY

The Fire Services is a State subject and has been included as a Municipal function in the XIIth Schedule of the Constitution of India under Article 243(w). It is therefore primarily the responsibility of the State Governments to ensure safety of life and property in their area of jurisdiction. State/Union Territories (UTs) in the country are implementing fire safety measures either through the provisions as stipulated in their State Fire Services Act or through their building byelaws. The construction of any building and its fire safety thereof has to be ensured as per the norms and standards prescribed by the State Building Bye Laws/Development Control Regulations of the State/UTs.

The Department of Fire Services in the States/UTs is one of the agencies to issue NOC to the buildings from fire and life safety aspects and it is for the State/UT Governments to provide stringent norms for issuing NOC for the same.

This Part of NBCS is only for guidance and referral for the state government/local authority in respect of fire safety in buildings.

BUREAU OF INDIAN STANDARDS

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National Building Code Sectional Committee, CED 46

FOREWORD

The first version of this Part was formulated as Part 4, in the National Building Code of India 1970 (NBC 1970) and was revised in 1983. Subsequently the first revision of this Part was modified in 1997 through Amendment No. 3 to 1983 version of NBC. The modified version of this Part included a few tables for the fire resistance ratings of various building components, such as walls, columns, beams and floors. The requirements for wet riser, down-comer, automatic sprinkler installation, high velocity (10 m/s to 15 m/s) water spray or foam generating system, etc, for buildings were modified. Annex giving guidelines for selection of fire detectors had been deleted and relevant Indian Standards on fire alarm system and smoke detectors had been referred. Also, an annex for determination of fire loads and flue load density for arriving at the classification of occupancy hazard and calorific values of some common materials was included. Annex for broad classification of industrial and non-industrial occupancies into low, moderate and high hazard had also been included.

The NBC was then revised in 2005. In this revision, the significant modifications incorporated were: The text was divided into the following broad clauses: (a) *Fire prevention* – Covering aspects of fire prevention pertaining to design and construction of buildings on passive fire protection measures, also describing the various types of building materials and their fire rating; (b) *Life safety* – Covering life safety provisions in the event of fire and similar emergencies, also addressing construction and occupancy features that are necessary to minimize danger to life from fire, smoke, fumes or panic; (c) *Fire protection* – Covering the significant appurtenances and their related components and guidelines for selecting the correct type of equipment and installation meant for fire protection of the building, depending upon the classification and type of the building. Also, the classification of building based on occupancy was elaborated, wherein, starred hotels were covered as a new Subdivision A-6 under occupancy Group A Residential; heritage structures and archaeological monuments were covered under Subdivision D-3 occupancy Group D Assembly buildings; mixed assembly occupancies were covered as a new Subdivision D-6; underground elevated railways were covered as a new Subdivision D-7 under occupancy Group D Assembly buildings; and TV stations were covered under Subdivision E-5 of occupancy Group E Business buildings. Further, for the external stairs for exit requirements, the width and treads were increased to 1 250 mm and 250 mm, respectively; under the requirements for institutional buildings the clear width of all required exits which serve as egress from hospital or infirmary section was increased from 1.5 m to 2 m. Also, provision of patient-lift was included; and due cognizance of halon phase out programme was taken, while specifying provisions in this Part with respect to fire protection using fire extinguishers/systems. Based on various comments received from time-to-time, an Amendment No. 2 relating to Part 4 of the 2005 version of NBC, was issued.

In the 2016 revision of NBC, the following changes were made:

General:

1) The scope of application of provisions of this Part of NBC for different occupancies was clarified.
2) Definitions of various new terms were included and definitions of some of the existing terms were updated based on latest developments and use.

Fire Prevention:

3) Based on the experience in the use of the provisions of NBC in relation to various occupancies and subdivision classification under various building occupancy types, the same were reviewed and updated. Also, mixed occupancy and minor occupancy were further clarified.
4) Table 1 on fire resistance ratings of structural and non-structural elements was updated.
5) The provisions relating to fire separating walls, fire separating floors and fire partitions were detailed.
6) Provisions of fire safety requirements of services shafts were rationalized and updated.
7) A separate comprehensive clause on electrical power supply distribution for fire and life safety systems was included.
8) Detailed clauses on air conditioning systems towards safety and smoke control integration were provided.

9) Glass facade requirements were detailed towards fire protection and smoke exhaust aspects.

10) A separate comprehensive clause on Fire Command Centre (FCC) was introduced covering various requirements.

Life Safety:

11) The components of means of egress were comprehensively brought out covering specific aspects relating to exit access, exit and exit discharge. The relationship of occupant load, exit width requirements and travel distances were duly detailed enabling efficient planning for enhanced life safety provisions. The table on capacity factors was modified based on aspect of width per person approach used globally.

12) Requirement for displaying the occupancy load for assembly buildings and call centres, was included.

13) The concept of firefighting shaft for safe and efficient use by the fire fighters to access the floor on fire and also allow egress/evacuation of the occupants with simultaneous use of refuge area used as staging of the occupants, were well integrated, including in the annex for high rise buildings.

14) Aspects of compartmentation with fire barrier and its passive fire safety requirements were detailed for respective occupancies.

15) Pressurization of exits and smoke extraction requirements for respective areas including car parking were updated with an approach towards selecting alternative means therefor.

16) The clause on gas supply was comprehensively updated.

17) The clause on fire detection and alarm system was completely reviewed and updated as per the latest practices.

Fire Protection:

18) The table on minimum requirements for firefighting installations (erstwhile Table 23 renumbered as Table 7) was comprehensively updated.

19) Detailed provisions were included on fire water storage, fire pump room, sprinkler system and various alternative fire suppression systems.

Additional Occupancy-wise Requirements:

20) Concept of progressive evacuation in case of hospital buildings was included in detail to ensure life safety of the inmates.

21) Provisions relating to requirement of refuge area were updated including for D-6 occupancy and introduced for apartment buildings of height 60 m and above.

22) Separate provisions on atrium were included in Annex E.

23) Detailed separate provisions were included on commercial kitchens as an Annex.

24) Detailed separate provisions were included on car parking facilities in Annex G.

25) Separate provisions on fire and life safety requirements for metro stations and metro trainways were included in Annex J and Annex K, respectively.

In this revision, the publication is renamed as National Building Construction Standards (NBCS).

This NBCS (Part F) deals with safety from fire. It specifies the demarcation of fire zones, restrictions on construction of buildings in each fire zone, classification of buildings based on occupancy, types of building construction according to fire resistance of the structural and non-structural components and other restrictions and requirements necessary to minimize danger to life from fire, smoke, fumes, or panic before the buildings can be evacuated. The NBCS recognizes that safety of life is more than a matter of means of egress and accordingly deals with various matters which are considered essential to the safety of life. The NBCS therefore covers provisions relating to means of egress covering various components thereof namely exit access, exit, and exit discharge. It also covers provisions relating to fire protection of buildings through portable and fixed firefighting installations.

Fire protection techniques have to be based on the fire behaviour characteristics of different materials and structural elements of buildings. The activities pursued by the occupants of buildings must also be taken into consideration for assessing the extent of hazards, and method should then be devised by which the hazards could be minimized. An indefinite combination of variables is involved in the phenomenon of fire, all of which cannot be quantified. The requirements of this NBCS should, therefore, be taken as a guide and an engineering design approach should be adopted for ensuring a fire safe design for buildings. Depending upon the type and complexities in a building, qualified and trained fire protection engineers should be associated with the planning of buildings, so that adequate fire and life safety measures could be incorporated in the building design right from the beginning.

Absolute safety from fire is not attainable in practice. The objective of this Part is to specify measures that will provide that degree of safety from fire which can be reasonably achieved. The NBCS endeavours to avoid requirements that might involve unreasonable hardships or unnecessary inconvenience or interference with normal use and occupancy of buildings but insists upon compliance with minimum standards of fire safety necessary for building occupants and users. For ensuring compliance of fire protection equipment/installations to the laid down quality requirements, it is desirable to use such equipment/installation duly certified under the BIS, Certification Marks Scheme.

While providing guidelines for minimizing chances of occurrence of fire through passive fire protection measures, this Part does not intend to cover all aspects of general fire prevention including sources of ignition. Nor does it cover the prevention of accidental personal injuries from fire during the course of normal occupancy of buildings.

This Part while recognizing that panic in a building on fire may be uncontrollable, deals with the potential panic hazard through measures designed to prevent the development of panic. Experience indicates that panic seldom develops even in the presence of potential danger, so long as occupants of buildings are moving towards exits which they can see within a reasonable distance and with no obstruction or undue congestion in the path of travel. However, any uncertainty as to the location or adequacy of means of egress, the presence of smoke or fumes and the stoppage of travel towards the exit, such as may occur when one person stumbles and falls on stairs, may be conducive to panic. Danger from panic is greater when a large number of people are trapped in a confined area particularly when people are not adequately guided towards egress and safety notifications are not implemented or practiced. Consideration towards announcements and annunciations needs to be given to guide the occupants to safe egress routes and to control panic during situation of distress. These aspects are addressed in this Part.

Experience has shown that concealed spaces within a building, such as, space between ceiling and false ceiling, horizontal and vertical ducts, and shafts, etc, tend to act as flues/tunnels during a fire. Provisions therefore exist to provide fire stopping within such spaces.

Nothing in this Part of the NBCS should be construed to prohibit better types of building construction, more exits, or otherwise safer conditions than the minimum requirements specified in this Part.

Compliance with this Part should not be construed as eliminating or reducing the necessity for other provisions for safety of persons using a building or structure under normal occupancy conditions. Nor should any provision of this Part be construed as requiring or permitting any addition that maybe hazardous under normal occupancy conditions.

One of the major points brought out then in this Part (until NBC 2016) is the limitation of heights and areas of buildings based on fire safety of the occupants. Individual municipal corporations were free to alter the then Table 2 (of NBC 2016) based on local conditions, but the ratios of areas as maintained in the table for different occupancies and types of construction should be adhered to.

Advantage has been taken of the developments, particularly in fire resistance rating of materials, designating types of construction in a rational manner and relating the area limitations of different occupancies to different types of construction.

Halons (halogenated hydrocarbons) which exhibit exceptional firefighting and explosion prevention/ suppression characteristics have been found to possess high ozone depleting potential. They come under Group II of Annex A of the Montreal Protocol on Substances that Deplete the Ozone Layer, the international environmental agreement for phasing out ozone depleting substances. Due to increasing evidence that the ozone layer is getting depleted at a faster rate than thought earlier, the NBCS continues to take into cognizance the need to promote use of halon alternatives as fire extinguishing media.

In this revision, the following significant changes have been made:

a) Minor occupancies have been clarified, in **3.1.1.1**;

b) Mixed occupancy has been detailed in **3.1.11**;

c) Fire resistance rating of roofs located over 6.7 m has been updated in Table 1;

d) Occupant load factor for various occupancies has been clarified in Table 2, also with respect to the net or gross floor area;

e) Various provisions on life safety have been updated in **4**;

f) Travel distance values have been updated in Table 4;

g) Compartmentation related provisions have been comprehensively updated in **4.5**;

h) Fire detection and suppression systems based on the specific type and intensity of industrial hazards has been introduced under **5.4**;

j) Table 7 on firefighting requirements for various occupancies has been reviewed and separately detailed (in Table 7A to Table 7J) for all the occupancies;

k) Basis for water quantity required for fire-fighting are recommended for combined system protection (using sprinkler and hose) and similarly for hose protection system in Table 7K and Table 7M, respectively;

m) Fire protection of commercial kitchen has been elaborated through reference to the detailed Indian Standard, IS 18271 : 2023 'Fire safety in commercial kitchen — Guidelines';

n) Water curtain requirement for basement compartmentation has been reviewed and deleted;

p) Annex H on fire and life safety requirements for metro stations has been elaborated;

q) Annex J on fire and life safety requirements for metro trainways has been updated;

r) A new Annex M on performance based design has been introduced;

s) A new Annex N on fire protection for specific industries is included as an informative guide; and

t) Height restrictions of buildings have been eliminated.

All standards cross-referred to in the main text of this Part, are subject to revision. The parties to agreement based on this Part are encouraged to investigate the possibility of applying the most recent editions of the standards.

As the regulation of land development and buildings is a State subject and is dealt by the States and local bodies such as urban local bodies within their jurisdiction through building regulatory documents like building regulations, building byelaws, and fire regulations, this document is voluntary in nature and is non-binding. The implementation depends on adoption by concerned parties or stipulations in a contract or by appropriate adoption by the concerned authorities.

For the purpose of deciding whether a particular requirement of this Part of the NBCS is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 'Rules for rounding off numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this Part.

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Important Explanatory Note for Users of the NBCS

In any Part/Section of this NBCS, where reference is made to **'good practice'** in relation to design, constructional procedures or other related information, and where reference is made to **'accepted standard'** in relation to material specification, testing, or other related information, the Indian Standards listed at the end of the Part/Section shall be used as a guide to the interpretation.

At the time of publication, the editions indicated in the standards were valid. All standards are subject to revision and parties to agreements based on any Part/Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

In the list of standards given at the end of a Part/Section, the number appearing within parentheses in the first column indicates the number of the reference of the standard in the Part/Section. For example:

a) Good practices [F(4)] refers to the Indian Standards give at serial number (4) of the list of standards given at the end of this Part F, that is, IS 8758 : 2013 'Recommendations for fire precautionary measures in the construction of temporary structures and pandals (*second revision*); and

b) Accepted standards [F(1)] refers to the Indian Standards given at serial number (1) of the list of standards given at the end of this Part F, that is, IS 3808 : 1979 'Method of test for non-combustibility of building materials (*first revision*)'.

NATIONAL BUILDING CONSTRUCTION STANDARDS

PART F FIRE AND LIFE SAFETY

1 SCOPE

1.1 This NBCS (Part F) covers the requirements for fire prevention, life safety in relation to fire, and fire protection of buildings. This NBCS (Part F) specifies occupancy-wise classification, constructional aspects, egress requirements and protection features that are necessary to minimize danger to life and property from fire.

1.2 The provisions of this Part are applicable to those high rise buildings having a height exceeding a certain value, or, to special buildings (having a certain area exceeded on any floor), as given below, unless otherwise mentioned specifically in this Part:

Sl No.	*Occupancy Type*	*Height beyond which Provisions of this Part are Applicable*	*Floor Area beyond which Provisions of this Part are Applicable*
(1)	(2)	(3)	(4)
i)	Residential	24 m	750 m^2
ii)	Educational	9 m	500 m^2
iii)	Institutional	15 m	500 m^2
iv)	Assembly	9 m	750 m^2
v)	Business	15 m	750 m^2
vi)	Mercantile	15 m	1 000 m^2
vii)	Industrial – Low hazard (G-1)	Any height and the total area of the building exceeds 2 000 m^2	
viii)	Industrial – Moderate hazard (G-2)	Any height and the total area of the building exceeds 2 000 m^2	
ix)	Industrial – High hazard (G-3)	15 m	500 m^2
x)	Storage	9 m	500 m^2
xi)	Hazardous	9 m	500 m^2
xii)	Mixed Use	15 m	1 000 m^2

NOTES

1 State/Local Authority may consider modifying the above values depending on the fire vulnerability and preparedness.

2 In the case of buildings (lesser than the height or area as above) with a single staircase, the same should be of firefighting shaft type and located only on the external periphery, with its lobby and stairwell both ventilated (having 1.6 m^2 minimum size opening through fixed louvres kept permanently open). A 2 h fire door for lobby and 1 h fire door for stairwell should be provided.

1.3 Also, the provisions of this Part are applicable when buildings are altered (on an area 1 000 m^2 or more) or when change of occupancies are made to buildings.

1.4 The provisions of performance-based design (Annex M) are applicable only to validate the fire safety aspects for heritage buildings that are either made accessible to public or are converted to other building occupancy (and are constrained to provide exits as per the codal requirements, as that could damage the heritage nature). For the applicability of such performance-based approach to other buildings such as large assembly buildings, air traffic control towers, special museums, and existing buildings being modified for occupancy change, careful consideration of Annex M should be done by the state/local fire authorities on the basis of detailed performance-based calculations/report.

2 TERMINOLOGY

For the purpose of this Part, the following definitions will apply.

2.1 Assisted Evacuation — Strategy that exists during which a designated person or persons provide assistance, during an emergency, to another person(s) to leave a building or a specific part of the built environment and to reach a final place of safety.

2.2 Atrium — A large-volume space created by a floor opening or series of floor openings connecting two or more stories that is covered at the top of the series of openings and is used for purposes other than an enclosed stairway; lifts hoist-way; an escalator opening; or as a utility shaft used for plumbing, electrical, air conditioning, or communications facilities.

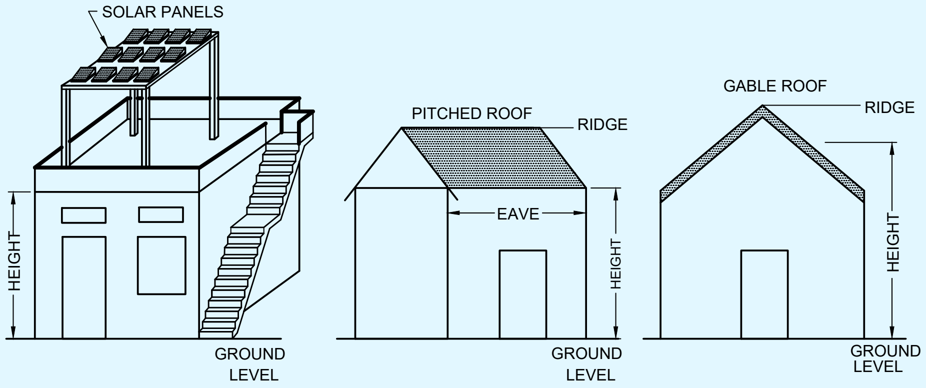
2.3 Authorities Concerned (known as Authority Having Jurisdiction) — An organization, office, or individual responsible for enforcing the requirements of a Code or standard, or for approving or accepting equipment, materials, an installation, or a procedure.

2.4 Automatic Fire Detection and Alarm System — A system comprising components and sub-systems required for automatically detecting smoke, heat or fire initiating an alarm and other actions as appropriate. This system also includes manually operated electronic fire alarm (MOEFA) system.

NOTE — MOEFA system (with or without automatic fire detection and alarm system) includes all or some of the components such as manual call stations (initiating an alarm for fire and other actions as required), talk-back system and public address system.

2.5 Building — Any structure for whatsoever purpose and of whatsoever materials constructed and every part thereof whether used as human habitation or not and includes foundation, plinth, walls, floors, roofs, chimneys, plumbing and building services, fixed platforms, veranda, balcony, cornice or projection, part of a building or anything affixed thereto, or any wall enclosing or intended to enclose any land or space and signs and outdoor display structures. Tents, *Shamianahs*, tarpaulin shelters, etc erected for temporary and ceremonial occasions with the permission of the Authority should not be considered as building.

2.6 Building, Height of — For the purposes of fire safety, the height of the multistoried building may be measured up to the floor level of the last occupiable floor from the grade level (where the fire tender/rescue vehicle will be located). In cases when the building height is measured up to the roof of the top-most floor, the following depictions may be considered. *See* Fig. 1.



(1A) 1-STORIED BUILDING

(1B) DOOR ON EAVES WALL

(1C) DOOR ON GABLE WALL

NOTES

1 Where a building is located in sloped terrain, height should be determined from the lowest level (that is approachable by the fire service vehicle) to the roof level.

2 The heights for design or sprinkler systems should be as per good practice [F(20)].

FIG. 1 BUILDING HEIGHT

2.7 Combustible Material — A material which either burns itself or adds heat to a fire, when tested for non-combustibility in accordance with accepted standard [F(1)].

2.8 Common Path of Travel — That portion of the exit access which the occupants are required to traverse before two (or more) separate and distinct routes to two (or more) exits become available. Common paths of travel are part of the travel distance. *See* Fig. 2.

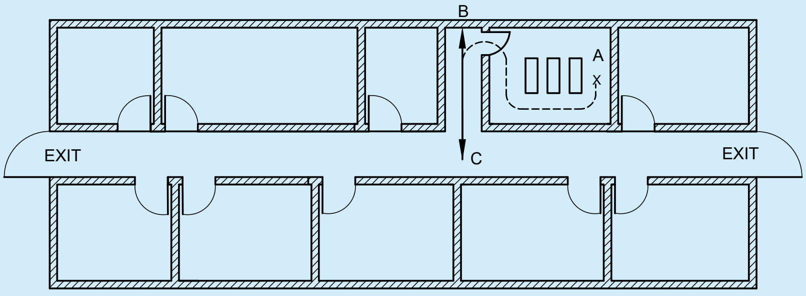


FIG. 2 COMMON PATH OF TRAVEL (A TO C) AND DEAD END (C TO B)

2.9 Covered Area (*also* Built-up Area)— Ground area covered by the building immediately above the plinth level. The area covered by the following in the open spaces is excluded from covered area:

a) Garden, rockery, well and well structures, plant nursery, water pool, swimming pool (if uncovered), platform a round a tree, tank, fountain, bench, *Chabutara* with open top and unenclosed on sides by walls and the like;

b) Drainage culvert, conduit, catch-pit, gully pit, chamber, gutter, and the like;

c) Compound wall, gate, unstoreyed porch and portico, slide, swing, uncovered staircases, ramp areas covered by *Chhajja* and the like; and

d) Watchman's booth, pump house, garbage shaft, electric cabin or substations, and such other utility structures meant for the services of the building under consideration.

NOTE — For the purpose of this Part, covered area equals the plot area minus the area due for open spaces in the plot.

2.10 Down-comer — An arrangement of firefighting within the building by means of down-comer pipe connected to terrace tank through terrace pump, gate valve and non-return valve and having mains not less than 100 mm internal diameter with landing valves on each floor/landing. It is also fitted with inlet connections at ground level for charging with water by pumping from fire service appliances and air release valve at roof level to release trapped air inside.

2.11 Dry Riser — An arrangement of firefighting within the building by means of vertical rising mains not less than 100 mm internal diameter with landing valves on each floor/landing which is normally dry but is capable of being charged with water usually by pumping from fire service appliances.

2.12 Emergency Lighting — Lighting provided for use when the supply to the normal lighting fails.

2.13 Emergency Lighting System — A complete but discrete emergency lighting installation also fed from the standby power source to the emergency lighting lamp(s), for example, self-contained emergency luminaire or a circuit from central battery (with or without monitoring system) connected through wiring to several escape lighting luminaries.

2.14 Escape Lighting — That part of the emergency lighting which is provided to ensure that the escape route is illuminated at all material times, for example, at all times when persons are on the premises, or at times the main lighting is not available, either for the whole building or for the means of egress.

2.15 Evacuation Lift — Lift that can be used, during an emergency, for self-evacuation.

2.16 Fire Exit — That unobstructed component of means of egress which is between the exit access and the exit discharge or public way. Exit components include exterior exit doors at the level of exit discharge, interior exit stairways (pressurised), exit stairway with external wall (pressurized or natural ventilated), exterior exit stairways, exit passageways, and exterior exit ramps (*see* Fig. 3). Fire exits should be provided with panic bar as applicable to facilitate entry of occupant into it.

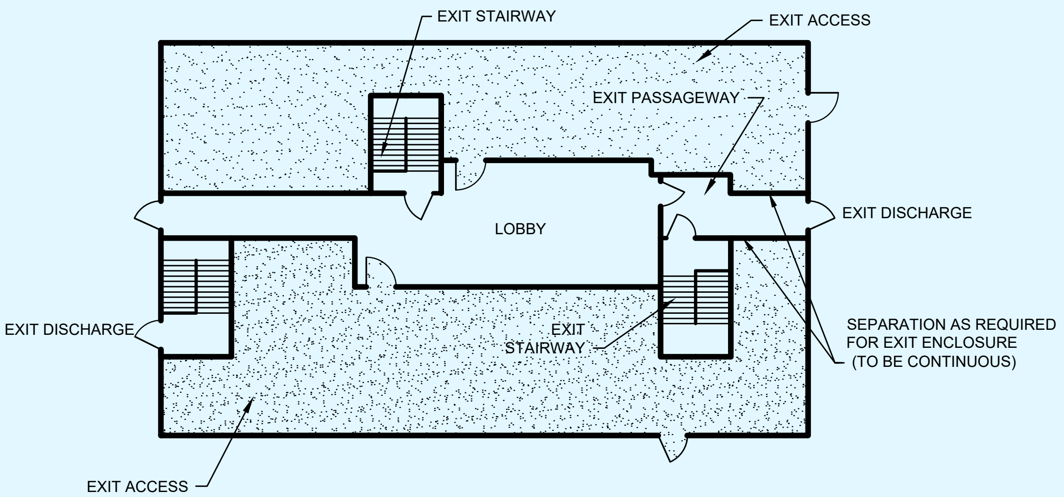


FIG. 3 COMPONENTS OF MEANS OF EGRESS

2.17 Exit Access — That portion of a means of egress that leads to fire exit (for example, habitable floor area, doorways, staircase lobby, ramps, veranda, corridor, or passageway leading to an exit) (*see* Fig. 3).

2.18 Exit Access Corridor — A corridor in exit access which may not necessarily have the requirement of exits being met.

2.19 Exit Discharge — The component of a means of egress between the termination of an exit and a public way (*see* Fig. 3).

2.20 Fire Barrier (or Fire Resisting Barrier) — A fire barrier is a vertically or horizontally aligned member such as a wall or a fire curtain, or a floor. These may be with discontinuities created by openings with a specified fire resistance rating, where such members are designed and constructed with a specified fire resistance rating to limit the spread of fire that also restricts the movement of smoke.

2.21 Fire Compartment — A space within a building that is enclosed by fire barrier or fire resistant walls on all sides, including the top and bottom.

2.22 Fire Door and Fire Door Assembly — Any combination of fire door, frame, hardware and other accessories that together provide a specific fire resistant rating to the opening in terms of its stability, integrity and insulation properties, when installed in the openings in fire separation walls. Fire door {*see* accepted standard [F(33)]} is a component of fire door assembly.

NOTES

1 Wherever reference has been made to fire door or fire check door in this Part, the same should be construed as fire door assembly.

2 Fire doors in exits should have fire rating as required in this Part to meet the requirement of integrity and stability; and the minimum insulation criteria should be 30 min.

3 Fire doors in exits should be provided with intumescent seal or such other globally accepted technologies/ devices (that expand upon contact with heat/hot gases, thereby forming an effective seal and aiding in integrity).

4 Fire doors in exits should not be allowed to be on hold open position and kept closed and to close by 'door closure - spring mechanism'.

5 Fire curtains should not be allowed as fire exits. If so provided for compartmentation, independent fire door should be provided meeting the requirement for fire door in exits as above (of the width as required) within the prescribed travel distance requirement.

6 Fire doors provided with panic bar should also be provided with the door handle on the other side on those levels to permit re-entry in designated floors.

2.23 Exit — A way out leading from exit access towards fire exit (fire exit is basically a protected staircase, *see* **2.16**). Exits not leading to fire exits should be displayed with signage as 'NOT A FIRE EXIT'.

2.24 Firefighting Shaft (Fire Tower) — An enclosed shaft having a protected area of 120 min fire resistance rating comprising a protected lobby, staircase, and fireman's lift, connected directly to the exit discharge or through an exit passageway with 120 min fire resistant wall at the level of exit discharge to exit discharge. These should also serve the purpose of exit requirement/strategy for the occupants. The lobby space should have arrangement to accommodate minimum two wheel chairs, and a minimum specified area for respective occupancy. The respective floors should be approachable from firefighting shaft enabling the fire fighters to access the floor and also enabling the fire fighters to assist in evacuation through fireman's lift. The firefighting shaft should be equipped with 120 min fire doors. The firefighting shaft should be equipped with firemen talk back, wet riser and landing valve in its lobby, to fight fire by fire fighters (*see* Fig. 4 for a typical firefighting shaft).

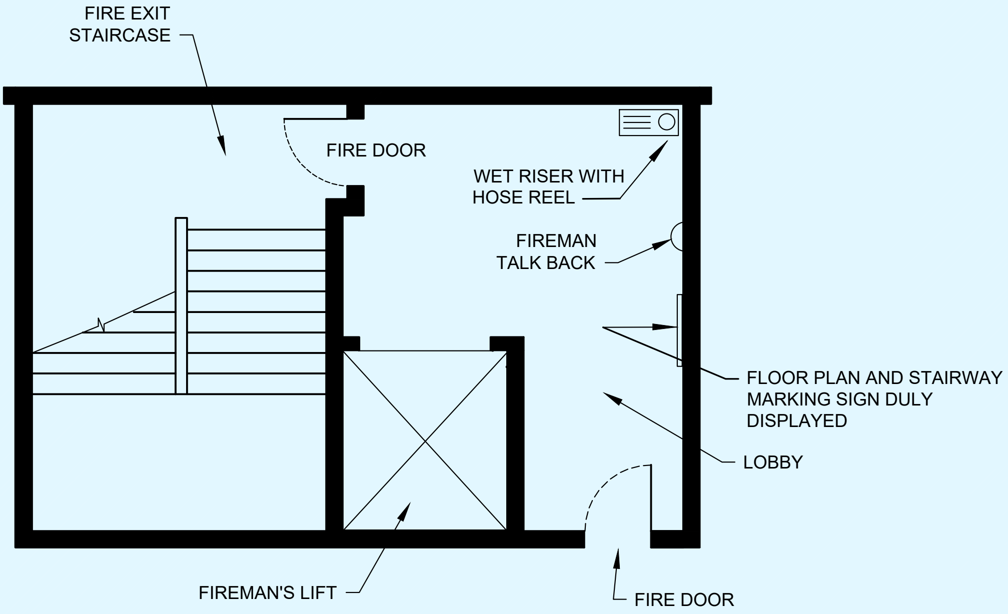


FIG. 4 TYPICAL FIREFIGHTING SHAFT

2.25 Fire Load — The total amount of energy that could be released during a fire in a given compartment, floor or building; usually expressed in Mega Joules (MJ) (or equivalent units).

2.26 Fire Load Density — Fire load per unit area of the compartment, floor or building concerned. It is obtained by dividing the fire load by the floor area of the concerned compartment, floor or building. It is usually expressed in megajoule (MJ) per m^2, or equivalent units with respect to wood, as below:

Sl No. (1)	*Building Type* (2)	*Fire Load Density (Expressed as Wood Equivalent* kg/m^2) (3)
i)	Residential (A)	25
ii)	Institutional (B) and Educational (C)	25
iii)	Assembly (D)	25 to 50
iv)	Business (E)	25 to 50
v)	Mercantile (F)	Up to 250
vi)	Industrial (G)	Up to 150
vii)	Storage (H) and Hazardous (J)	Up to 500

2.27 Fireman's Lift — A lift or a group of lifts invariably associated with all the features and requirements of a firefighting shaft. Such lift(s) are installed to enable fire services personnel to reach different floors with minimum delay, and meets the additional features as required in accordance with this Part. This lift also serves the purpose of meeting the requirement of evacuation lift for assisted evacuation.

NOTES

1 Lifts in firefighting shaft and fireman's lift are required to go to basements and the lobby should be pressurized.

2 Regular lifts serving floors above should terminate at the level of exit discharge. Lifts serving basements should be separate. In the case of lift bank, it is preferred to have all the lifts as fireman's lift instead of one or few lifts.

3 Lifts in the firefighting shaft should reach the terrace level, in the case of habitable spaces in terrace.

2.28 Fire Resistance — Fire resistance is a property of an element of building construction and is the measure of its ability to satisfy for a stated period, some, or all of the following criteria:

a) *Load bearing capacity* (*Stability*) (*R*) – The ability of a load bearing element to withstand fire exposure without any loss of structural stability.

b) *Integrity* (*E*) – Resistance to penetration of flame and hot gases.

c) *Insulation* (*I*) – Resistance to temperature rise on the unexposed face up to a maximum of 180 °C at any single point and average temperature of 140 °C.

NOTE — Radiation (W) can be used as one of the criteria for glass used in building, which refers to the ability to resist the passage of heat from one side to another.

2.29 Fire Resistance Rating — The time that a material or construction will withstand the standard fire exposure as determined by fire test done in accordance with the standard methods of fire tests of materials/structures as per the accepted standard [F(2)].

NOTES

1 The requirement of rating of various building elements as given in this Part should be applicable in accordance with the provisions given in the accepted standard [F(2)].

2 The fire resistance rating should be specified in terms of minutes.

3 Fire resistance rating for non-structural material/assembly should bear a label of compliance to such rating as per the approval of competent authority based on testing and evaluation. The label should be permanently affixed to the material/assembly and may carry other relevant details such as name and type of the product, and manufacturer's details.

2.30 Fire Resistant Wall — Fire resistance rated wall, having opening(s) with specified fire resistant rating, which restricts the spread of fire from one part of a building to another part of the same building.

2.31 Fire Separation — The distance in metre, measured from the external wall of the building concerned to the external wall of any other building on the site, or from other site, or from the opposite side of street or other public space for the purpose of preventing the spread of fire.

2.32 Fire Stop — A fire resistant material, or construction, having a fire resistance rating of not less than the fire separating elements, installed in concealed spaces or between structural elements of a building to prevent the spread/propagation of fire and smoke through walls, ceilings, and the like as per the laid down criteria. See accepted standard [F(34)].

NOTES

1 Fire stop assembly for through penetrations is a combination of firestop compatible for use with the penetrant, penetration items such as cables, cable tray, conduits, ducts, pipes, etc, and their means of support through the wall or opening that together restores the fire resistance rating of the fire separating elements in terms of its integrity and/or insulation properties.

2 Fire stop assembly for joints is the one where fire stop with movement capability is used to seal the linear joints between adjacent fire separating elements, to maintain the fire resistance of the separating elements, which should be installed within its tested design limits with regard to size of the joint, type of assembly, and anticipated compression and extension of the joint.

2.33 Fire Suppression Systems

a) *Gas Based Systems* — Systems that use gaseous agents as fire suppression media, such as, all agents alternate to halon gases, as conforming to relevant Indian Standards; other methods/types of gas based systems where their protection is equal to or better than what is suggested above for the type of application subject to the acceptance of Authorities concerned may also fall under such systems; and

b) *Water Based Systems* — Systems that use mainly water as firefighting media such as hydrant system, sprinkler system, water spray system, foam system and water mist system.

2.34 Fire Wall or Fire Separating Wall — A fire resistance rated wall having fire protected openings, which restricts the spread of fire and extends continuously from the foundation to the roof (and through the roof at least 1 m above the roof in case of combustible roof), with sufficient structural stability under fire conditions to allow collapse of construction on one side or either side without collapse of the wall.

2.35 Floor Area (Gross) — The area of the floor within the inside perimeter of the outside walls of the floor of the building under consideration with no deductions for corridors and passage-ways, stairs, closets, thickness of interior walls, columns, lifts and building shafts or other features. Typically used for low density occupant load calculations.

2.36 Floor Area (Net) —The area of the floor within the inside perimeter of the outside walls of the floor of the building under consideration obtained after deducting the areas of corridors and passage-ways, stairs, closets (toilets and bathrooms), thickness of interior walls, columns, lifts, building shafts, services (floor mounted AHU, electrical, and the like), area of atrium, and escalator cut out. Typically used for high density occupant load calculations thus, net floor area is not the carpet area.

2.37 Floor Area Ratio (FAR) — The quotient obtained by dividing the total covered area (plinth area) on all floors by the area of the plot:

$$\text{FAR} = \frac{\text{Total covered area of all floors}}{\text{Plot area}}$$

2.38 Fire Exit Hardware — A door-latching assembly incorporating an actuating member or panic bar that releases the latch bolt upon the application of a force in the direction of egress travel, provided on exits.

2.39 High Rise Building — A building 24 m or above in height (irrespective of its occupancy).

2.40 Horizontal Exit — A defend in place or a staging arrangement, providing safety from fire and smoke originating from the area of incidence, by allowing alternative egress from a compartment to an area of refuge or another compartment at or near the same level. This also includes such egress from a compartment to an adjoining building. A horizontal exit is thus through a fire door of 120 min rating in a fire-resistant wall. Horizontal exit requires separation from the refuge area or adjoining compartment through 120 min fire barrier. The adjoining compartment of the horizontal exit should allow for unlocked and ease of egress and exits for the occupants using defend in place strategy.

2.41 Internal (Interior) Exit Stairway – A stairway that is enclosed with a fire-rated enclosure (towards building occupancy) in order to provide a protected path between the exit access and exit discharge. This enclosure must extend directly to the exterior at grade; extend through an exit passageway to grade; or comply with one of the allowances for exit discharge through a lobby, vestibule or horizontal exit.

2.42 External (Exterior) Exit Stairway – A stairway that is located on an exterior wall of the building, is open to external environment on at least one side and meets the requirements for openness as specified under **4.4.2.4.3.4**, and is separated from the interior of the building by construction with the fire resistance rating required for enclosed stairs. The external exit stair leads directly to an open courtyard or public way at the level of exit discharge.

2.43 Lift Lobby — A space from which people directly enter a lift car(s) and into which people directly enter upon exiting a lift car(s).

2.44 Means of Egress — A continuous way of travel from any point in a building or structure to a public way, consisting of three separate and distinct parts, that is, exit access, exit, and exit discharge.

2.45 Means of Escape — A way out of a building or structure that does not conform to the strict definition of 'means of egress' but does provide an alternate way out.

2.46 Metro Station

2.46.1 *Concourse* — Intermediate level(s) or area(s) connecting a station platform(s) to a public way through stairs, escalators, or corridors.

2.46.2 *Crush Train Load* — The number of passengers inside a train when it is filled to maximum capacity permissible by rolling stock design.

2.46.3 *Entraining Load* —The number of passengers boarding a train at a platform.

2.46.4 *Headway* — The interval of time between the arrivals of consecutive trains at a platform in a station.

2.46.5 *Mass Rapid Transit* — Any station building or part thereof, permanent, or temporary, through which people transit for the duration of time required to enter the building and board the train to depart the station platform or to alight from the train and depart from the station building.

2.46.6 *Non-transit Occupancy* — Occupancy not under the control of the system operating authority.

2.46.7 *Point of Safety* — One of the following: (a) An enclosed exit that leads to a public way or safe location outside the station, trainway, or vehicle, (b) An at-grade point beyond the vehicle, enclosing stations, or trainway, (c) A point on open track beyond the open or enclosed station or enclosed train-way, and (d) Any other location approved by the Authorities concerned.

2.46.8 *Station* — A place designated for the purpose of loading and unloading passengers, including service area and ancillary spaces associated with the same structure.

2.46.8.1 *Composite station* — A transit station that is constructed contiguous with non-transit occupancy.

2.46.8.2 *Enclosed station* — A station or portion thereof that does not meet the definition of an open station.

2.46.8.3 *Open station* — A station that is constructed such that it is directly open to the atmosphere, and smoke and heat are allowed to disperse directly into the surrounding open atmosphere.

2.46.9 *Station Platform* — The area of a station immediately adjacent to a guideway, used primarily for loading and unloading passengers.

2.46.10 *Link Load* — The number of passengers travelling between two stations on board a train or trains during peak headway.

2.46.11 *Incidental Occupancy within Station* — An occupancy within a station that provides additional services which are not directly related to transportation operation or transportation services.

2.47 Mixed Occupancy — A multiple occupancy where the occupancies are intermingled.

2.48 Multiple Occupancy — A building or structure in which two or more classes of occupancy exist.

2.49 Occupancy or Use Group — The principal occupancy for which a building or a part of a building is used or intended to be used. For the purpose of classification of a building according to the occupancy, an occupancy should be deemed to include subsidiary occupancies which are contingent upon it.

2.50 Occupant Load — Maximum number of persons that might occupy a building or portion thereof at any one time.

2.51 Place of Comparative Safety — Places within a building where people can stay little longer until evacuation, for example, refuge areas, terraces, fire/smoke separated compartments, etc.

2.52 Pressurization — The establishment of a pressure difference across a barrier to protect exit, stairway, lobby, exit passageway or room of a building from smoke penetration.

2.53 Performance Based Design — An engineering approach to fire protection design based on (1) agreed upon fire safety goals and objectives, (2) deterministic and/or probabilistic analysis of fire scenarios, and (3) quantitative assessment of design alternatives against the fire safety goals and objectives using accepted engineering tools, methodologies, and performance criteria.

2.54 Pressurization Level — The pressure difference between the pressurized space and the adjoining area served by the pressurized space expressed in Pascal (Pa).

2.55 Public Way — A street, alley, or other similar parcel of land essentially open to the outside air, dedicated, or otherwise permanently appropriated to the public for public use and having a clear width and height of not less than 3 m.

2.56 Ramp — The construction, in the form of an inclined plane that is steeper than or equal to 1 : 20 (5 percent) from the horizontal, together with any intermediate landing, that makes it possible to pass from one level to another.

2.57 Refuge Area — An area within the building for a temporary use during egress. It generally serves as a staging area which is protected from the effect of fire and smoke. The lift lobby spaces provided with adequate area (called refuge spaces) on all floors within the firefighting shaft can also serve as an alternate to refuge areas.

NOTE — Such refuge areas/spaces on every floor of firefighting shaft's lift lobby provide staging opportunity to those persons residing on any floor and are incapable of rescuing out of the building themselves.

2.58 Roof Exits — A means of escape on to the roof of a building, where the roof has access to it from the ground through alternative staircase or adjacent building.

2.59 Separated Occupancy — A multiple occupancy where the occupancies are separated by fire resistance–rated assemblies.

NOTE — Separate occupancy of a building is not incidental to the principal/main occupancy of that building.

2.60 Site (Plot) — A parcel (piece) of land enclosed by definite boundaries.

2.61 Smoke Barrier — A continuous membrane, or a membrane, where such membrane is designed and constructed to restrict the movement of smoke.

2.62 Smoke Compartment — A space within a building enclosed by smoke barriers on all sides.

2.63 Stack Pressure — Pressure difference caused by a temperature difference creating an air movement within a duct, chimney, or enclosure.

2.64 Travel Distance — The distance to be travelled from any point in a building to a protected exit or external escape route or final exit measured along the line of travel.

2.65 Ventilation — Supply of outside air into, or the removal of inside air from, an enclosed space.

2.66 Venting Fire — The process of facilitating heat and smoke to leave a building as quickly as possible by such paths so that lateral spread of fire and heat is checked, firefighting operations are facilitated, and minimum fire damage is caused.

2.67 Visual Strobes/Flashing — It is an audio-visual fire alarm for alerting persons with hearing impairment with flashing light. The strobe frequency should be from 0.5 Hz to 4.0 Hz, or as may be decided by the State Fire Authority, subject to performance required in smoke scenario.

NOTE — Care should be taken to ensure that overlapping strobes do not combine to result in a higher frequency of flashing.

2.68 Volume to Plot Area Ratio (VPR) — The ratio of volume of building measured in cubic metre to the area of the plot measured in square metre and expressed in metre.

2.69 Water Based Systems

2.69.1 *Hydrant System* — A distribution system having a network of piping installed underground/above-ground around and/or through inside of a building with internal and/or external hydrants fitted with landing valves at regular intervals according to the occupancy. The distribution system is connected to water supply system for firefighting.

2.69.2 *Automatic Sprinkler System* — A system of water pipes fitted with sprinkler heads at suitable intervals and heights and designed to actuate automatically, control and extinguish a fire by the discharge of water.

2.69.3 *Automatic Water Spray Systems* — A special fixed pipe system connected to a reliable source of fire protection water supply and equipped with water spray nozzles for specific water discharge and distribution over the surface or area to be protected. The piping system is connected to the water supply through an automatically actuated deluge valve which initiates flow of water. Automatic actuation is achieved by operation of automatic detecting equipment installed along with water spray nozzles. There are two types of systems namely high velocity and medium velocity systems.

2.69.4 *Water Mist Systems* — A distribution system connected to a pumping and water supply system that is equipped with nozzles capable of delivering water mist to the part/entire enclosure or area, intended to control, suppress, or extinguish fire and is capable of meeting the specified performance requirements.

2.69.5 *Foam Protection System* — Firefighting systems where foam is made by mechanically mixing air with a solution consisting of fresh water to which a foaming agent (liquid concentrate) has been added. Firefighting foam is a stable aggregation of small bubbles of density lower than oil or water, and shows tenacious qualities for covering horizontal surfaces. There are three types of foam applications, that is, low, medium, and high expansion foams depending upon the application.

2.70 Wet Riser — An arrangement for firefighting within the building by means of vertical rising mains not less than 100 mm nominal diameter with landing valves on each floor/landing for firefighting purposes and permanently charged with water from a pressurized supply.

NOTE — For definition of other terms, reference be made to accepted standards [F(3)].

3 FIRE PREVENTION

3.1 Classification of Buildings Based on Occupancy

3.1.1 *General Classification*

All buildings, whether existing or hereafter erected, should be classified according to use or the character of occupancy in one of the following groups:

Group A: Residential

Group B: Educational

Group C: Institutional

Group D: Assembly

Group E: Business

Group F: Mercantile

Group G: Industrial

Group H: Hazardous

Group J: Storage

Group K: Mixed use

The details of each occupancy and example of buildings in each group are given in **3.1.2** to **3.1.11**.

3.1.1.1 *Minor occupancy*

This is purely incidental to operations in a main occupancy, which should be considered as part of the main occupancy and should be classified under the relevant group for the main occupancy. Minor occupancy should not exceed 30 percent of the floor area. When the area exceeds 30 percent, it should be categorized as mixed occupancy (**3.1.11**).

3.1.1.2 *Mixed occupancy*

Where two or more types of occupancies intermingle in the same building, the entire building should be treated as mixed occupancy and the same should comply with **3.1.11**.

3.1.2 *Group A*: *Residential Buildings*

These include any building in which sleeping accommodation is provided for normal residential purposes with or without cooking or dining or both facilities, except any building classified under Group C.

Buildings and structures under Group A are subdivided as follows:

a) *Subdivision A*-I *Lodging and rooming houses* — These include any building or group of buildings under the same management, in which separate sleeping accommodation on a transient or permanent basis, with or without dining facilities but without cooking facilities for individuals is provided. This includes inns, clubs, motels, and guest houses. If sleeping accommodation for more than 20 persons is provided in any one residential building, it is classified here OR as a building in Subdivision A-III as the case may be.

   NOTE — A lodging or rooming house is classified as a one or two family dwelling, if no room in any of its private dwelling units is rented to more than three persons.

b) *Subdivision A*-II *Dormitories* — These include any building in which group sleeping accommodation is provided, with or without dining facilities for persons who are not members of the same family, in one room or a series of closely associated rooms under joint occupancy and single management, for example, school and college dormitories, students, and other hostels and military barracks.

c) *Subdivision A*-III *Apartment houses* — These include any building or structure in which living quarters are provided for three or more families, living independently of each other and with independent cooking facilities, for example, apartment houses, mansions and Chawls.

d) *Subdivision A*-IV *Hotels* — These include any building or group of buildings under single management, in which sleeping accommodation is provided, with or without dining facilities for hotels classified up to Four Star Category.

e) *Subdivision A*-V *Starred hotels* — These include the hotels duly approved by the concerned authorities as Five Star and above hotels.

3.1.3 *Group B*: *Educational Buildings*

These include any building used for school, college, other training institutions involving assembly for instruction, education, or recreation for not less than 20 students.

In the case of temporary buildings/structures which are utilized for educational purposes, the provisions of **3.2.3** apply.

If residential accommodation is provided in the schools/institutions, that portion of occupancy should be classified as a building in Subdivision A-II.

3.1.4 *Group C*: *Institutional Buildings*

These include any building which is used for purposes, such as medical or other treatment or care of persons suffering from physical or mental illness, disease, or infirmity; care of infants, convalescents, or aged persons and for penal or correctional detention in which the liberty of the inmates is restricted. Institutional buildings ordinarily provide sleeping accommodation for the occupants.

Buildings and structures under Group C are further subdivided as follows:

a) *Subdivision C*-I *Hospitals and sanatoria* — This subdivision includes any building or a group of buildings under single management, which is used for housing persons suffering from physical limitations because of health or age and those incapables of self-preservation, for example, hospitals, infirmaries, sanatoria, and nursing homes;

b) *Subdivision C*-II *Custodial institutions* — This subdivision includes any building or a group of buildings under single management, which is used for the custody and care of persons, such as children, convalescents and the aged who are incapable of self-preservation, for example, homes for the aged and infirm, convalescent homes and orphanages; and

c) *Subdivision C*-III *Penal and mental institutions* — This subdivision includes any building or a group of buildings under single management, which is used for housing persons under restraint, or who are detained for penal or corrective purposes, in which the liberty of the inmates is restricted, for example, jails, prisons, mental hospitals, mental sanatoria and reformatories.

3.1.5 *Group D*: *Assembly Buildings*

These include any building where not less than 50 persons congregate or gather for amusement, recreation, social, religious, patriotic, civil, travel and similar purposes, for example, shopping malls, theatres/multiplexes, motion picture houses; assembly halls; auditoria; exhibition halls; museums; skating rinks; gymnasiums; restaurants/food courts; places of worship; dance halls; club rooms; passenger stations and terminals of air, surface and marine public transportation services; stadia; and underground and elevated railways.

3.1.6 *Group E*: *Business Buildings*

These include any building which is used for transaction of business for keeping of accounts and records and similar purposes, professional establishments, service facilities, etc, city halls, town halls, courthouses and libraries are classified in this group so far as the principal function of these is transaction of public business and keeping of books and records. These occupancies also include laboratories, outpatient clinics, research establishments, libraries, test houses, electronic data processing centres, computer installations, information technology parks and call centres; telephone exchanges; broadcasting stations, T.V. stations, and air traffic control towers; and datacentres.

Buildings under Group E are further subdivided as follows:

a) Subdivision E-I Business buildings (human occupied); and

b) Subdivision E-II Datacentres (machine environment).

3.1.7 *Group F Mercantile Buildings*

These include any building which is used as shops, stores, market, for display and sale of merchandise, either wholesale or retail.

Mercantile buildings are further subdivided as follows:

a) Subdivision F-I Shops, stores, departmental stores, markets; and

b) Subdivision F-II Underground shopping centres.

3.1.8 *Group G*: *Industrial Buildings*

These include any building or structure, in which products or materials of all kinds and properties are fabricated, assembled, manufactured, or processed, for example, assembly plants, industrial laboratories, dry cleaning plants, power plants, generating units, pumping stations, fumigation chambers, laundries, buildings or structures in gas plants, refineries, dairies and saw-mills, etc.

Buildings under Group G are further subdivided as follows:

a) Subdivision G-I Buildings used for low hazard industries;

b) Subdivision G-II Buildings used for moderate hazard industries; and

c) Subdivision G-III Buildings used for high hazard industries.

The hazard of occupancy, for the purpose of this NBCS, should be the relative danger of the start and spread of fire, the danger of smoke or gases generated, the danger of explosion or other occurrences potentially endangering the lives and safety of the occupants of the buildings.

Hazard of occupancy should be determined by the Authority on the basis of the fire loads of the contents, and the processes or operations conducted in the building, provided, however, that where the combustibility of the material, the flame spread rating of the interior finish or other features of the building or structure are such as to involve a hazard greater than the occupancy hazard, the greater degree of hazard should govern the classification.

For determination of fire loads for arriving at the classification of occupancy hazard, guidance on calorific values of some common materials is given at Annex A.

A broad classification of industrial occupancies based on ‘fire hazard only’ into low, moderate, and high hazard classes is given at Annex B, for guidance. Any occupancy not covered in Annex B, should be classified in the most appropriate class depending on the degree of hazard.

> NOTE — This Annex B is only based on 'fire hazard'. Other classification of industries based on chemical hazard, pollution, etc, are not addressed in this NBCS.

Where different degrees of hazard of occupancy exist in different parts of a building, the most hazardous of those should govern the classification for the purpose of this NBCS, except in cases where hazardous areas are segregated or protected as specified in this NBCS.

a) *Subdivision G*-I — This subdivision includes any building in which the contents are of such comparative low combustibility and the industrial processes or operations conducted therein are of such a nature that there is hardly any possibility for any self-propagating fire to occur and the only consequent danger to life and property may arise from panic, fumes or smoke, or fire from some external source;

b) *Subdivision G*-II — This subdivision includes any building in which the contents or industrial processes or operations conducted therein are liable to give rise to a fire which will burn with moderate rapidity or result in other hazardous situation and may give off a considerable volume of smoke, but from which neither toxic fumes nor explosions are to be feared in the event of fire; and

c) *Subdivision G*-III — This subdivision includes any building in which the contents or industrial processes or operations conducted therein are liable to give rise to a fire which will burn with extreme rapidity or result in other hazardous situation or from which poisonous fumes or explosions are to be feared in the event of a fire.

3.1.9 *Group H*: *Storage Buildings*

These include any building primarily for the storage or sheltering (including servicing, processing or repairs incidental to storage) of goods, ware or merchandise (except those that involve highly combustible or explosive products or materials), vehicles or animals, for example, warehouses, cold storages, freight depots, transit sheds, storehouses, truck and marine terminals, garages, hangars, grain elevators, barns and stables. Storage properties are characterized by the presence of relatively small number of persons in proportion to the area. Any new use which increases the number of occupants to a figure comparable with other classes of occupancy should change the classification of the building to that of the new use, for example, hangars used for assembly purposes, warehouses used for office purposes, garage buildings used for manufacturing.

3.1.10 *Group J*: *Hazardous Buildings*

These include any building which is used for the storage, handling, manufacture or processing of highly combustible or explosive materials or products which are liable to burn with extreme rapidity and/or which may produce poisonous fumes or explosions for storage, handling, manufacturing or processing which involve highly corrosive, toxic or noxious alkalis, acids or other liquids or chemicals producing flame, fumes and explosive, poisonous, irritant or corrosive gases; and for the storage, handling or processing of any material producing explosive mixtures of dust which result in the division of matter into fine particles subject to spontaneous ignition. Examples of buildings in this class are those buildings which are used for,

a) storage, under pressure of more than 0.1 N/mm^2 and in quantities exceeding 70 m^3, of acetylene, hydrogen, illuminating and natural gases, ammonia, chlorine, phosgene, sulphur dioxide, carbon dioxide, methyl oxide and all gases subject to explosion, fume or toxic hazard, cryogenic gases, etc;

b) storage and handling of hazardous and highly flammable liquids, liquefiable gases like LPG, rocket propellants, etc;

c) storage and handling of hazardous and highly flammable or explosive materials (other than liquids); and

d) manufacture of artificial flowers, synthetic leather, ammunition, explosives, and fireworks.

> NOTE — A list of hazardous substances giving quantities, for which or exceeding which owners handling such substances are required to be covered under The *Public Liability Insurance Act*, 1991, has been notified under the 'Rules on Emergency Planning, Preparedness and Response for Chemical Accidents' by the Government of India, Ministry of Environment and Forests Notification No. G.S.R. 347(E) dated 01 August 1996.

3.1.11 *Group K*: *Mixed Occupancy*

3.1.11.1 These include any building having multiple occupancy where the occupancies are intermingled. The following table guides on the possible mixing of occupancies (two or more occupancies may be mixed) in a building.

Sl No.	*Occupancy to be Mixed with*	*Minimum Required Fire Resistance Rating for the Separation between Any Two Occupancies* in min										
		Residential	**Educational**	**Institutional**	**Assembly**	**Business**	**Mercantile**	**Industrial**			**Storage**	**Hazardous**
								Low (G-1)	**Moderate (G-2)**	**High (G-3)**		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
i)	**Residential**	–	120	120	120	120	120	120	NP	NP	NP	NP
ii)	**Educational**	120	–	120	120	120	120	NP	NP	NP	NP	NP
iii)	**Institutional**	120	120	–	120	120	120	NP	NP	NP	NP	NP
iv)	**Assembly**	120	120	120	–	120	120	120	120	NP	NP	NP
v)	**Business**	120	120	120	120	–	120	120	120	240	NP	NP
vi)	**Mercantile**	120	120	120	120	120	–	120	120	NP	120	NP
vii)	**Industrial – Low (G-1)**	120	NP	NP	120	120	120	–	120	240	120	NP
viii)	**Industrial – Moderate (G-2)**	NP	NP	NP	120	120	120	120	–	240	180	240
ix)	**Industrial – High (G-3)**	NP	NP	NP	NP	240	NP	240	240	–	240	240
x)	**Storage**	NP	NP	NP	NP	NP	120	120	180	240	–	240
xi)	**Hazardous**	NP	NP	NP	NP	NP	NP	NP	240	240	240	–

NP – Not permitted, being highly dangerous/vulnerable.

3.1.11.2 For mixed occupancy building typology as above, if these co-exist in a building (such as large retail occupancy and business occupancy), in so far as fire protection is concerned, the entire building should be governed by the most restrictive provisions of this NBCS among those applicable for individual occupancies. However, the exits can be shared between mixed occupancies provided its aggregate provision meets the requirement of the mixed occupancy, and should be permitted if such exits are with unrestricted egress of the occupants based on the business operational hours of the occupancies sharing such exits. If such unrestricted egress of the mixed-use occupancy is not planned, each occupancy should be provided with its independent exits.

Exits in such mixed occupancy should be so arranged as to ensure that means of egress is not decreased in the direction of egress travel.

Further, in such mixed occupancies, the occupancies are also required to be separated (horizontally and/or vertically as the case may be) by fire resistance rating, *see* 3.1.11.1.

3.1.12 Where change in the occupancy of any building places it in a different group or in a different subdivision of the same group, such building should be made to comply with the requirements of this NBCS for the new group or its subdivision.

3.1.13 Where the new occupancy of a building is less hazardous, based on life and fire risk, than its existing occupancy, it should not be necessary to conform to the requirements of this NBCS for the new group or its subdivision.

3.1.14 A certificate of occupancy should be necessary, before any change is effected in the character of occupancy of any building.

3.2 Temporary Buildings or Structures

3.2.1 Temporary buildings and structures may be permitted according to the purpose for which these are to be used, by special permit from the Authority for a limited period and subject to such conditions as may be imposed in the permit.

3.2.2 Such buildings and temporary structures should be completely removed on the expiry of the period specified in the permit.

3.2.3 Adequate fire precautionary measures in the construction of temporary structures and *Pandals* should be taken in accordance with good practice [F(4)].

3.3 Existing Buildings

The existing buildings need not be required to comply with the requirements of this part unless these are altered, or in the opinion of the Local Authority, such building constitutes a hazard to the safety of the adjacent property or to the occupants of the building itself or is an unsafe building. In the event of alteration, it should be necessary to obtain permission of the Authority for such alteration consistent with fire hazard.

Alterations/modifications/renovations should be accomplished so as to ensure conformity with all the safety requirements of the new buildings. Such alterations should not in any way bring down level of fire and life safety below that which existed earlier. Any addition or alterations or construction of cubicles or partitioning (that will effect/increase the travel distance requirement), changes in the typology of the occupancy or densification of an existing occupancy for floor area exceeding 1 000 m^2 should be with the approval of local fire authority.

3.4 Types of Construction

3.4.1 The design of any building and the type of materials used in its construction are important factors in making the building resistant to a complete burn-out and in preventing the rapid spread of fire, smoke, or fumes, which may otherwise contribute to the loss of lives and property.

The fire resistance of a building or its structural and non-structural elements is expressed in minutes against a specified fire load which is expressed in $kcal/m^2$, and against a certain intensity of fire. The fire-resistance test for structural element should be done in accordance with accepted standards [F(2)]. For the purpose of this Part, the types of construction according to fire resistance should be classified into four categories, namely, Type 1 Construction, Type 2 Construction, Type 3 Construction and Type 4 Construction. The minimum fire resistance ratings of structural and non-structural members for various types of construction is given in Table 1.

Non-combustible materials should be used for construction of buildings, and the internal walls of staircase enclosures should be of brick work or reinforced concrete or any other material of construction with minimum of 120 min rating. The walls for the chimney should be of Type 1 or Type 2 Construction depending on whether the flue gas temperature is above 200 °C or less, respectively.

3.4.2 It is required that a structural and/or non-structural element/component to have the requisite fire resistance rating as per Table 1. The fire resistance rating for the structural and non-structural elements are based on guidelines as per approved and accepted standards. The fire rating should be validated and certified with a view to meeting the requirements of Table 1. In the absence of any validated/certified rating, guidance may be obtained from the information available in Annex C.

3.4.3 Load bearing steel beams and columns of buildings having total covered area of 500 m^2 and above need to be protected against failure/collapse of structure in case of fire. This could be achieved by use of appropriate methodology using suitable fire resistance rated materials along with suppression system (*see* Annex C, Table 25, and Table 26).

3.4.4 The false ceiling, including all fixtures used for its suspension, need to be of non-combustible material. To provide adequate fire resistance to the ceiling in order to prevent spread of fire across ceiling.

3.5 General Requirements of All Individual Occupancies

3.5.1 *General*

All buildings should satisfy certain requirements, which contribute, individually and collectively, to the safety of life from fire, smoke, fumes, and panic arising from these or similar causes. There are, however, certain general principles and common requirements, which are applicable to all or most of the occupancies.

Table 1 Fire Resistance Ratings of Structural and Non-Structural Elements (in minutes)

(*Clauses* 3.4.1, 3.4.2, 3.5.9.1, 3.5.9.2 *and* F-2.1)

Sl No.	**Structural/Non-Structural Element**	**Fire Resistance Ratings (min) for Type of Construction**			
		Type 1	Type 2	Type 3	Type 4
(1)	(2)	(3)	(4)	(5)	(6)
i)	Exterior walls:				
	a) Fire separation less than 3.7 m:				
	1) Bearing	240	120	120	60
	2) Non-bearing	120	90	60	60
	b) Fire separation of 3.7 m or more but less than 9 m:				
	1) Bearing	240	120	120	60
	2) Non-bearing	90	60	60	60
	c) Fire separation of 9 m or more:				
	1) Bearing	240	120	120	60
	2) Non-bearing	60	60	60	60
ii)	Fire separation assemblies (like fire check doors)	120	120	120	120
iii)	Fire enclosures of exits	120	120	120	120
iv)	Shafts for services, lift hoistway and refuse chutes	120	120	120	120
v)	Vertical separation between adjacent tenant spaces	60	60	60	60
vi)	Dwelling unit separation:				
	a) Load bearing	120	120	60	60
	b) Non-load bearing	60	60	30	30
vii)	Interior bearing walls, bearing partitions, columns, beams, girders, trusses (other than roof trusses) and framing				
	a) Supporting more than one floor	240	120	120	120
	b) Supporting one floor only	180	90	60	60
	c) Supporting a roof only	180	90	60	60

Sl No.	Structural/Non-Structural Element	Fire Resistance Ratings (min) for Type of Construction			
		Type 1	Type 2	Type 3	Type 4
(1)	(2)	(3)	(4)	(5)	(6)
viii)	Walls supporting structural members	180	90	60	60
ix)	Floor construction	120	90	60	60
x)	Roof construction:				
	a) 5 m or less in height to lowest member	120	90	60	60
	b) More than 5 m but less than 6.7 m in height to lowest member	60	60	60	60
	c) 6.7 m or more in height to lowest member	0 60*	0 60*	0 60*	0 60*
* 60 min should be adopted when associated building services/cables are running at higher levels and supported from/near the roof, like in airports.					

3.5.2 *Exceptions and Deviations*

Exceptions and deviations to the general provisions of requirements of individual occupancies are given as applicable to each type of occupancy in 6.1 to 6.9. In case of practical difficulty or to avoid unnecessary hardship, without sacrificing reasonable safety, local head, fire services may consider exemptions from this Part.

3.5.3 *Occupation of Buildings under Construction*

3.5.3.1 A building or portion of the building may be occupied during construction, repairs, alterations, or additions only if all means of exit and fire protection measures are in place and continuously maintained for the occupied part of the building.

3.5.3.2 A high rise building during construction should be provided with the following fire protection measures, which should be maintained in good working condition at all the times:

a) Dry riser of minimum 100 mm diameter pipe with hydrant outlets on the floors constructed with a fire service inlet to boost the water in the dry riser and maintenance should be in accordance with good practice [F(5)].

b) Drums of 2 000 litre capacity filled with water with two fire buckets on each floor;

c) A water storage tank of minimum 20 000 litre capacity, which may be used for other construction purposes also.

3.5.4 *Openings in Fire Resistant Walls and Floors*

3.5.4.1 At the time of designing openings in fire-resistant walls and floors, particular attention should be paid to all such factors which limit fire spread through these openings and maintain fire rating of the structural members.

3.5.4.2 For Types 1 to 3 constructions, a doorway or opening in a fire resistant wall on any floor should be limited to 5.6 m^2 in area with a maximum height/width of 2.75 m. Every wall opening should be protected with fire-resisting doors, having the fire rating of not less than 120 min. The openings in the floors should be protected by vertical enclosures extending above and below such openings, such enclosures having a fire resistance of not less than 120 min and all openings therein being protected with a fire-resisting assembly as specified in 3.5.4.6.

For escalator-like openings, the smoke spill should be avoided by provision of smoke barrier (of 450 mm to 600 mm) thereby creating smoke compartment. Further, the protection should be ensured through installation of sprinklers on all sides of the cut out opening on each floor (*see* Fig. 5 for details).

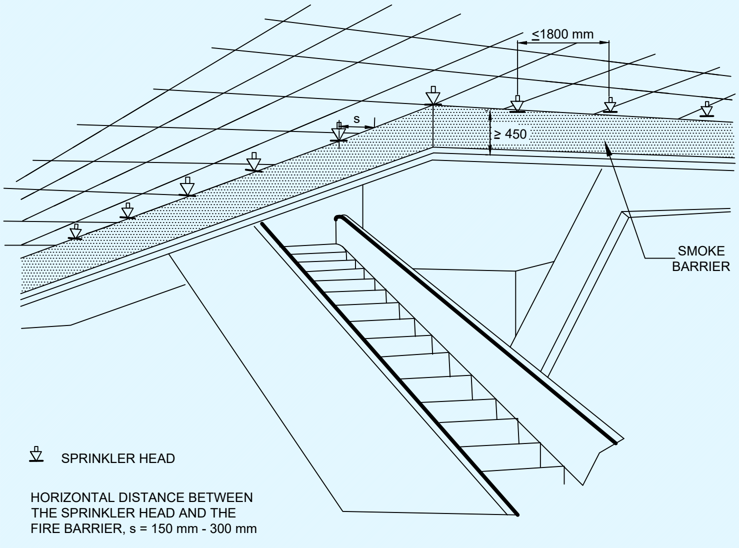

≤1800 mm
s
≥ 450
SMOKE BARRIER
SPRINKLER HEAD
HORIZONTAL DISTANCE BETWEEN THE SPRINKLER HEAD AND THE FIRE BARRIER, s = 150 mm - 300 mm

FIG. 5 SPRINKLERS AROUND ESCALATOR OPENING

3.5.4.3 For Type 4 construction, openings in the fire separating walls or floors should be fitted with 120 min fire-resistance rated assemblies.

3.5.4.4 *Service ducts and shafts*

Openings in walls or floors which are necessary to be provided to allow passages of all building services like cables, electrical wirings, telephone cables, plumbing pipes, etc, should be protected by enclosure in the form of ducts/shafts having a fire resistance not less than 120 min. The inspection door for electrical shafts/ducts should be not less than 120 min, with 30 min insulation. Further, medium, and low voltage wiring running in shafts/ducts, should either be armoured type or run through metal conduits.

The space between the electrical cables/conduits and the walls/slabs should be filled in by a fire stop material {see accepted standard [F(34)]} having fire resistance rating of not less than 120 min. This should exclude requirement of fire stop sealing for low voltage services shaft.

For plumbing shafts in the core of the building, with shaft door opening inside the building, the shafts should have inspection doors having fire resistance rating not less than 30 min.

For plumbing shafts doors which open in wet areas or in naturally ventilated areas or on external wall of the building, the shafts may not require doors having any specified fire rating.

NOTE — In the case of buildings where it is necessary to lower or lift heavy machinery or goods from one floor to the other, it may be necessary to provide larger openings in the floor. Such openings should be provided with removable covers which should have the same strength and fire resistance as the floor.

3.5.4.5 *Refuse chutes*

Refuse chutes, if any provided in a building, should have opening at least 1 m above roof level for venting purpose and they should have an enclosure wall of non-combustible material with fire resistance of not less than 120 min. They should not be located within the staircase enclosure or service shafts, or air conditioning shafts. Refuse chutes inspection panel and doors should be tight fitting with 60 min fire resistance. Sprinkler protection system should be provided for the refuse chutes. Refuse chutes should be at least 3 m away from exits.

3.5.4.6 *Vertical opening*

Every vertical opening between the floors of a building should be suitably enclosed or protected, as necessary, to provide the following:

a) Reasonable safety to the occupants while using the means of egress by preventing spread of fire, smoke, or fumes through vertical openings from floor to floor to allow occupants to complete their use of the means of egress. Further it should be ensured to provide a clear height of 2 100 mm in the exit access.

b) Limitation of damage to the building and its contents.

3.5.5 *Electrical Installation*

3.5.5.1 For requirements regarding electrical installations from the point of view of fire safety, reference may be made to good practice [F(6)] and Part D 'Building Services, Section 2 Electrical and Allied Installations' of this NBCS.

In general, it is desirable that the wiring and cabling are with flame retardant property. Medium and low voltage wiring running in shafts, and within false ceiling should run in metal conduit. Any 230 V wiring for lighting or other services, above false ceiling, should have 660 V grade insulation. See also Part D/Sec 2 for wires having options of fire resistance.

The electric distribution cables/wiring should be laid in a separate shaft. The shaft should be sealed at every floor with fire stop materials, see accepted standard [F(34)] having the same fire resistance as that of the floor. High, medium, and low voltage wiring running in shaft and in false ceiling should run in separate shaft/conduits.

Water mains, gas pipes, telephone lines, intercom lines or any other service line should not be laid in the duct for electrical cables; use of bus ducts/solid rising mains instead of cables is preferred.

All metallic items like steel structural members, etc, should be bonded properly to the earthing system.

3.5.5.2 *Emergency power for fire and life safety systems*

Emergency power supplying distribution system for critical requirement for functioning of fire and life safety system and equipment should be planned for efficient and reliable power and control supply to the following systems and equipment where provided:

a) Fire pumps;

b) Pressurization and smoke venting; including its ancillary systems such as dampers and actuators;

c) Fireman's lifts (including all lifts);

d) Exit signage lighting;

e) Emergency lighting;

f) Fire alarm system;

g) Public address (PA) system (relating to emergency voice evacuation and annunciation);

h) Magnetic door hold open devices; and

j) Lighting in fire command centre and security room.

Power supply to these systems and equipment should be from normal and emergency (standby generator) power sources with changeover facility (*see* Fig. 6A and Fig. 6B indicating options). If power supply is from HV source and HV generation, the transformer should be planned in standby capacity to ensure continuity of power to such systems. Wherever transformers are installed at higher levels in buildings and backup DG sets are of higher voltage rating, then dual redundant cables should be taken to all transformers. The generator should be capable of taking the starting current of all the fire and life safety systems and equipment as above. Where a parallel HV/LV supply from a separate substation fed from a different grid is provided with an appropriate transformer for emergency, the provision of generator may be waived in consultation with the Authority.

The power supply to the panel/distribution board of these fire and life safety systems should be through fire proof enclosures (tested and certified) or fire survival cables or through alternate route in the adjoining fire compartment to ensure supply of power is reliable to these systems and equipment. It should be ensured that the cabling from the adjoining fire compartment is protected within the compartment of vulnerability. The location of the panel/ distribution board feeding the fire and life safety system should be in fire safe zone ensuring supply of power to these systems.

Circuits of such emergency system should be protected at origin by an automatic circuit breaker with its no-volt coil removed. Master switches controlling essential service circuits should be clearly labelled.

Cables for fire alarm and PA system should be laid in metal conduits or armoured to provide physical segregation from the power cables.

3.5.5.3 *Substation/Transformers*

Areas in substation should not be used as storage/dump areas or for other utility purposes other than those required for the functioning of the substation.

The substation area should be adequately ventilated.

An independent, ventilated or air conditioned electrical substation and LT panel room/area should be provided on the ground level or first basement. They should be provided with access from outside (or through exit passageway accessible from outside). The electrical substation and LT panel room/area should be provided with fire resistant walls and doors of fire resistance of not less than 120 min.

If the licensees agree to provide meters on upper floors, the licensees' cables should be segregated from consumers' cables by providing a partition in the shaft. Meter rooms on upper floors should not open into staircase enclosures and should be ventilated directly to open air outside or in electrical room of 120 min fire resistant walls.

Electrical MV main distribution panel and lift panels should be provided with CO_2/inert gas flooding system for all panel compartments with a cylinder located beside the panel.

3.5.5.3.1 *Oil filled substation*

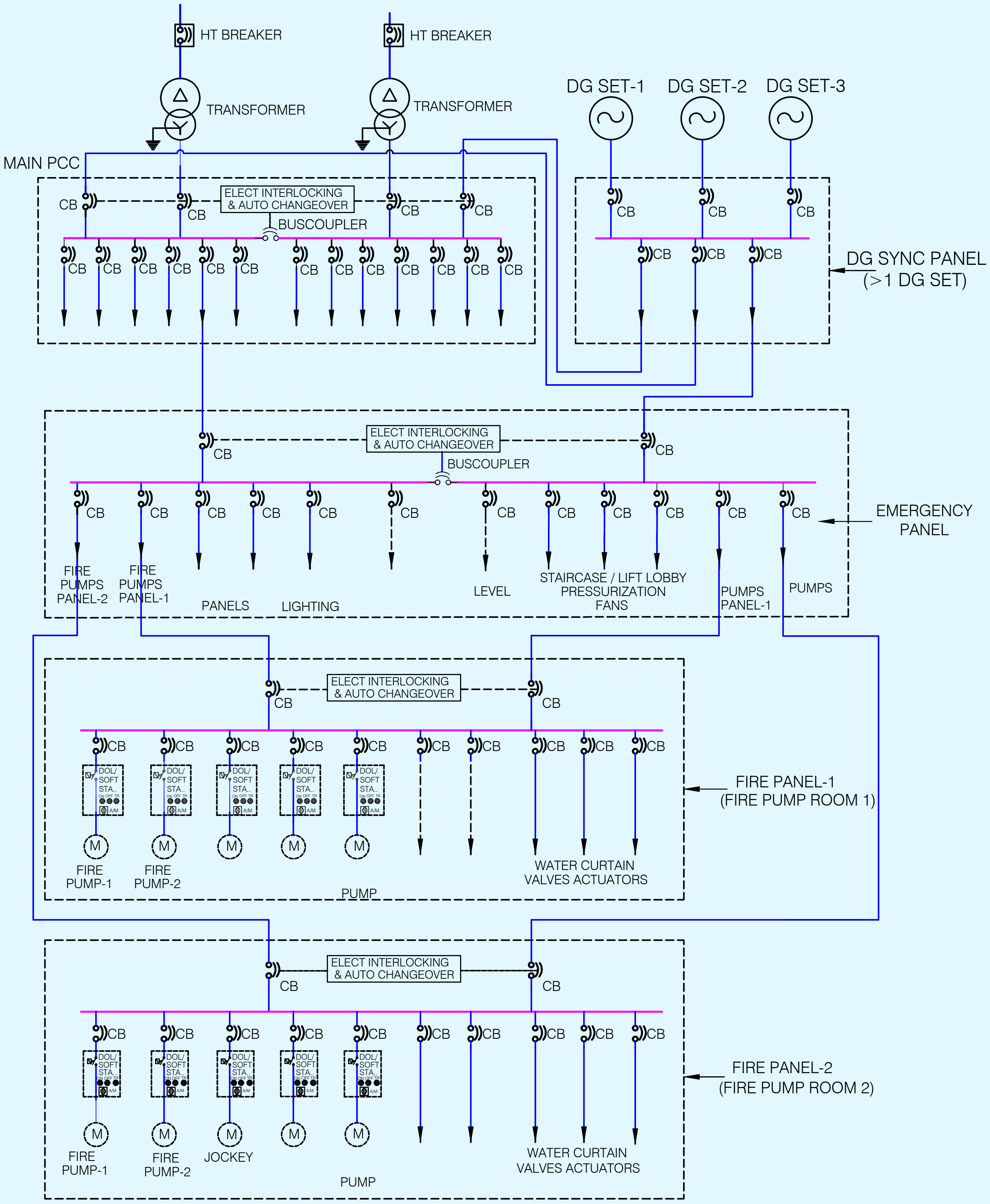
A substation or a switch-station with oil filled equipment should be limited to be installed in utility building or in outdoor location. Such substation/utility building should be at least 6 m away (or as per local requirements/actual width of fire driveway) from the adjoining building(s).

Substation equipment (exceeding aggregate oil capacity of 2 000 litre) in utility building should have fire rated baffle walls of 240 min rating constructed between such equipment, raised to at least 600 mm above the height of the equipment (including height of oil conservators/explosion vents) and exceeding 300 mm on each side of the equipment.

All transformers where capacity exceeds 10 MVA should be protected by high velocity water spray systems/ high pressure water mist system. In addition, nitrogen injection systems may also be provided where applicable.

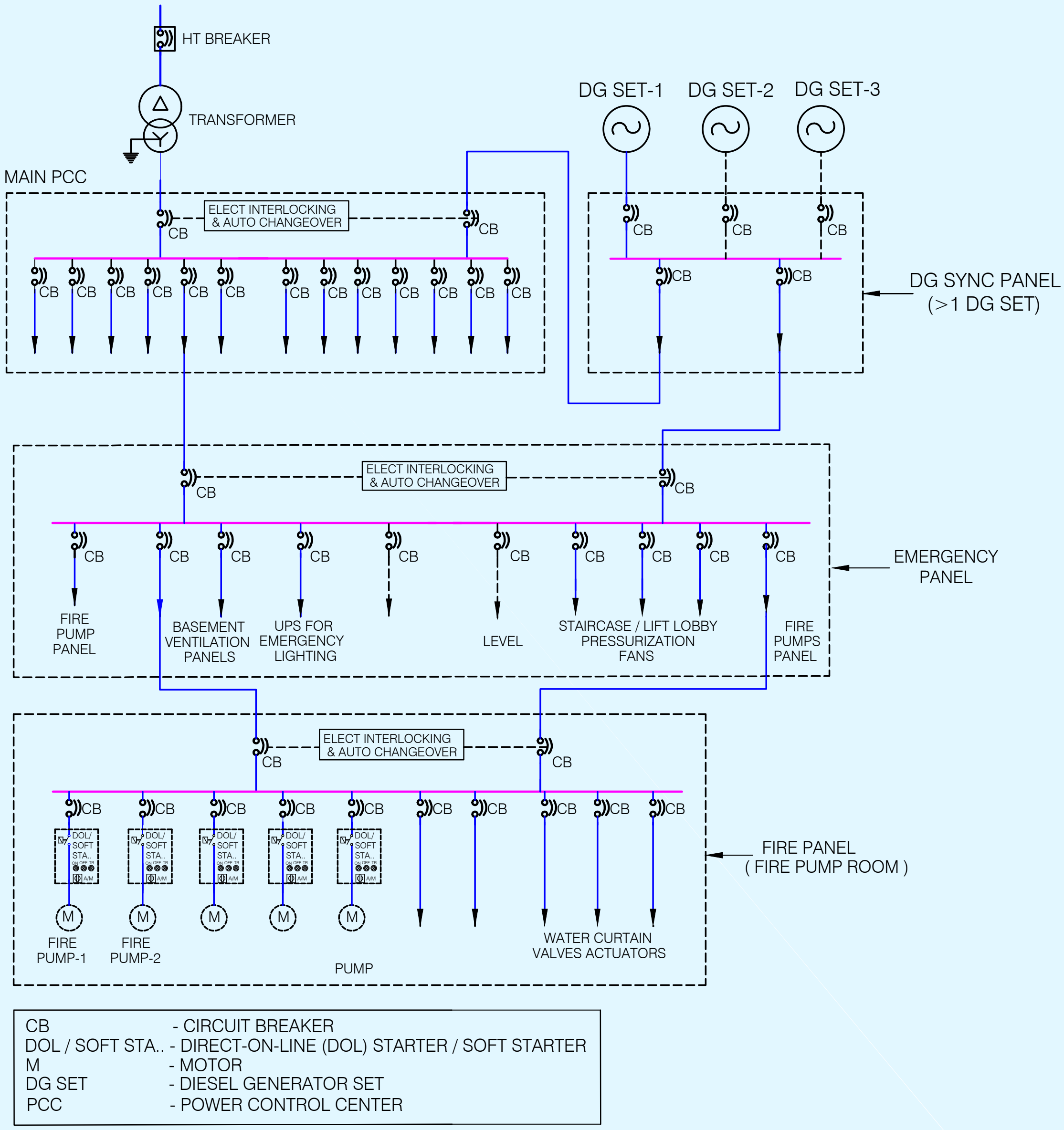
3.5.5.3.2 *Dry type substation*

Transformers located inside a building should be of dry type and all substation/switch room walls, ceiling, floor, opening including doors should have a fire resistance rating of 120 min. Access to the substation should be provided from the nearest fire exit/exit staircase for the purpose of electrical isolation.


HT BREAKER
HT BREAKER
TRANSFORMER
TRANSFORMER
DG SET-1
DG SET-2
DG SET-3
MAIN PCC
CB
ELECT INTERLOCKING
& AUTO CHANGEOVER
BUSCOUPLER
DG SYNC PANEL
(>1 DG SET)
ELECT INTERLOCKING
& AUTO CHANGEOVER
BUSCOUPLER
EMERGENCY
PANEL
FIRE
PUMPS
PANEL-2
FIRE
PUMPS
PANEL-1
PANELS
LIGHTING
LEVEL
STAIRCASE / LIFT LOBBY
PRESSURIZATION
FANS
PUMPS
PANEL-1
PUMPS
ELECT INTERLOCKING
& AUTO CHANGEOVER
DOL/
SOFT
STA..
A/M
M
FIRE
PUMP-1
FIRE
PUMP-2
PUMP
WATER CURTAIN
VALVES ACTUATORS
FIRE PANEL-1
(FIRE PUMP ROOM 1)
ELECT INTERLOCKING
& AUTO CHANGEOVER
FIRE
PUMP-1
FIRE
PUMP-2
JOCKEY
PUMP
WATER CURTAIN
VALVES ACTUATORS
FIRE PANEL-2
(FIRE PUMP ROOM 2)

CB	- CIRCUIT BREAKER
DOL / SOFT STA..	- DIRECT-ON-LINE (DOL) STARTER / SOFT STARTER
M	- MOTOR
DG SET	- DIESEL GENERATOR SET
PCC	- POWER CONTROL CENTER

6A FIRE PUMP CIRCUIT DEPICTING DISTRIBUTION SCHEME WITH MULTIPLE TRANSFORMERS AND DG SETS


HT BREAKER
TRANSFORMER
MAIN PCC
ELECT INTERLOCKING & AUTO CHANGEOVER
CB
DG SET-1
DG SET-2
DG SET-3
DG SYNC PANEL (>1 DG SET)
EMERGENCY PANEL
FIRE PUMP PANEL
BASEMENT VENTILATION PANELS
UPS FOR EMERGENCY LIGHTING
LEVEL
STAIRCASE / LIFT LOBBY PRESSURIZATION FANS
FIRE PUMPS PANEL
FIRE PANEL (FIRE PUMP ROOM)
DOL/ SOFT STA..
M
FIRE PUMP-1
FIRE PUMP-2
PUMP
WATER CURTAIN VALVES ACTUATORS
CB - CIRCUIT BREAKER
DOL / SOFT STA.. - DIRECT-ON-LINE (DOL) STARTER / SOFT STARTER
M - MOTOR
DG SET - DIESEL GENERATOR SET
PCC - POWER CONTROL CENTER

6B FIRE PUMP CIRCUIT DEPICTING DISTRIBUTION SCHEME WITH SINGLE TRANSFORMER AND DG SETS

FIG. 6 FIRE PUMP CIRCUIT DRAWINGS

3.5.5.4 *Standby supply*

Diesel generator set(s) should not be installed at any floor other than ground/first basement. If the same are installed indoors, proper ventilation and exhaust should be planned. The DG set room should be separated by 120 min fire resistance rated walls and doors.

The oil tank for the DG sets (if not in the base of the DG) should be provided with a dyked enclosure having a volumetric capacity of at least 10 percent more than the volume of the oil tank. The enclosure should be filled with sand for a height of 300 mm.

See Table 9 for specific fire protection guidelines. For detailed information regarding fire safety requirements for hazardous petroleum products, reference may be made to *The Petroleum Act*, 1934 and the Rules framed thereunder.

3.5.5.5 *Lightning protection of buildings*

Routing of down conductors (insulated or uninsulated) of lightning protection through electrical or other service shafts are not allowed as it can create fire and explosion during lightning. For details, *see* Part D 'Building Services, Section 2 Electrical and Allied Installations' of this NBCS.

3.5.6 *Escape Lighting and Exit Signage*

Exit access, exits, and exit discharge should be properly identified, with adequate lighting maintained in the elements of the egress systems so that all occupants should be able to leave the facility safely.

3.5.6.1 *Lighting*

a) The exit, exit access and exit discharge systems should be illuminated continuously. The floors of the means of egress should be illuminated at all points, including angles and intersections, in corridors and passageways, stairwells, landings of stairwells and fire exit;

b) Emergency lighting should be powered from a source independent of that supplying the normal lighting;

c) Escape lighting should be capable of,

    1) indicating clearly and unambiguously the escape routes;

    2) providing adequate illumination along such routes to allow safe movement of persons towards and through the fire exits; and

    3) ensuring that fire alarm call points and firefighting equipment provided along the escape routes can be readily located.

d) The horizontal luminance at floor level on the centreline of an escape route should not be less than 10 lumen/m^2. In addition, for escape routes up to 2 m wide, 50 percent of the route width should be lit to a minimum of 5 lumen/m^2. In auditoriums, theatres, concert halls and such other places of assembly, the illumination of floor exit/access may be reduced during period of performances to values not less than 2 lux;

e) Required illumination should be arranged such that the failure of any single lighting unit, such as the burning out of one luminaire, will not leave any area in darkness and does not impede the functioning of the system further;

f) The emergency lighting should be provided to be put on within 5 s of the failure of the normal lighting supply. Also, emergency lighting should be able to maintain the required illumination level for a period of not less than 90 min in the event of failure of the normal lighting even for smaller premises;

g) Battery pack emergency lighting, because of its limited duration and reliability, should not be allowed to be used in lieu of a diesel engine driven emergency power supply;

h) Escape lighting luminaires should be sited to cover the following locations:

    1) Near each intersection of corridors,

    2) At exits and at each exit door,

    3) Near each change of direction in the escape route,

    4) Near each staircase so that each flight of stairs receives direct light,

    5) Near any other change of floor level,

    6) Outside each final exit and close to it,

    7) Near each fire alarm call point,

    8) Near firefighting equipment, and

    9) To illuminate exit and safety signs as required by the enforcing authority.

    NOTE — For the purpose of this clause 'near' is normally considered to be within 2 m measured horizontally.

j) The luminaires should be mounted as low as possible, but at least 2 m above the floor level; and

k) Signs are required at all exits, emergency exits and escape routes, which should comply with the graphic requirements of the relevant Indian Standards.

3.5.6.2 Exit passageway and staircase lighting should also be connected to alternative supply. The alternative source of supply may be provided by battery continuously trickle charged from the electric mains. Suitable arrangements should be made by installing double throw switches to ensure that the lighting installed in the staircase and the corridor does not get connected to two sources of supply simultaneously. Double throw switch should be installed in the service room for terminating the stand-by supply.

3.5.6.3 The emergency lighting system should be well maintained by periodical inspections and tests so as to ensure their perfect serviceability at all times.

3.5.6.4 *Exit signage*

Where exit access is provided through corridors/paths, the occupants should be able to easily identify the way to exits. Exit signs should be provided such that no point in an exit access is more than 30 m from a visible exit directional sign. An exit sign indicating the direction to an exit should be provided at all changes in direction.

Exits should be clearly visible and the route to reach the exits should be clearly marked and signs posted to guide the occupants of the floor concerned. Signs should be illuminated and wired to an independent electrical circuit on an alternative source of supply. The sizes and colours of the exit signs should be in accordance with good practice [F(7)]. The colour of the exit signs should be green.

NOTE — This provision should not apply to A-II and A-IV occupancies less than 15 m in height.

The exit sign with arrow indicating the way to the escape route should be provided at a suitable height from the floor level on the wall and should be illuminated by electric light connected to corridor circuits. All exit way marking signs should be so installed that no mechanical damage should occur to them due to moving of furniture or other heavy equipment. Further, all landings of floor should have floor indicating boards prominently indicating the number of the floor.

Photo luminescent markings should be pasted at internal hydrant boxes.

3.5.7 *Air Conditioning, Ventilation and Smoke Control*

3.5.7.1 Air conditioning and mechanical ventilation requirements of different rooms or areas in any occupancy should be as given in Part D 'Building Services, Section 1 Lighting and Natural Ventilation' and 'Section 3 Air conditioning, Heating and Mechanical Ventilation' of this NBCS.

Air conditioning and ventilating systems should be so installed and maintained as to minimize the danger of spread of fire, smoke, or fumes from one floor to another or from outside to any occupied building or structure.

Many high-rise buildings integrate smoke management systems into their conventional HVAC systems. In such installation, it requires special design considerations, including safe and adequate controls, acceptable and documented testing, and regular maintenance systems.

Wherever batteries are provided, the same should be segregated by 120 min fire rated construction. Ventilation to the room should be provided as per manufacturer's instructions.

3.5.7.2 *Air handling unit*

3.5.7.2.1 From fire safety point of view, separate air handling units (AHU) for each floor should be provided so as to avoid the hazards arising from spread of fire and smoke through the air conditioning ducts. The air ducts should be separate from each AHU to its floor and in no way should interconnect with the duct of any other floor. Within a floor it would be desirable to have separate air handling unit provided for each compartment.

Air handling unit should be provided with effective means for preventing circulation of smoke through the system in the case of a fire in air filters or from other sources drawn into the system, and should have smoke sensitive devices for actuation in accordance with the accepted standard [F(8)] and control.

3.5.7.2.2 Shafts or ducts, if penetrating multiple floors, should be of masonry construction with fire damper in connecting ductwork or should have fire rated ductwork with fire dampers at floor crossing. Alternatively, the duct and equipment may be installed in room having walls, doors and fire damper in duct exiting/entering the room of 120 min fire resistance rating. Such shafts and ducts should have all passive fire control meeting 120 min fire resistance rating requirement to meet the objective of isolation of the floor from spread of fire to upper and lower floors through shaft/duct work.

NOTE — Zoned and compartmented HVAC systems are encouraged with an approach to avoid common exhaust shafts and fresh air intake shafts which will limit the requirement of such passive measure and fire rated duct work and dampers.

3.5.7.2.3 The air filters of the air handling units should be made of non-combustible materials.

3.5.7.2.4 The air handling unit room should not be used for storage of any combustible materials.

3.5.7.3 *Duct work*

3.5.7.3.1 Air ducts serving main floor areas, corridors, etc, should not pass through the fire exits/exit passageway/ fire exit enclosure. Fire exits and lift lobbies, etc, should not be used as return air passage.

3.5.7.3.2 As far as possible, metallic ducts (of suitable rating) should be used even for the return air instead of space above the false ceiling.

3.5.7.3.3 Wherever the ducts pass through fire walls or floors, the opening around the ducts should be sealed with materials having fire resistance rating of the compartment {*see* accepted standard [F(34)]}. Such duct should also be provided with fire dampers at all fire walls and floors unless such ducts are required to perform for fire safety operation; and in such case fire damper may be avoided at fire wall and floor while integrity of the duct should be maintained with 120 min fire resistance rating to allow the emergency operations for fire safety requirements.

3.5.7.3.4 The ducting within compartment would require minimum fire resistance rating of 30 min. Such ducting material in substantial gauge should be in accordance with good practice [F(9)]. If such duct crosses adjacent compartment/floor and not having fire dampers in such compartment/floor, it would require fire resistance duct work rating of 120 min. The requirements of support of the duct should meet its functional time requirement as above.

3.5.7.3.5 The materials used for insulating the duct system (inside or outside) should be of non-combustible type. Any such insulating material should not be wrapped or secured by any material of combustible nature.

3.5.7.3.6 Inspection panels should be provided in the ductwork to facilitate the cleaning of accumulated dust in ducts and to obtain access for maintenance of fire dampers.

3.5.7.4 *Fire or fire/smoke dampers*

3.5.7.4.1 These dampers should be evaluated to be located in supply air ducts, fresh air and return air ducts/ passages at the following points:

a) At the fire separation wall,

b) Where ducts/passages enter the vertical shaft,

c) Where the ducts pass through floors, and

d) At the inlet of supply air duct and the return air duct of each compartment on every floor.

3.5.7.4.2 Damper should be of motorized type/fusible link. Damper should be so installed to provide complete integrity of the compartment with all passive fire protection sealing. Damper should be accessible to maintain, test and also replace, if so required. Damper should be integrated with fire alarm panel and should be sequenced to operate as per requirement and have interlocking arrangement for fire safety of the building. Manual operation facilities for damper operation should also be provided. Tested and certified dampers for dynamic condition are preferable.

3.5.8 *Heating*

3.5.8.1 Installation of chimney and heating apparatus should be in accordance with good practice [F(10)].

3.5.8.2 *Boiler rooms*

3.5.8.2.1 Provisions of boiler and boiler rooms should conform to *The Boilers Act*, 1923.

3.5.8.2.2 Further, the following additional aspects may be taken into account in the location of boiler room:

a) The boilers should be installed in a fire resisting room of 180 min fire resistance rating;

b) Entry to this room should be provided with a composite door of 120 min fire resistance rating;

c) The boiler room should be provided with its dedicated natural or mechanical ventilation system. Mechanical ventilation system for the boiler room would be accepted with 120 min fire resistance rating ductwork if it has interface with other mechanical areas. Ventilation system should not be allowed to be routed through electrical room area or through exit corridor/exits; and

d) The oil tank for the boiler should be provided with a dyked enclosure having a volumetric capacity of at least 10 percent more than the volume of the oil tank. The enclosure should be filled with sand for a height of 300 mm.

3.5.9 *Glazing*

3.5.9.1 The glazing should be in accordance with Part C 'Structural Design, Section 8 Glass and Glazing' of this NBCS. The entire glazing assembly should be rated to that type of construction as given in Table 1. This should be applicable along with other provisions of this Part related to respective uses as specified therein. The use of glass should not be permitted for enclosures of exits and exit passageway.

3.5.9.2 Glass facade should be in accordance with the following:

a) For fully sprinklered buildings having fire separation of 9 m or more, tempered glass in a non-combustible assembly, with ability to hold the glass in place, should be provided. It should be ensured that sprinklers are located within 600 mm of the glass facade providing full coverage to the glass. Where the fire separation is less than 9 m, additional protection such as using a minimum 900 mm spandrel panel of 1 h fire resistance rating should be provided;

NOTE — In case of all other buildings, fire resistance rating of glass facade should be in accordance with Table 1.

b) All gaps between floor-slabs and facade assembly should be sealed at all levels by approved fire resistant sealant material of equal fire rating as that of floor slab to prevent fire and smoke propagation from one floor to another. *See also* accepted standard [F(35)]; and

c) Openable panels should be provided on each floor and should be spaced not more than 10 m apart measured along the external wall from centre-to-centre of the access openings. Such openings should be operable at a height between 1.2 m and 1.5 m from the floor, and should be in the form of openable panels (fire access panels) of size not less than 1 000 mm × 1 000 mm opening outwards. The wordings, 'FIRE OPENABLE PANEL — OPEN IN CASE OF FIRE, DO NOT OBSTRUCT' of at least 25 mm letter height should be marked on the internal side. Such panels should be suitably distributed on each floor based on occupant concentration. These should not be limited to cubicle areas and should be also located in common areas/corridors to facilitate access by the building occupants and fire personnel for smoke exhaust in times of distress.

3.5.10 *Surface Interior Finishes*

3.5.10.1 The use of combustible surface finishes on walls (including facade of the building) and ceilings affects the safety of the occupants of a building. Such finishes tend to spread the fire and even though the structural elements may be adequately fire resistant, serious danger to life may result. It is, therefore, essential to have adequate precautions to minimize spread of flame on wall, facade of building and ceiling surfaces. The finishing materials used for various surfaces and decor should be such that it should not generate toxic smoke/fumes.

3.5.10.2 The susceptibility of various types of wall surfaces to fire is determined in terms of the rate of spread of flame. Based on the rate of spread of flame, surfacing material should be considered as divided into four classes as follows {*see* also good practice [F(11)]}:

a) Class 1 Surfaces of very low flame spread;

b) Class 2 Surfaces of low flame spread;

c) Class 3 Surfaces of medium flame spread; and

d) Class 4 Surfaces of rapid flame spread.

3.5.10.3 The uses for which surface materials falling into various classes should be adopted in building construction are given below:

Class 1 (1)	*Class 2* (2)	*Class 3* (3)
May be used in any situation	May be used in any situation, except on walls, facade of the building, staircase, and corridors	May be used only in living rooms and bed rooms (but not in rooms on the roof) and only as a lining to solid walls and partitions; not on staircases or corridors or facade of the building.

NOTE — Panelling (lining) may be permitted in a limited area; and is not to be permitted in a vestibule.

3.5.10.4 Materials of Class 4 which include untreated wood fibreboards may be used with due fire-retardant treatment as ceiling lining, provided the ceiling is at least, 2.4 m from the top surface of the floor below, and the wall surfaces conform to requirements of the class [*see* Note under **3.5.10.3**]. Class 4 materials should not be used in kitchens, corridors, and staircases. Some materials contain bitumen and, in addition to risk from spread of fire, emit dense smoke on burning; such materials should be excluded from use under these conditions and should also not be used for construction of ceiling where the plenum is used for return air in air-conditioned buildings.

3.5.10.5 When frames, walls, partitions, or floors are lined with combustible materials, the surfaces on both sides of the materials should conform to the appropriate class, because there is considerable danger from fire starting and rapidly spreading within the concealed cavity unknown to the occupants whose escape may be hampered thereby. For detailed information on materials and details of construction with their fire resistance rating, reference may be made to good practice [F(12)].

3.5.10.6 The use of aluminium composite panels as external facade of the buildings should be avoided; if used, such panels should have a minimum of 70 percent mineral core and pass the tests as in accepted standards (*see* Note 2).

NOTES

1 When combustible materials are used for lining frames, walls, partitions, or floors, the surfaces on both sides of the materials must meet the required fire resistance class. This precaution helps mitigate the risk of fire spreading within concealed cavities, which may not be immediately visible to occupants and can hinder evacuation.

2 Accepted standards can be ISO 3957 or ISO 13785 (Part 1 and Part 2).

3.5.11 *Fire Command Centre* (*FCC*)

a) Fire command centre should be on the entrance floor of the building having direct access. The control room should have the main fire alarm panel with communication system (suitable public address system) to aid floors and facilities for receiving the message from different floors;

b) Fire command centre should be constructed with 120 min rating walls with a fire door and should be provided with emergency lighting. Interior finishes should not use any flammable materials. All controls and monitoring of fire alarm systems, pressurization systems, smoke management systems should happen from this room. Monitoring of integrated building management systems, CCTVs or any other critical parameters in building may also be from the same room.

c) Details of all floor plans along with the details of firefighting equipment and installations (2 sets laminated and bound) should be maintained in fire command centre. The fire staff in charge of the fire command centre should be responsible for the maintenance of the various services and firefighting equipment and installations in coordination with security, electrical and civil staff of the building.

NOTE — Panelling (lining) should be permitted in a limited area. It should not be permitted in a vestibule.

4 LIFE SAFETY

4.1 General

Every building should be so designed, constructed, equipped, maintained, and operated as to provide adequate means of egress to avoid undue danger to the life and safety of the occupants from fire, smoke, fumes, or panic during the time period necessary for escape.

For high occupancy areas, it may be required to have annunciation, announcements, and voice guided/aided system to direct the occupants towards safe egress routes, areas of comparative safety or exits, and to avoid situation of panic during distress.

Every main occupancy may have certain occupancies which may be incidental to the main occupancy. The exit requirements pertaining to such incidental occupancies from the floor of the occupancy to the level of exit discharge should be calculated to meet the requirement of the actual occupancy of such type, to ensure adequate means of egress of the occupants.

See also good practice [F(31)] for accessibility for elderly and persons with disabilities, for various requirements for enabling a smooth and safe egress.

4.2 General Exit Requirements

4.2.1 Fire exits are unobstructed component of means of egress which is between the exit access and the exit discharge or public way. Exit components include exterior exit doors at the level of exit discharge, interior exit stairways (pressurised), exit stairway with external wall (pressurised or naturally ventilated), exterior exit stairways, exit passageways, and exterior exit ramps. Fire exits should be provided with panic bar to facilitate entry of occupant into fire exit.

An exit may also include a horizontal exit leading to an adjoining building/fire compartment having its further access to unlocked/public exit at the same level.

4.2.2 Unless otherwise specified, lifts, escalators, moving walks and revolving doors should not be considered as fire exits and should not constitute any part of the required fire exit.

4.2.3 Every fire exit, exit passageway and exit discharge should be continuously maintained free of all obstructions or impediments to full use in the case of fire or other emergency.

4.2.4 Every building having human occupancy should be provided with fire exits sufficient to permit safe egress of occupants, in case of fire or other emergency.

4.2.5 In every building or structure, fire exits should comply with the minimum requirements of this Part, except those not accessible for general public use.

4.2.6 No building should be so altered as to reduce the number, width, or protection of fire exits to less than that required.

4.2.7 For non-naturally ventilated areas (that is, pressurized areas), fire doors with 120 min fire resistance rating should be provided and particularly at the entrance to lift lobby and stair well where a 'funnel or flue effect' may be created, inducing an upward spread of fire, to prevent spread of fire and smoke.

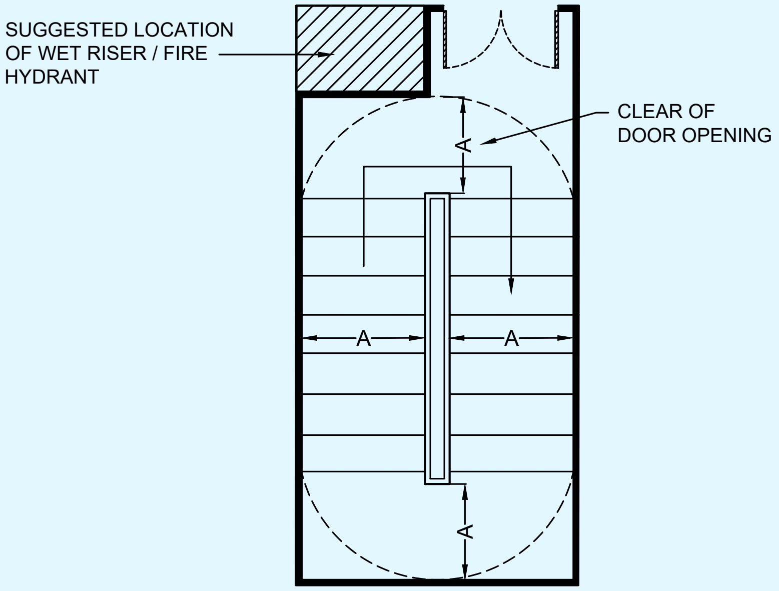
4.2.8 Fire exits should be so arranged that they may be reached without passing through another occupied unit/passage in others control if they pose challenge or restriction in means of egress.

4.2.9 Doors in fire exits should open in the direction of exit. In case of assembly buildings (Group D) and institutional buildings (Group C-1), exit door should not open immediately upon a flight of stair and all such entries to the stair should be through a landing, so that such doors do not impede movement of people descending from a higher floor when fully opened (*see* Fig. 7A). While for other occupancies, such doors should not reduce the pathway in the landing by more than half the width of such staircase (*see* Fig. 7B). Over- head or sliding doors should not be installed.

4.2.10 At least half of the required exit stairs from upper floors (rounded to the next higher number) should discharge directly to the exterior or through exit passageways. For buildings less than 60 m in height, firefighting shaft should be planned having one side on the external wall and discharging directly to the exterior. In the case of tall buildings (60 m and above), where structural design requires the location of firefighting shaft along with the structural core members, firefighting shaft(s) in the building should discharge directly to the exterior (through exit passageway).

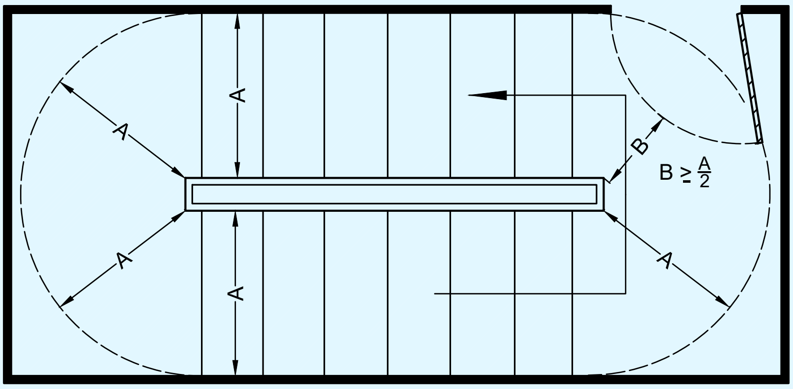
4.2.11 Unless otherwise specified, all the fire exits and exit passageways to exit discharge should have a clear ceiling height of at least 2.4 m. However, the height of fire exit door should be at least 2.0 m (*see* Fig. 8).

4.2.12 Where changes in elevation of more than 300 mm are encountered in the exits, ramps or sloped surfaces should be used with handrails and floor finish materials that contrast with the adjacent finish materials.



NOTE — DOOR WIDTH SHALL BE BASON TYPE OF OCCUPANCY

7A MINIMUM REQUIRED UNOBSTRUCTED CLEARANCE WITH DOOR LEAF ENCROACHING ON LANDING IN INSTITUTIONAL AND ASSEMBLY BUILDING



A - REQUIRED WIDTH

7B MINIMUM REQUIRED UNOBSTRUCTED CLEARANCE WITH DOOR LEAF ENCROACHING ON LANDING

FIG. 7 DOOR LOCATION AT LANDING IN FIRE EXITS

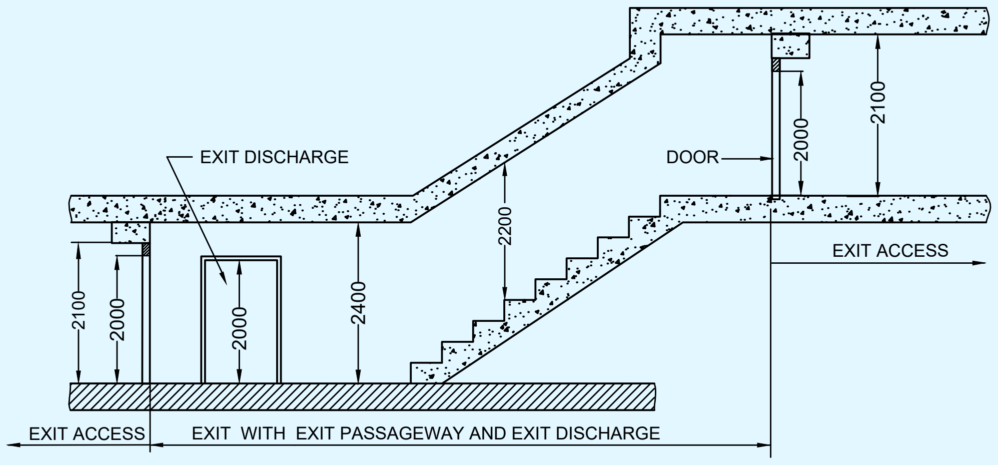


FIG. 8 MINIMUM HEAD ROOM MEASUREMENT

4.2.13 The capacity of the means of egress required from any storey of the building should-not be reduced along the path of egress travel until arrival to the exit discharge.

4.2.14 The lifts, escalators, moving walks, turnstiles and revolving doors should not be considered in determining the required capacity of means of egress for the individual floor(s) or the building.

4.2.15 Turnstiles or similar devices that restrict travel to one direction or that are used to restrict unauthorized entry should not be so placed as to obstruct any required means of egress. Alternative door openings of required exit width should be available within 3 m of such devices, if installed.

4.2.16 Suitable means should be provided so that all access-controlled exit doors, turnstiles, boom barriers and other such exits should automatically operate to open mode during emergencies like fire, smoke, acts of terrorism, etc, so that people can safely and quickly egress into safe areas outside. If required, a master controlling device may be installed at a strategic location to achieve this.

4.2.17 Penetrations into and openings through fire exit are prohibited except those necessary, like for the fire protection piping, ducts for pressurization and similar life safety services. Such openings as well as vertical passage of shaft through floors should be protected by passive systems, {see accepted standard [F(34)]}.

4.2.18 Walking surfaces in exit access should comply with the following requirements for smooth exit:

a) Walking surfaces should be nominally level;

b) The slope of walking surface in the direction of travel should not exceed 1 in 20 unless the ramp requirements are met (*see* **4.4.2.4.3.5**);

c) Slope perpendicular to the direction of travel should not exceed 1 in 48; and

d) Walking surfaces should be slip-resistant along the entire path of travel.

4.2.19 *Basement*

4.2.19.1 The basement should not be used for hazardous and vulnerable activities, like sleeping purposes, class rooms, hazardous industries, restaurant kitchen (*see also* **4.7.9**), battery rooms, UPS rooms, fuel oil storage, etc However, the State Authorities may prescribe the list of such activities based on their own assessment. Basements should have smoke ventilation systems, high-density sprinkler systems, and redundant/enclosed exits.

4.2.19.2 The fire exits in a basement should be sufficient to provide for the capacity of the basement occupancy as determined in accordance with **4.4.2.1**. In no case should there be fewer than two independent basement exits.

4.2.19.3 Basements with incidental occupancies to the main occupancy should be planned with exit requirements for the actual occupancy within the basement.

4.2.19.4 Where a basement is used for car parking and also there is direct approach from any occupancy above to the basement, door openings leading to the basement should be protected with fire doors with 120 min fire resistance rating, except for exit discharge doors from the basements.

4.2.19.5 Basements should have a minimum clear height of 3.4 m towards effective performance in the event of fire/smoke. Impulse or duct ventilation system needs to be designed to ensure removal of hot gases and smoke from each compartment to achieve reasonable visibility and heat reduction for firefighting operations.

4.3 Occupant Load

For determining the fire exits required, the number of persons within any floor area or the occupant load should be based on the actual number of occupants declared, but in no case less than that specified in Table 2. The occupant load of a mezzanine floor discharging to a floor below should be added to that floor occupancy and the capacity of the fire exits should be designed for the total occupancy load thus established.

The occupant load of each storey considered individually should be required to be used in computing the number of means of egress at each storey, provided that the required number of means of egress is not decreased in the direction of egress travel.

Table 2 Occupant Load

[*Clauses* 4.3, 4.4.2.1 *and* H-4.1(j)]

Sl No.	Building Occupancy	Net Occupant Load Factor (m^2/person) (*see* Note 7)	Gross Occupant Load Factor (m^2/person) (*see* Note 1)
(1)	(2)	(3)	(4)
i)	Group A: Residential	12.5	-
ii)	Group B: Educational	3.0	-
iii)	Group C: Institutional (*see* Note 2)		
	a) Nursing homes	-	12.0
	b) Clinic (daycare)	-	12.0
	c) Inpatient area in hospital (like ward, sleeping area)	11.0	-
	d) Outpatient area in hospital	7.0	-
iv)	Group D: Assembly		
	a) Concentrated use without fixed seating	0.65	-
	b) Less concentrated use without fixed seating such as pre-function, multipurpose hall)	1.40	-
	c) Fixed seating	*see* Note 4	-
	d) Dining areas and restaurants with seating and table	1.80	-
	e) Gymnasium, sports room, library and alike with equipment, stacks and the like. This includes performance stages, indoor badminton court, squash court with	4.6	-

Table 2 (*Continued*)

Sl No. (1)	Building Occupancy (2)	Net Occupant Load Factor (m^2/person) (*see* Note 7) (3)	Gross Occupant Load Factor (m^2/person) (*see* Note 1) (4)
	limited number of performers and player (while audience for the same if any should be under (c) as above).		
	f) Swimming pool		
	1) Water surface	3.5	-
	2) Deck	2.0	-
	g) Mall – Basement with sales floor	2.1	-
	h) Mall – Street floor	2.1	-
	j) Mall – Upper sales floor	4.3	-
	k) Mall – Food court	-	1.8
	m) Mall – Theatre screens	-	*see* Note 4
	n) Storage/warehouse, receiving and the like	14.3	-
v)	Group F: Mercantile		
	a) Street floor and above	-	2.1
	b) Below street floor	-	3.0
vi)	Group E: Business	7.1	-
vii)	Group E: For Datacentres	-	20.0
	a) Admin areas	-	10.0
	b) Data hall, server room, equipment room areas	-	50.0
		see Annex G	*see* Annex G
viii)	Group G: Industrial	-	
	a) Low hazard	-	20.0
	b) Moderate hazard	-	15.0
	c) High hazard	-	10.0
ix)	Group H: Storage (*see* Note 5)	-	30.0
x)	Group J: Hazardous	-	10.0

NOTES

1 Gross area is the floor area as defined in **2.35**.

2 Occupant load factor in dormitory portions of homes for the aged, orphanages, insane asylums, etc, where sleeping

Table 2 (*Concluded*)

Sl No.	Building Occupancy	Net Occupant Load Factor (m^2/person) (*see* Note 7)	Gross Occupant Load Factor (m^2/person) (*see* Note 1)
(1)	(2)	(3)	(4)

accommodation is provided, should be calculated at not less than 7.5 m^2 gross floor area/person.

3 Commercial kitchen in the above occupancies should be calculated at 9.3 m^2 net floor area/person.

4 In case of assembly occupancy having fixed seats, the occupant load should be determined by multiplying the number of seats by 1.2.

5 Car parking areas under occupancy other than storage should also be 30 m^2 per person.

6 Usable carpet area is the total of all corridors, passages, enclosed offices/rooms excluding rack and UPS/battery foot print

7 Net area is not the carpet area. *See* **2.36**.

* Gross area is highly recommended to be used than the net area, to avoid double counting. Net area is possible to be indicated for spaces having concentration of people is typical in certain occupancies; and other common spaces/areas in a floor plate may be used by the same set of occupants. Moreover, gross area provides a safer, more conservative occupant load for the entire floor, ensuring exits are sized for the maximum possible capacity. Further, net area is used for specific rooms (like classrooms or assembly halls) where the furniture and layout are predictable, but using it for an entire floor plate often underestimates the total population because it excludes corridors, closets, and wall thicknesses where people still circulate.

4.4 Egress Components

Egress components to be considered are the number of exits to which access is provided, capacity of exit access, travel distance to a fire exit, the obviousness of the direction to a fire exit, and any hindrance including due to security issues involved.

4.4.1 *Exit Access*

a) A common path of travel is desirable in exit access which leads to two independent directions to separate fire exits;

b) *Capacity of Exit Access* — The width of corridors, aisles or ramps required for exit access should be sufficient to ensure a smooth flow of occupants to the fire exit. Where a corridor is the only way of access to a fire exit, the corridor width should not be less than the calculated exit width;

c) Objects like tables, chairs or any other temporary/permanent structures in exit access corridors should be avoided as this may result in congestion and also impeding smooth flow of personnel during emergencies;

d) In order to ensure that each element of the means of egress can be effectively utilized, they should all be properly lit and marked. Lighting should be provided with emergency power back-up in case of power failures. Also, exit signs of adequate size, marking, location, and lighting should be provided so that all those unfamiliar with the location of the fire exits may safely find their way;

e) Exit access to fireman's lift and refuge area/spaces on the floor should be step free and clearly signposted with the international symbol of accessibility;

f) Exit access should not pass through storage rooms, closets or spaces used for similar purpose; and

g) The calculation of capacity of exit access should be in accordance with **4.4.2.4**.

4.4.2 *Exits*

4.4.2.1 *Number of fire exits*

The minimum required number of exits in a building should be determined based on occupant load (*see* Table 2) and width required per person (*see* Table 3) as appropriate to the type of exit for respective occupancies, subject to complying with maximum travel distance requirement (*see* Table 4).

4.4.2.2 *Arrangement of fire exits*

a) Fire exits should be so located that the travel distance on the floor should not exceed the distance given in Table 4.

b) Travel distance should be measured from the most remote point within a storey or a mezzanine floor along the natural and unobstructed path of horizontal or vertical egress travel to the door of a fire exit.

c) The dead-end corridor length in exit access should not exceed 6 m for educational, institutional and assembly occupancies. For other occupancies, the same should not exceed 15 m (*see* Fig. 9).

d) Fire exits should be placed as remote from each other as possible and should be arranged to provide direct access in separate directions from any point in the area served (*see* Fig. 10).

4.4.2.3 *Capacities of means of egress*

a) Exit capacity is the number of people that can pass through a stairway, and level components (door and corridor) and ramps. The total capacity of all the respective means of egress serving a floor should be sufficient to allow egress of the entire population of the floor.

b) The unit of exit width, used to measure the capacity of any exit, is 500 mm. A clear width of 250 mm needs to be counted as an additional half unit. Clear widths less than 250 mm need not be counted for exit width.

c) Width per person for stairways, and level components and ramps are to be determined using the capacity factors in accordance with Table 3.

   For example, if an exit doorway measures 1 000 mm in clear width its capacity factor being 6.5, it would be defined as providing exit capacity for 1 000/6.5 occupants, that is, 153 persons (say 150 persons) and number of such exit doorways can then be calculated depending on the occupant load.

d) When calculating stairways, level components and ramps and other exit means, the capacity of the entire system should have to be based upon the minimum capacity available from any part of the system. The corridor, if so provided, should also to be planned with consideration of exit access adequacy for the number of occupants. Further, consider the situation of doors opening to an exit stairway. If the stairway provides an exit capacity of 150 persons, and the doors leading into the stairway provide an exit capacity of 153 persons, the overall exit system would be considered to provide the minimum exit capacity of only 150 persons afforded by the stairway. The exit planning will be limited by the most restrictive exit calculation under the means of egress.

e) In the procedures for determining required egress capacity, the number of required means of egress is based on a floor-by-floor consideration, rather than the accumulation of the occupant loads of all the floors. However, the number of means of egress cannot decrease as an occupant proceeds along the egress path.

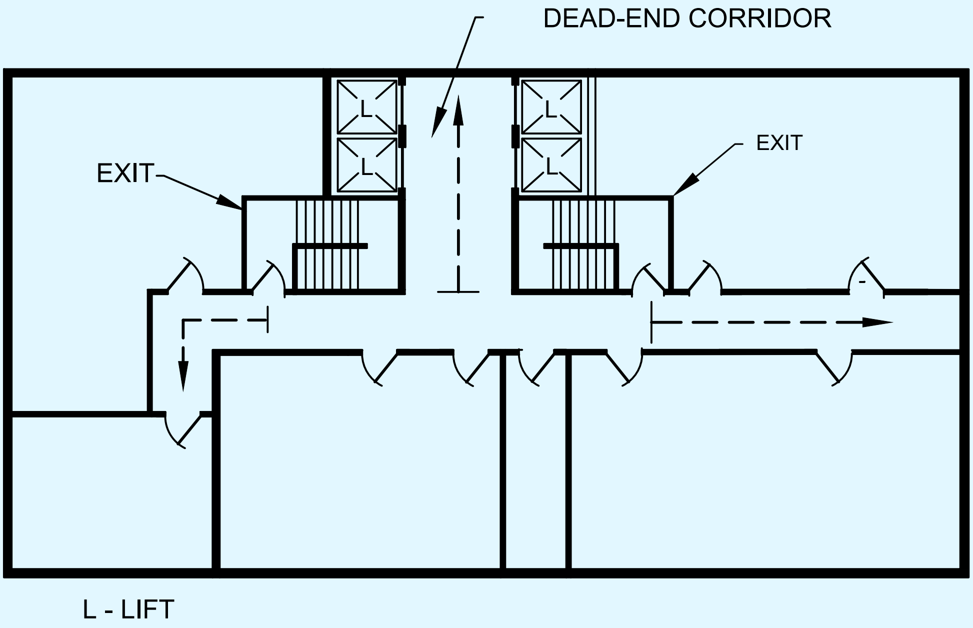
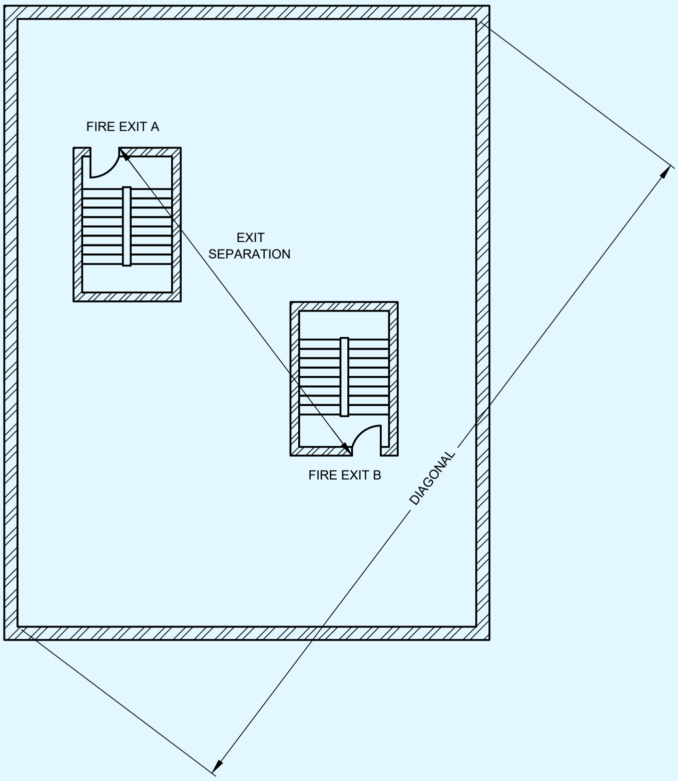

DEAD-END CORRIDOR
EXIT
EXIT
L
L
L
L
L - LIFT

FIG. 9 DEAD END CORRIDOR


FIRE EXIT A
EXIT SEPARATION
FIRE EXIT B
DIAGONAL

NOTE — MINIMUM EXIT SEPARATION = DIAGONAL/2 (FOR UNSPRINKLERED)
= DIAGONAL/3 (FOR SPRINKLERED)

FIG. 10 FIRE EXIT SEPARATION

Table 3 Capacity Factors

[*Clauses* 4.4.2.1, 4.4.2.3(c), 4.4.2.4.1(b), 4.4.2.4.2(a) *and* 4.4.2.4.3.5(a)]

Sl No.	**Occupancy Group**	**Width per Person** mm	
		Stairways	Level Components and Ramps
(1)	(2)	(3)	(4)
i)	Residential (Group A)	10	6.5
ii)	Educational (Group B)		
iii)	Institutional (Group C)	15	13
iv)	Assembly (Group D)	10	6.5
v)	Business (Group E)		
vi)	Mercantile (Group F)		
vii)	Industrial (Group G)		
viii)	Storage (Group H)		
ix)	Hazardous (Group J)	18	10

4.4.2.4 *Types of exit access and exits*

Various types of exit access and exits are doorways, corridors and passageways, horizontal exits, internal staircases, exit passageways, external staircases, and ramps.

4.4.2.4.1 *Doorways*

a) Every exit doorway should open into an enclosed stairway or a horizontal exit of a corridor or passageway providing continuous and protected means of egress (*see* Fig. 11 on unaccepted arrangement of doors in a stair).

b) No exit doorway should be less than 1 000 mm in width. Door width in exits should also meet requirement of level components given in Table 3 except assembly buildings, where door width should be not less than 2 000 mm (*see* Fig. 12). Doorways should be not less than 2 000 mm in height.

c) Exit doorways should be operable from the side which they serve, without the use of a key.

d) Mirrors should not be placed on exit doors and in exits, to avoid confusion regarding the direction of exit.

e) Revolving doors can be accepted as a component in a means of egress where the following requirements are fully complied with:

   1) Doors should be capable of collapsing to a book fold position with parallel egress paths, of width not less than 1 000 mm.

   2) Doors should not be located within 3 m of the foot or top of stairs or escalators. A dispersal area should be provided between the stairs or escalators and the doors.

   3) Each revolving door should be provided with a hinged door in the same wall within 3 m thereof, with same exiting capacity.

   4) Each revolving door should be considered as capable of exiting only 50 persons.

f) All fire rated doors and assembly should be provided with certificate and labels prominently indicating the manufacturer's identification, door details covering door type, serial/batch number, month and year of manufacture, fire resistance rating, etc. The doors and assembly should be certified with all prescribed hardware such as hinges, locks, panic bars, door closers, and door viewers.

g) *Access controlled doors* — Access controlled doors and electromagnetic doors should fall under this category. These should meet the following requirements:

   1) Doors should have fire rating as per the requirements at the location of installation;

   2) Activation of the building automatic sprinkler or fire detection system, if provided, should automatically unlock the doors in the direction of egress, and the doors should remain unlocked until the automatic sprinkler system or fire-alarm system has been manually reset;

   3) Loss of power to the part of the access control system that locks the doors should automatically unlock the doors in the direction of egress;

   4) A manual release device should be provided in the readily accessible vicinity of the egress door with a signage 'PUSH TO EXIT' and when the same is operated, it should result in direct interruption of power to the lock, independent of the access control system electronics.

h) *Turnstiles* — Turnstiles or similar devices that restrict travel to one direction or are used to collect fares or admission charges should not be placed so as to obstruct any required means of egress unless door openings of required width are available within 3 m thereof.

   Turnstiles or such similar devices should also be disengaged through automatic or manual intervention to allow egress in the direction of exit.

j) Doors in folding partition should not be treated as approved means of egress.

Table 4 Travel Distance (Based on Occupancy and Construction Type)

[*Clauses* 4.4.2.1, 4.4.2.2 (a), 4.4.2.4.2 (a) *and* 6.8.1.1]

Sl No.	**Occupancy Group**	**Maximum Travel Distance** m		
		Types 1 and 2 (Unsprinklered)	Types 1 and 2 (Sprinklered)	Types 3 and 4
(1)	(2)	(3)	(4)	(5)
i)	Residential (Group A)	30.00	60.00	22.5
ii)	Educational (Group B)	30.00	45.00	22.5
iii)	Institutional (Group C)	30.00	45.00	22.5
iv)	Assembly (Group D)	30.00	45.00	30.00
v)	Business (Group E)			
	Businesses (including admin area of Datacentre building)	30.00	60.00	30.00
	Datacentre building	N.A.	60.00	N.A.
vi)	Mercantile (Group F)	30.00	45.00	30.00

Table 4 (*Concluded*)

Sl No.	Occupancy Group	Maximum Travel Distance m		
		Types 1 and 2 (Unsprinklered)	Types 1 and 2 (Sprinklered)	Types 3 and 4
(1)	(2)	(3)	(4)	(5)
vii)	Industrial (Group G)			
	G-1, G-2	45.00	60.00	*see* Note 3
	G-3	22.50	45.00	
viii)	Storage (Group H)	30.00	90.00	
ix)	Hazardous (Group J)	22.50	30.00	

NOTES

1 The common path of travel should be not more than 50 percent of the above distances.

2 Ramps are not to be counted as an exit in case of basements below the first basement in car parking.

3 Construction of Type 3 or Type 4 is not permitted.

4 Utility service areas and equipment areas may be exempt from the measurement of travel distance from within the room.

5 For ceiling height 10 m or above at ground floor in buildings such as airports, exhibition halls, convention centres, atrium in shopping malls, entrance lobbies and the like and provided with sprinkler system, the travel distance in such areas may be increased by 100 percent of the values specified. This is not to be applied to the values given in col (4) above.

6 In such buildings having ceiling heights 17 m or more and would have sprinkler exemption, the travel distance of such areas may be allowed to be increased by 100 percent of the values specified. This is not to be applied to the values given in col (4) above. In such cases, to prevent heat build-up at ceiling level, suitable smoke/heat venting systems are recommended.

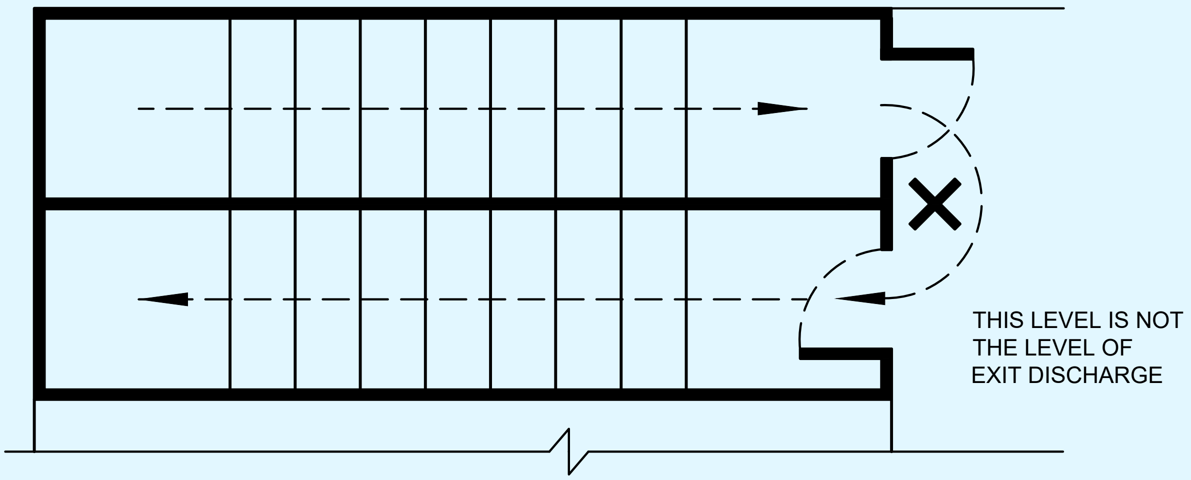


FIG. 11 UNACCEPTABLE ARRANGEMENT FOR ENCLOSING A STAIR SERVING AS A REQUIRED EXIT

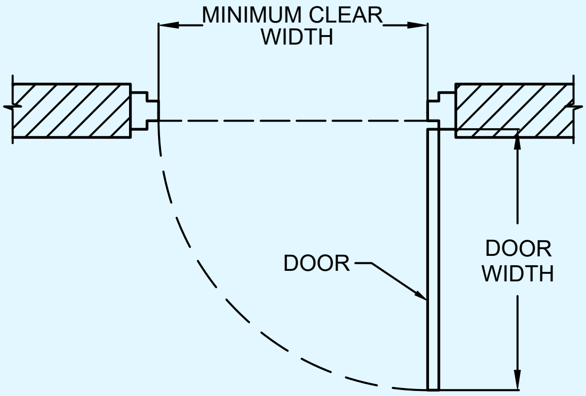


FIG. 12 MINIMUM CLEAR DOOR WIDTH

4.4.2.4.2 *Corridors and passageways of means of egress*

a) Corridors and passageways should be of width not less than the calculated aggregate width of exit doorways leading from them in the direction of travel to the exit (*see* Table 3 and Table 4); and

b) In the case of buildings where there is a central corridor, which is part of exit access, the doors of rooms (except for rooms having assembly occupancy) should open inwards to permit smooth flow of traffic in the corridor.

4.4.2.4.3 *Staircases*

4.4.2.4.3.1 *General*

The requirements of number of staircases should supplement the requirement of different occupancies in **6.1** to **6.9**.

All high rises and special buildings, as mentioned in **1.2**, should have a minimum of two staircases. The actual number of staircases should comply with the requirement of **4.4.2.1**.

NOTE — These required fire exit staircases calculated as per the laid down provisions, are recommended to be free of FAR.

All exit staircases should discharge, at the level of exit discharge, to the exit discharge, either,

a) directly, or

b) through an exit passageway, or

c) through a large lobby.

At least 50 percent of the staircases should discharge as per (a) and/or (b) above. For firefighting shafts, it is preferred to have the discharge through (a), or as an alternate through (b). Option (c) is not applicable for firefighting shafts. In case of residential buildings and educational buildings, firefighting shafts should discharge through (a) only.

Each compartment should be planned with its access to the firefighting shaft. In buildings/floors having three or more compartments, there should be at least two firefighting shafts to serve the compartments. In buildings/floors having three or more compartments, there should be at least two firefighting shafts to serve the compartments.

The minimum width of tread without nosing should be 250 mm for staircase of residential buildings. This should be minimum 300 mm for assembly, hotels, educational, institutional, business, and other buildings. The treads should be constructed and maintained in a manner to prevent slipping. The maximum height of riser should be 175 mm for staircase of one or two family dwelling residential buildings and 150 mm for other buildings. The number of risers in a flight is recommended as 12. However, considering the floor-to-floor height, there should not be more than 15 risers in a flight.

The staircases may be internal staircases or external staircases.

4.4.2.4.3.2 *Internal staircases*

The internal staircases may be constructed with an external wall, or otherwise, and should comply with the following:

a) Internal stairs should be constructed of non-combustible materials throughout, and should have fire resistant rating of minimum 120 min.

b) A staircase should not be arranged round a lift shaft.

c) Fire exits should not be used as a portion of a supply, return or exhaust air system serving adjoining areas. Any opening(s) should not be permitted in walls or in doors, separating fire exits from adjoining areas.

d) No flue chimney, electromechanical equipment, air conditioning units, gas piping or electrical panels should be allowed in the stairway.

e) Notwithstanding the detailed provision for exits in accordance with **4.2** and **4.3**, the following minimum width should be provided for staircases for respective building typology:

   1) Residential building (One or two family dwellings) : 1.00 m

      NOTE — For row housing with 2 storeys, the minimum width should be 0.75 m.

   2) Residential building (A-I, A-II and A-III) : 1.25 m

   3) Residential hotel building (A-IV and A-V) : 1.50 m

   4) Assembly building : 2.00 m

      NOTE — The width of stairs may be accepted to be 1.50 m in case of assembly occupancy having less than 150 persons.

   5) Educational building : 1.50 m

   6) Institutional building : 2.00 m

      Maximum width of stairs in hospitals should be 2.00 m.

   7) All other buildings : 1.50 m

      NOTE — Where staircase width is above 2.00 m, it is recommended to provide a central handrail.

f) A handrail should be provided on one side of the staircase of width less than 1 500 mm, and on both sides of the staircase of width 1 500 mm and more. The projection of handrail(s) in the staircase width should not be more than 90 mm.

g) Handrails may project inside the measured width by not more than 90 mm.

h) The design of staircase should also take into account the following:

   1) The minimum headroom in a passage under the landing of a staircase and under the staircase should be 2.2 m.

   2) Access to fire sexit staircase should be through a fire door of a minimum 120 min fire resistance rating.

   3) No living space, store or other fire risk should open directly into staircases.

   4) The exit (including staircases) should be continuous from refuge floors or terrace level, as applicable, to the level of exit discharge.

   5) No electrical shafts/air conditioning ducts or gas pipes, etc, should pass through or open in the staircases.

   6) Lifts should not open in staircase (or in mid-landings).

   7) No combustible material should be used for decoration/wall panelling in the staircase.

   8) Beams/columns and other building features should not reduce the head room/width of the staircase.

   9) The floor indication board, indicating the location/designated number of staircase, respective floor number and direction to exit discharge should be placed inside the staircase, on the wall nearest to the fire door. It should be of size not less than 300 mm × 200 mm (*see* Fig. 13).

   10) Individual floors should be prominently indicated on the wall outside the staircase and facing it.

11) All staircase should terminate at the level of exit discharge. The access to the basement should be by a separate staircase.

12) Scissors type staircases (of type where intermingling of persons in the landing is possible or of type where both stairs use the common air space) should not be treated as part of exit.

4.4.2.4.3.3 *Curved stairs*

Curved stairs should not be treated as part means of egress. However, these may be used as part of exit access provided the depth of tread is not less than 280 mm at a point 350 mm from the narrower end of the tread and the smallest radius is not less than twice the stair width.

4.4.2.4.3.4 *External staircases*

The external staircases are the staircases provided on the external wall/facade, and should comply with the following:

a) External stairs should always be kept in sound and usable condition;

b) All external stairs should be directly connected to the ground;

c) Entrance to the external stairs should be separate and remote from the internal staircase;

d) Where an external staircase is provided, it should be ensured that the use of it at the time of fire is not prejudiced by smoke and flame from openings (for example, windows, doors) in the external face of the building. Care should be taken to ensure that no external wall or window opening opens on to or close to an external stair. If such openings exists within 3 m from an external staircase, they should be protected with fire rated doors/window assemblies with rating of at least 60 min (*see* Fig. 14);

e) The external stairs should be constructed of non-combustible materials, and any doorway leading to it should have minimum 120 min fire resistance;

f) No external staircase, should be inclined at an angle greater than 45° from the horizontal;

g) External stairs should have straight flight not less than 1 500 mm wide;

h) Handrails, to be provided on both sides, should be of a height not less than 1 000 mm and not exceeding 1 200 mm. There should be provisions of balusters with maximum gap of 150 mm; and

j) The use of spiral staircase should be limited to low occupant load and to a building not exceeding 9 m in height. A spiral staircase should be not less than 1 500 mm in diameter and should be designed to give adequate headroom.

4.4.2.4.3.5 *Ramps*

a) Ramps should comply with all the applicable requirements for staircases regarding enclosure, capacity (*see also* Table 3) and limiting dimensions, except where specified in **6.1** to **6.9** for special uses and occupancies;

b) The slope of a ramp should not exceed 1 in 12 (8 percent);

c) Ramp(s) should be surfaced with approved slip resistant materials that are securely attached. No perforations are permissible on ramp floors;

d) Any changes in travel direction in ramp should be preceded by landings of minimum 1.5 m × 1.5 m size;

e) Ramps and intermediate landings should continue with no decrease in width along the direction of egress travel;

f) Outside ramps and landings should be designed to minimize water accumulation on their surfaces;

g) Ramps should have landings located at the top, at the bottom, and at doors opening onto the ramp;

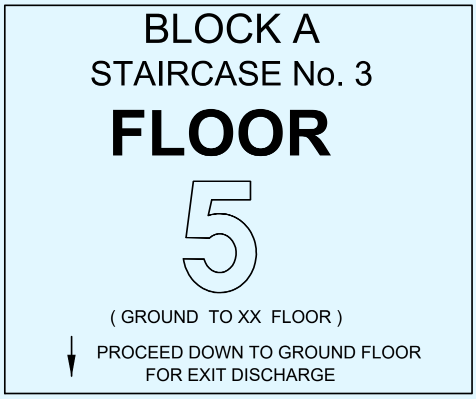
h) Every landing should be not less than 1 500 mm long in the direction of travel;

j) Where the ramp is not part of an accessible route, the ramp landings should not be required to exceed 1 250 mm in the direction of travel, provided that the ramp has a straight run; and

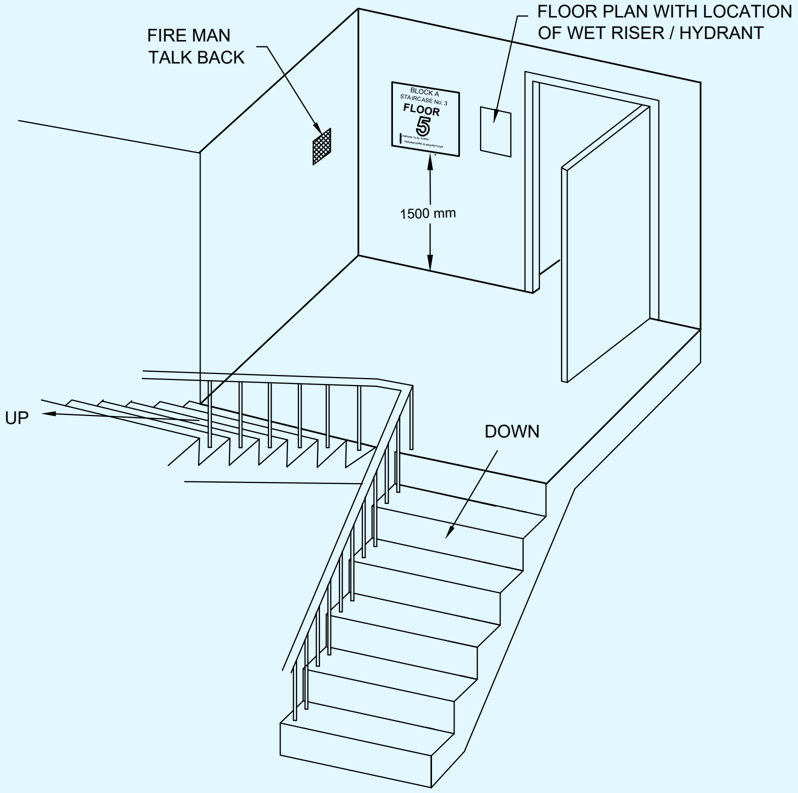
k) Handrails should be provided on all ramps on both sides (*see* **4.4.2.4.3.4**).

NOTE — Above requirements are not applicable to basement car parking ramps.

The ramps should, in addition, comply with the requirements given in good practice [F(31)].


BLOCK A
STAIRCASE No. 3
FLOOR
5
(GROUND TO XX FLOOR)
PROCEED DOWN TO GROUND FLOOR
FOR EXIT DISCHARGE

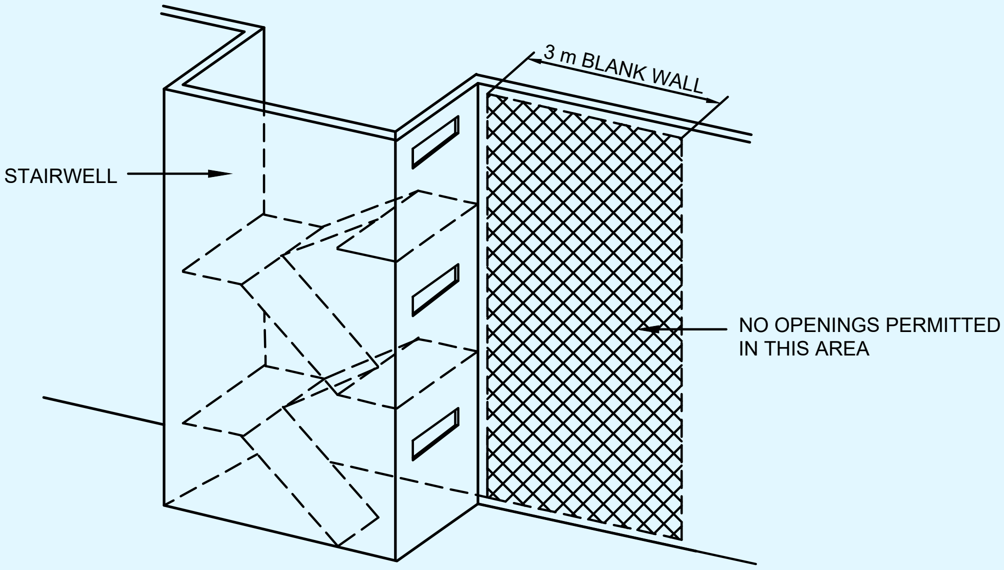
9A Example of a Stairway Marking Sign (Floor Indication Board)


FIRE MAN
TALK BACK
FLOOR PLAN WITH LOCATION
OF WET RISER / HYDRANT
BLOCK A
STAIRCASE No. 3
FLOOR
5
1500 mm
UP
DOWN

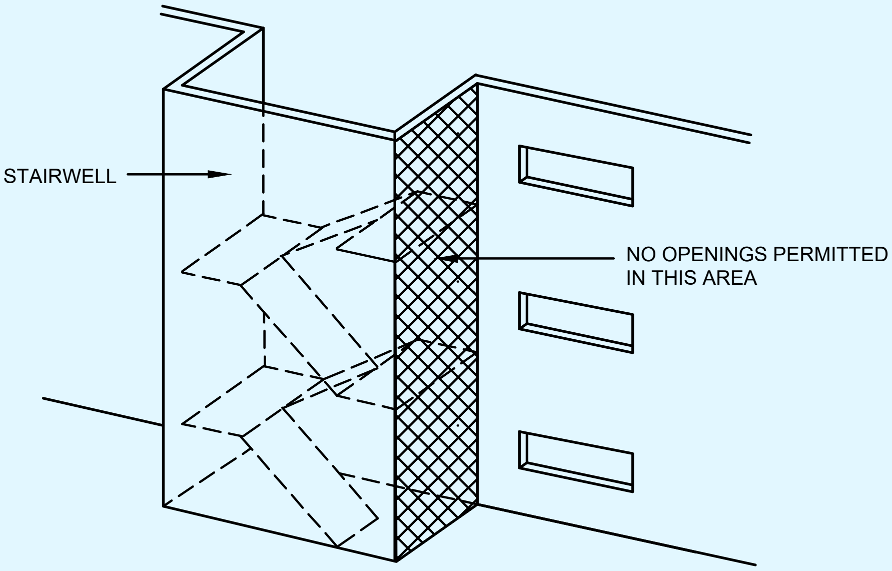
9B Stair Sign Placement

NOTE — BLOCK/WING/BUILDING NAME TO BE PROJECT SPECIFIC. STAIRCASE No. SHOWN AS "3" IS INTENDING TO SHOW THE NUMBER ASSIGNED TO THE STAIRCASE. ALL EXITS PREFERABLY TO BE ASSIGNED WITH NUMBER /IDENTIFICATION ENABLING OCCUPANT/FIRE MAN TO DECLARE LOCATION / POSITION.

Fig. 13 Sign Marking and Requirement in Exit


3 m BLANK WALL
STAIRWELL
NO OPENINGS PERMITTED
IN THIS AREA

14A Limitations on Openings Near Stairwell


STAIRWELL
NO OPENINGS PERMITTED
IN THIS AREA

14B Opening Restrictions on Stairwell Walls

Fig. 14 Opening Restrictions

4.4.2.5 *Smoke control of exits*

a) In building design, compartmentation plays a vital part in limiting the spread of fire and smoke. The design should ensure avoidance of spread of smoke to adjacent spaces through the various leakage openings in the compartment enclosure, such as cracks, openings around pipes ducts, airflow grills and doors. In the absence of proper sealing of all these openings, smoke and toxic gases will obstruct the free movement of occupants of the building through the exits. Pressurization of staircases is of great importance for the exclusion of smoke and toxic gases from the protected exit.

b) Pressurization is a method adopted for protecting the exits from ingress of smoke, especially in high-rise buildings. In pressurization, air is injected into the staircases, lobbies, etc, as applicable, to raise their pressure slightly above the pressure in adjacent parts of the building. As a result, ingress of smoke or toxic gases into the exits will be prevented. The pressurization of staircases and lift lobbies should be adopted as given in Table 5.

   The pressure difference for staircases should be 50 Pa.

   Pressure differences for lobbies (or corridors) should be between 25 Pa and 30 Pa. Further, the pressure differential for enclosed staircase adjacent to such lobby (or corridors) should be 50 Pa. For enclosed staircases adjacent to non-pressurized lobby (or corridors), the pressure differential should be 50 Pa.

c) Equipment and ductwork for staircase pressurization should be in accordance with one of the following:

   1) Directly connected to the stairway by ductwork enclosed in non-combustible construction.

   2) If ducts used to pressurize the system are passed through shafts and grilles are provided at each level, it should be ensured that hot gases and smoke from the building cannot ingress into the staircases under any circumstances.

d) The normal air conditioning system and the pressurization system should be designed and interfaced to meet the requirements of emergency services. When the emergency pressurization is brought into action, the following changes in the normal air conditioning system should be effected:

   1) Any re-circulation of air should be stopped and all exhaust air vented to atmosphere.

   2) Any air supply to the spaces/areas other than exits should be stopped.

   3) The exhaust system may be continued provided,

      i) the positions of the extraction grills permit a general air flow away from the means of egress;

      ii) the construction of the ductwork and fans is such that, it will not be rendered inoperable by hot gases and smoke; and

      iii) there is no danger of spread of smoke to other floors by the path of the extraction system which can be ensured by keeping the extraction fans running.

e) For pressurized stair enclosure systems, the activation of the systems should be initiated by signalling from fire alarm panel.

f) Pressurization system should be integrated and supervised with the automatic/manual fire alarm system for actuation.

g) Wherever pressurized staircase is to be connected to unpressurized area, the two areas should be segregated by 120 min fire resistant wall.

h) Fresh air intake for pressurization should be away (at least 4 m) from any of the exhaust outlets/grille.

Table 5 Pressurization of Staircases and Lift Lobbies

[*Clauses* 4.4.2.5 (b) *and* D-2]

Sl No.	Component	Height of the Building		
		Less than 15 m	15 m to 30 m	More than 30 m
(1)	(2)	(3)	(4)	(5)
i)	Internal staircase not with external wall	Pressurized except for residential buildings (apartment houses and one or two family dwellings)	Pressurized	Pressurized
ii)	Internal staircase with external wall	Pressurized except for residential buildings (Apartment houses and one or two family dwellings) or Naturally ventilated	Naturally ventilated or Pressurized	Cross-ventilated or Pressurized
iii)	Lift lobby	Not required at ground and above. However, lift lobby segregation and pressurization is required for lift commuting from ground to basement	Naturally ventilated or Pressurized1)	Cross-ventilated or Pressurized1)

NOTES

1 The natural ventilation requirement of the staircase should be achieved through opening at each landing, of an area 0.5 m^2 to 1.5 m^2 (as defined earlier) in the external wall. A cross ventilated staircase should have 2 such openings in opposite/adjacent walls or the same should be cross-ventilated through the corridor.

2 Enclosed staircase leading to more than one basement should be pressurized.

1) Lift lobby with fire doors (120 min) at all levels with pressurization of 25 Pa to 30 Pa is required. However, if lift lobby cannot be provided at any of the levels in air-conditioned buildings or in internal spaces where funnel/flue effect may be created, lift hoistway should be pressurized at 50 Pa. For building greater than 30 m, multiple point injection air inlets to maintain desired pressurization level should be provided. If the lift lobby, lift, and staircase are part of firefighting shaft, lift lobby necessarily has to be pressurized in such case, unless naturally ventilated.

4.5 Compartmentation

4.5.1 *General*

It is important to limit the spread of a fire in special/high rise buildings, usually through the use fire barriers. In some instances, these barriers need to be penetrated for ductwork, plumbing and electrical systems, and in such cases, use of passive fire protection measures should be done so that the integrity of these barriers is not compromised.

4.5.2 The compartmentation can be achieved with following type of construction/type of fire barrier with protected openings:

a) Type A — Masonry construction with fire rated door assembly;
b) Type B — Fire rated fabric dropdown curtain assembly;
c) Type C — Fire rated glazed partition and door assembly;
d) Type D — Fire rated gypsum board/cementitious board assembly; and
e) Type E — Masonry construction with fire rated metal sliding door.

Integrity (E) is the ability of the fire curtain assembly when exposed to fire from one side to withstand temperature up to 1 050 °C, to resist passage of flames and hot gases for a period of 120 min.

Radiation control (EW) is the ability of the fire curtain assembly when exposed to fire from one side to resist transfer of heat on the other side. When measured, it should does not exceed 15 kW/m^2 at 1 m distance.

Insulation (EI) is the ability of the fire curtain assembly when exposed to fire from one side to limit temperature rise on the other not exceeding 140 °C above the ambient.

Smoke control (Sa) is the ability of fire curtain assembly when exposed to a fire from one side resist passage of hot/cold smoke not exceeding 3 $m^3/m/h$ at a pressure of smoke leakage rate of 25 Pa.

4.5.2.1 *Type B — Fire rated fabric dropdown curtain assembly*

The fire rated fabric should be tested and certified by any reputed third-party independent certification body for following parameters:

a) Type 1 — Integrity (E) of 120 min + Radiation (EW) of 60 min + Smoke control (Sa);

b) Type 2 — Integrity (E) of 120 min + Radiation (EW) of 120 min + Smoke control (Sa); and

c) Type 3 — Integrity + Radiation (EW) of 120 min + Insulation (EI) of 60 min + Smoke control (Sa).

4.5.2.2 *Type C — Fire rated glazed partition and door assembly*

The fire rated glazed partition and door assembly should be tested and certified by any reputed third-party independent certification body for following parameters:

a) Type 1 — Integrity (E) of 120 min + Radiation (EW) of 120 min + Insulation (EI) of 30 min + Smoke control (Sa); and

b) Type 2 — Integrity (E) of 120 min + Radiation (EW) of 120 min + Insulation (EI) of 60 min + Smoke control (Sa)

4.5.3 Floor(s) should be compartmented with area as given in Table 6. The maximum size of the compartment is suggested as follows. However, State/Local Authorities may prescribe their own requirements based on their risk assessment and other fire safety provisions.

Table 6 Compartmentation

(*Clause* 4.5.3)

Sl No. (1)	**Type of Building** (2)	**Floor Area Compartmentation Area (without Sprinkler)** m^2 (3)	**Floor Area Compartmentation (when Sprinklered)** m^2 (4)	**Type of Construction/ Type of Fire Barrier with Protected Openings** (5)
i)	Enclosed basement vehicle parking in residential, educational, institutional, assembly, business, mercantile, industrial or storage occupancies	750	5 000	E - Barrier between the designated fire compartments/zones B - Limited to driveway not exceeding 9 m with Type-2 only.

Table 6 (*Continued*)

Sl No.	**Type of Building**	**Floor Area Compartmentation Area (without Sprinkler)** m^2	**Floor Area Compartmentation (when Sprinklered)** m^2	**Type of Construction/ Type of Fire Barrier with Protected Openings**
(1)	(2)	(3)	(4)	(5)
ii)	Basements other than car parking in residential, educational, institutional, assembly, business, mercantile, industrial and storage occupancies	750	2 000	A/D - barrier between the designated fire compartments/zones
iii)	Hospitals and nursing homes with beds/sleeping patients in institutional occupancies	750	2 000	Any combination of A, B (Type-3 only), D - barrier between the designated fire compartments/zones
iv)	Buildings used for custody and care of children, convalescents, aged people who are incapable of self-preservation	750	1 500	Any combination of A, B (Type-3 only), D - barrier between the designated fire compartments/zones
v)	Mercantile buildings, multistorey mercantile buildings consisting of shops, departmental stores, markets	750	Not essential	Any combination of A, B (Type 2 only), D - barrier between the designated fire compartments/zones
vi)	Assembly buildings with/without atriums	1 500	Not essential	Any combination of A, B (Type 2 only), D - barrier between the designated fire compartments/zones
vii)	Buildings under business occupancy	750	3 000	Any combination of A, B, C (Type 1), D - barrier between the designated fire compartments/zones
viii)	Datacentre buildings	*See* Note 1	2 000	Any combination of A, C (Type 2) , D - barrier between the designated fire compartments/zones
ix)	Hotel building with or without dining facilities	750	3 000	Any combination of A, C (Type 1) , D - barrier between the designated fire compartments/zones
x)	Industrial buildings less than 6.7 m in height	1 500	10 000	Any combination of A, E - barrier between the designated fire compartments/zones

Table 6 (*Concluded*)

Sl No. (1)	Type of Building (2)	Floor Area Compartmentation Area (without Sprinkler) m^2 (3)	Floor Area Compartmentation (when Sprinklered) m^2 (4)	Type of Construction/ Type of Fire Barrier with Protected Openings (5)
xi)	Hazardous or high hazard buildings	*See* Note 1	500	A-barrier between the designated fire compartments/zones
xii)	Buildings with atrium with smoke management system	*See* Note 1	Not required	Subject to compliance of atrium as in Annex E
xiii)	Warehouses less than 5.0 m in height	*See* Note 1	5 000	*See* also good practice [F(142)]

NOTES

1 Compartmentation size is not specified, as the buildings have to be sprinklered.

2 Ceiling level partition may be considered (from ceiling level to 25 percent of floor height) to act as a smoke reservoir and venting thereof.

4.5.3.1 For space with large heights [such as airports, exhibition halls, convention centres, atrium in shopping-malls, warehouses (of height beyond 5 m), industrial (of height beyond 6.7 m), double height entrance lobbies and the like], these may be exempted from above requirement of compartmentation.

4.5.3.2 In addition to the above floor area compartmentation, all critical utility rooms within each compartment area construction should be 2 h fire rated. Rooms such as electrical room, server room, uninterrupted power supply (UPS) room, battery room, lift machine rooms, IT networking room, main distribution frame (MDF), intermediate distribution frame (HUB/IDF rooms), main communication room (MCR room), network switch rooms, multiplexer (MUX) rooms, telecom equipment room, janitor storage room, chemical storage room, QA and QC laboratories, etc, should be enclosed from all sides and construction should be 2 h fire rated irrespective of the size/area.

4.5.3.3 Guest rooms, guest room corridors, banquets, should be 60 m fire compartmented with 30 min fire rated doors, in addition to above area of compartmentation.

4.5.3.4 In buildings with open atrium, the effect of compartmentation on the atrium should be disregarded, provided the fire safety requirements given in Annex E on atrium are complied.

4.5.3.5 In industrial and storage occupancies, all hazardous areas irrespective of area/size should be compartmented namely, vehicle charging areas, ignitable chemical storage areas, hazardous waste storage areas, flammable scrap storage areas, unless these are located 30 m away from any adjacent occupied buildings.

4.5.3.6 All live cooking areas with any type of fuel (induction, LPG, PNG, etc) in hotels, IT parks, business buildings cafeteria, hostels, educational facility, food courts, malls, any commercial kitchens should be 120 min fire rated segregated from other areas.

4.5.3.7 Pantries without live cooking, buffet setting counters (*bain-marie* serving) (with/without re-heating facility), breakout areas with microwave stations, water and dispensing areas, collaboration areas, tea coffee maker areas should be exempted from above compartmentation requirements.

4.6 Smoke Control

4.6.1 *Smoke Exhaust and Pressurization of Areas Above Ground*

Corridors in exit access (exit access corridor) are created for meeting the requirement of use, privacy, and layout in various occupancies. These are most often noted in hospitality, health care occupancies and sleeping accommodations.

Exit access corridors of guest rooms and indoor patient department/areas having patients lacking self-preservation and for sleeping accommodations such as service apartments, custodial, penal, and mental institutions, etc, should be provided with 60 min fire resistant wall and 30 min self-closing fire doors along with all fire stop sealing of penetrations.

Smoke exhaust system having make-up air and exhaust air system or alternatively pressurization system with supply air system for these exit access corridors should be required.

Smoke exhaust system having make-up air and exhaust air system should also be required for theatres/auditoria.

Such smoke exhaust system should also be required for large lobbies and which have exit through staircase leading to exit discharge. This would enable eased exit of people through smoke-controlled area to exit discharge.

All exit passageway (from exit-to-exit discharge) should be pressurized or naturally ventilated. The mechanical pressurization system should be automatic in action with manual controls in addition. All such exit passageway should be maintained with integrity for safe means of egress and evacuation. Doors provided in such exit passageway should be fire rated doors of 120 min rating.

Smoke exhaust system where provided, for above areas and occupancies should have a minimum of 12 air changes per hour smoke exhaust mechanism.

Pressurization system where provided, should have a minimum pressure differential of 25-30 Pa in relationship to other areas.

The smoke exhaust fans in the mechanical ventilation system should be fire rated, that is, 250 °C for 120 min.

For naturally cross-ventilated corridors or corridors with operable windows, such smoke exhaust system or pressurization system will not be required.

4.6.2 *Smoke Exhaust and Pressurization of Areas Below Ground*

a) Each basement should be separately ventilated;

b) Vents with cross-sectional area (aggregate) not less than 2.5 percent of the floor area spread evenly round the perimeter of the basement should be provided in the form of grilles, or breakable stall board lights or pavement lights or by way of shafts.

   Alternatively, a system of mechanical ventilation system may be provided. Mechanical ventilation system should be designed to permit 12 air changes per hour (ACPH) in case of fire or distress call. However, for normal operation, air changes schedule should be as given in Part D 'Building Services, Section 3 Air conditioning, Heating and Mechanical Ventilation' of this NBCS. In case of single basement, fresh-air may be considered from ramp and perimeter opening to achieve 12 ACPH ventilation requirement.

c) In multi-level basements, independent air intake and smoke exhaust shafts (masonry or reinforced concrete) for respective basement levels and compartments therein should be planned with its make-up air and exhaust air fans located on the respective level and in the respective compartment. Alternatively, in multi-level basements, common intake masonry (or reinforced cement concrete) shaft may serve respective compartments aligned at all basement levels. Similarly, common smoke exhaust/outlet masonry (or reinforced cement concrete) shafts may also be planned to serve such compartments at all basement levels. All supply air and exhaust air fans on respective levels should be installed in fire resisting room of 120 min. Exhaust fans at the respective levels should be provided with back draft damper connection to the common smoke exhaust shaft ensuring complete isolation and compartmentation of floor isolation to eliminate spread of fire and smoke to the other compartments/floors.

d) Due consideration should be taken for ensuring proper drainage of such shafts to avoid insanitation condition. Inlets and extracts may be terminated at ground level with stall board or pavement lights as before. Stall board and pavement lights should be in positions easily accessible to the fire brigade and clearly marked 'AIR INLET' or 'SMOKE OUTLET' with an indication of area served at or near the opening.

e) Smoke from any fire in the basement should not obstruct any fire exit serving the ground and upper floors of the building.

f) The smoke exhaust fans in the mechanical ventilation system should be fire rated, that is, 250 °C for 120 min.

g) The smoke ventilation of the basement car parking areas should be through provision of supply and exhaust air ducts duly installed with its supports and connected to supply air and exhaust fans. Alternatively, a system of impulse fans (jet fans) may be used for meeting the requirement of smoke ventilation complying with the following:

    1) Structural aspects of beams and other down stands/services should be taken care of in the planning and provision of the jet fans.

    2) Fans should be fire rated, that is, 250 °C for 120 min.

    3) Fans should be adequately supported to enable operations for the duration as above.

    4) Power supply panels for the fans should be located in fire safe zone to ensure continuity of power supply.

    5) Power supply cabling should meet circuit integrity requirement in accordance with accepted standard [F(13)].

The smoke extraction system should operate on actuation of flow switch actuation of sprinkler system. In addition, a local and/or remote 'manual start-stop control/switch' should be provided for operations by the fire fighters.

Visual indication of the operation status of the fans should also be provided with the remote control.

No system relating to smoke ventilation should be allowed to interface or cross the transformer area, electrical switchboard, electrical rooms or exits.

Smoke exhaust system having make-up air and exhaust air system for areas other than car parking should be required for common areas and exit access corridor in basements/underground structures and should be completely separate and independent of car parking areas and other mechanical areas.

Supply air should not be less than 5 m from any exhaust discharge openings.

For specific details on smoke management using mechanical means, *see* Part D ‘Building Services, Section 3 Air Conditioning, Heating and Mechanical Ventilation’ of this NBCS.

4.7 Gas Supply

4.7.1 *Town Gas/LPG Supply Pipes*

Where gas pipes are run in buildings, the same should be run in separate shafts exclusively for this purpose and these should be on external walls, away from the staircases. Gas distribution pipes should always be below the false ceiling. The length of these pipes should be as short as possible. In the case of kitchen cooking range area, hood should have grease filters using metallic grille to trap oil vapours escaping into the fume hood.

NOTE — For detailed information on gas pipe installations, reference may be made to Part E ‘Plumbing services, Section 4 Gas supply’ of this NBCS.

4.7.2 *Thermal Detectors*

These should be installed into fume hoods of large kitchens for hotels, hospitals, and similar areas located in high rise buildings. Arrangements should be made for automatic tripping of the exhaust fan in case of fire. If gas is used, the same should be shut off. The voltage should be 24 V or 100 V d.c. operated with external rectifier. The valve should be of the hand re-set type and should be located in an area segregated from cooking ranges. Valves should be easily accessible. The hood should have manual facility for steam or suitable hood extinguishing gas released depending on duty condition.

4.7.3 Gas cylinders and manifold should need to be housed in a detached location with no other occupancy within distances prescribed in good practice [F(14)] thereof. There should be an enclosure suitably ventilated. It is desirable to provide medium velocity spray nozzles which can be operated by quick opening valve situated away from the enclosure.

4.7.4 In the case of gas cylinders, if manifold has to be installed on podium/close to podium, the same should be away from any air intakes/smoke exhaust openings/any windows.

4.7.5 Pressure regulating stations should be designed and installed at critical locations for excess flow shut off valves. Seismic shut off valve at the main distribution point should be installed for buildings having mixed use assembly occupancy (like malls) and institutional occupancy above 15 m.

4.7.6 Gas meters should be housed in a suitably constructed metal cupboard located in a well-ventilated space, keeping in view the fact that LPG is heavier than air and natural gas is lighter than air.

4.7.7 Wherever LPG reticulation/cylinders are used in buildings above 100 m, gas leak detectors should be provided at the usage points and monitored from fire command centre. The cables used for signalling should be circuit integrity cables.

4.7.8 The gas lines should not be installed through any enclosed staircase or electrical shafts, escape routes, refuge areas/refuge floors.

4.7.9 Kitchens working on LPG fuel should not be permitted in basements. Small kitchen using other than LPG fuel, such as induction/PNG/electricity-based, may be permitted in incidental occupancies in the basement.

4.8 Hazardous Areas, Gaseous, Oil Storage Yard, etc

Rooms containing high pressure boilers, refrigerating machinery, transformers, or other service equipment subject to possible explosion should not be located directly under or adjacent to fire exits. All such rooms should be effectively cut-off from other parts of the building and should be provided with adequate vents to the outside air.

All rooms or areas of high hazard in additions to those hereinbefore mentioned, should be segregated, or should be protected with fire resistant walls having fire rating of 120 min as fire, explosion or smoke therefrom is likely to interfere with safe egress from the building. Further,

a) each building should be provided with an approved outside gas shut-off valve conspicuously marked. The detailed requirements regarding safe use of gas should be as specified in Part E ‘Plumbing services, Section 4 Gas Supply’ of this NBCS; and

b) all exterior openings in a boiler room or rooms that contain central heating equipment, if located below opening in another storey or if less than 3 m from other doors or windows of the same building should be protected by a fire assembly as in **3.5.4**. Such assemblies should be fixed, automatic or self-closing.

4.9 Fire Detection and Alarm

a) The requirements of fire detection and alarm systems are covered for each occupancy in Table 7A to Table 7J and under **6.1** to **6.9** for annunciation to occupants in view of the ensuing vulnerability and to warn occupants early of the existence of fire, so as to facilitate orderly and safe egress;

b) Fire detection and alarm systems in buildings should be so planned and programmed so as to enable operations of various systems and equipment to facilitate requirements leading to life safety, compartmentation and fire protection. These systems and equipment may include electromechanical systems such as air handling units; pressurization systems; smoke management systems; creation of compartmentation through the release of fire barrier, hold-up fire doors, etc; and monitoring of fire water storage tanks and pumps, pressures in hydrant and sprinkler system, etc. These planning and requirements should be based on building occupancy and other requirements on case-to-case basis;

c) Voice evacuation systems should employ English, Hindi and vernacular language using pre-recorded messages and integrate with fire alarm panels for alerting the zone of fire and surrounding zones/floors as required for annunciation (*see also* Table 7A to Table 7J);

d) Appropriate visual warning arrangement through visual strobes/beacons may be considered in appropriate situations particularly in public buildings, at required locations to ensure visual as well as alarm for persons with hearing impairment;

e) For assembly buildings, institutional buildings and all buildings above 30 m in height where fire alarm system is provided in accordance to Table 7A to Table 7J, detectors should also be provided inside the electrical shafts, lift machine rooms, etc, besides occupancy areas;

f) Fire alarm panels should be connected in peer-to-peer network or with redundant cables, run in different shafts. Each panel should be able to work in standalone mode and master slave architecture may be used where required;

g) The fire detection system should be in accordance with accepted standards [F(15)];

h) Guidelines for selection of various types of fire detectors for different occupancies and their installation and maintenance should be in accordance with good practice [F(16)]. *See also* Handbook for 'Asset and Facility Management' for guidance;

j) In buildings where automatic fire alarm system is provided, the following should be monitored from fire alarm panel:

    1) Water level in all tanks.

    2) Hydrant and sprinkler pressures of respective zones, as provided.

    3) Pump ‘ON/OFF’ status.

    4) All isolation valves, wherever provided with supervisory switch (non-padlock valves).

    5) Other requirements to meet electro-mechanical services interface.

Table 7A Requirements for Firefighting Installations – For Residential Buildings

[*Clauses* 4.9 (a), 4.9 (c), 4.9(e), 5.1.1 (a), 5.1.1(d), 5.1.2.1, 5.1.3 (a), D-6.1, G-2(f) *and* Table 31]

Sl No.	Type of Building Occupancy	Type of Installation							
		Fire Extinguisher	First Aid Hose Reel	Down Comer	Wet Riser	Yard Hydrant	Automatic Wet Sprinkler System	Automatic Fire Detection and Alarm System and LPG/PNG Gas Detector	Public Address and Voice Evacuation System
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	RESIDENTIAL BUILDINGS (A)								
a)	**Lodging and Rooming Houses (A- I)**	**Up to 500 m^2 area and up to 24 m height (both conditions to be met), self-certification by a certified and State approved building professional should be treated acceptable**							
1)	24 m and above in height and, having any area Or Less than 24 m in height but of area,								
i)	floor area on any single floor 501 m^2 to 1 000 m^2 **(HL-1)** *See* Notes 1, 2, 3 and 4	R	R	NR	NR	NR	NR	R	NR
ii)	1 001 m^2 and above (**HL-2**) *See* Notes 2, 3 and 4	R	R	R	NR	NR	NR	R	R

Table 7A (*Continued*)

Sl No.	**Type of Building Occupancy**	**Type of Installation**							
		Fire Extinguisher	First Aid Hose Reel	Down Comer	Wet Riser	Yard Hydrant	Automatic Wet Sprinkler System	Automatic Fire Detection and Alarm System and LPG/PNG Gas Detector	Public Address and Voice Evacuation System
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
b)	**Dormitories (A-II)**	**Up to 500 m^2 area and up to 24 m height (both conditions to be met), self-certification by a certified and State approved building professional should be treated acceptable**							
1)	501 m^2 to 1 000 m^2 **(HL-1)** *See* Notes 1, 2, 3 and 4	R	R	NR	NR	NR	NR	NR	NR
2)	1 001 m^2 and above **(HL-2)** *See* Notes 2, 3 and 4	R	R	R	NR	NR	NR	R	NR
c)	**Apartment Houses (A-III)**	**Up to 500 m^2 area and up to 24 m height (both conditions to be met), self-certification by a certified and State approved building professional should be treated acceptable**							
1)	24 m and above but not exceeding 60 m in height; and, height less than 24 m, but of area:								
i)	501 m^2 to 1 000 m^2 **(HL-2)** See Notes 2, 3, 4, 7 and 9	R	R	R	NR	NR	NR	NR	NR

Table 7A (*Continued*)

Sl No.	Type of Building Occupancy	Type of Installation							
		Fire Extinguisher	First Aid Hose Reel	Down Comer	Wet Riser	Yard Hydrant	Automatic Wet Sprinkler System	Automatic Fire Detection and Alarm System and LPG/PNG Gas Detector	Public Address and Voice Evacuation System
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
ii)	1 001 m^2 and above **(HL-3)** *See* Notes 2, 3, 4, 5, 7, 9 and 10	R	R	NR	R	R	NR	R	R
2)	Above 60 m height **(CL-4)** *See* Notes 3, 4, 5, 7, 8, 9, and 10	R	R	NR	R	R	R	R	R
d)	**Hotels (A-IV)**	**Up to 500 m^2 area and up to 24 m height (both conditions to be met), self-certification by a certified and State approved building professional should be treated acceptable**							
1)	Up to 24 m in height, but of area:								
i)	501 m^2 to 1 000 m^2 **(HL-3)** *See* Notes 2, 3, 4, 7 and 9	R	R	R	NR	NR	NR	R	NR
ii)	1 001 m^2 and above **(CL-3)** *See* Notes 3, 4, 7 and 9	R	R	NR	R	NR	R	R	R

Table 7A (*Concluded*)

Sl No.	**Type of Building Occupancy**	**Type of Installation**							
		Fire Extinguisher	First Aid Hose Reel	Down Comer	Wet Riser	Yard Hydrant	Automatic Wet Sprinkler System	Automatic Fire Detection and Alarm System and LPG/PNG Gas Detector	Public Address and Voice Evacuation System
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
2)	24 m and above but not exceeding 60 m in height OR 3/4 Star Hotels **(CL-4)** *See* Notes 3, 4, 5, 7, 8 and 9	R	R	NR	R	R	R	R	R
3)	Above 60 m – *See* Note 5								
e)	**Starred (Franchise – 5 Star) Hotels (A-V)**								
1)	Up to 60 m **(CL-5)** *See* Note 4	R	R	NR	R	R	R	R	R
2)	Above 60 m – *See* Note 5								

R – Required NR – Not Required

REMARK 1: Any state or area where the municipal supply caters to municipal/public yard hydrant system with hydrant outlets provided throughout the premises with adequate water supply meeting the wet riser requirement demand flow and pressure 24 × 7 uninterrupted, such states/areas/ jurisdiction can replace the wet riser system and its associated pumping with water storage with a dry riser system. Dry riser system is also recommended for areas where ambient temperature below is 4 °C and has facility of connecting the yard hydrant to the dry riser in any event of fire in the building. This system is to be maintained with quarterly checks to ensure the system integrity to handle the required flow and pressure. This is applicable for buildings height only up to 24 m where HL Protection is required as per above Table**.**

REMARK 2: Sharing of water storage tank may be permitted between the adjacent neighbouring properties including industry clusters, without any loss of hydraulic effects (which is essential to fight the fire during an emergency).

NOTES

1 If the building has kitchen, the protection level will be **HL-2**.

2 If the building has basement to be protected with sprinklers, the protection level should comply with **CL-3**.

3 If the building has electrical vehicles (EV) parks in podium or basements, it should be protected with sprinklers and complying to **CL-5**.

4 Rate of rise of heat sensor/detection system should be provided in EV (Electrical Vehicles) parks and charging areas. Smoke sensor/detectors should be provided in all basements in all areas other than internal combustion engine (ICE) vehicles parks as part of the fire alarm system. ICE vehicle parks should be provided with carbon monoxide sensors as part of fire alarm system to activate ventilation system.

5 If the building height exceeds 60 m the hydraulic calculations meeting recommended system architecture with multi-level pumping and storage with gravity redundant down comer may be considered. The pumps considered should not exceed 12 bar shutoff pressure.

6 Pump pressure and quantity should be supported by hydraulic calculations.

7 2,500 lpm at 10 bar common pumping and water storage of 2,55,000 litre should be provided for a cluster of maximum 5 buildings, with or without common basement. The buildings should not be closer than 9 m. If the buildings are closer than 9 m, or the basement is used for EV parking and or charging facilities, the protection level should comply with **CL-5**.

8 Multi-level pumping and water storage as per schematic line drawing (SLD) may be considered for cluster buildings more than 45 m in height; and water storage at every 45 m above should be provided for individual buildings.

9 If the cluster of buildings exceeds 5, another set of pumps and water storage of similar capacity should be provided. A maximum of two such sets is recommended, provided it satisfies the hydraulic requirements and functioning at the remotest point.

10 Table 7K and Table 7M suggesting the basis for water quantity required for fire-fighting, respectively for combined (sprinkler and hose) protection and hose protection be considered.

Table 7B Requirements for Firefighting Installations – For Educational Buildings

[*Clauses* 4.9 (a), 4.9 (c), 4.9(e), 5.1.1 (a), 5.1.1(d), 5.1.2.1, 5.1.3 (a), D-6.1, G-2(f) *and* Table 31]

Sl No.	**Type of Building Occupancy**	**Type of Installation**							
		Fire Extinguisher	First Aid Hose Reel	Down Comer	Wet Riser	Yard Hydrant	Automatic Wet Sprinkler System	Automatic Detection and Alarm System	Public Address and Voice Evacuation System
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	EDUCATIONAL BUILDINGS (B)	**Up to 500 m^2 area and up to 24 m height (both conditions to be met), self-certification by a certified and State approved building professional should be treated acceptable**							
1)	24 m and above but not exceeding 45 m; And, height less than 24 m, but of area:								
i)	501 m^2 to 1 000 m^2 **(HL-3)** *See* Notes 1, 2, 3, 5, 7 and 9	R	R	NR	R	R	NR	R	R
ii)	1 001 m^2 and above **(CL-4)** *See* Notes 3, 5, 7, 9 and 10	R	R	NR	R	R	R	R	R
2)	45 m and above but not exceeding 60 m in height **(CL-4)** (*See* Notes 5, 6, 7, 8, 9 and 10)	R	R	NR	R	R	R	R	R
3)	Above 60 m – *See* Note 5								

R – Required NR – Not Required

REMARK 1: Any state or area where the municipal supply caters to municipal/public yard hydrant system with hydrant outlets provided throughout the premises with adequate water supply meeting the wet riser requirement demand flow and pressure 24 × 7 uninterrupted, such states/areas/ jurisdiction can replace the wet riser system and its associated pumping with water storage with a dry riser system. Dry riser system is also recommended for areas where ambient temperature below is 4 °C and has facility of connecting the yard hydrant to the dry riser in any event of fire in the building. This system is to be maintained with quarterly checks to ensure the system integrity to handle the required flow and pressure. This is applicable for buildings height only up to 24 m where HL Protection is required as per above Table**.**

REMARK 2: Sharing of water storage tank may be permitted between the adjacent neighbouring properties including industry clusters, without any loss of hydraulic effects (which is essential to fight the fire during an emergency).

NOTES

1 If there are laboratories, AV/computer rooms, auditoriums, they should be protected with sprinkler and the protection level should comply with **CL-3**.

2 If the building has basement to be protected with sprinklers, the protection level should comply with **CL-3**.

3 If the building has electrical vehicles (EV) parks in podium or basements, it should be protected with sprinklers and complying to **CL-5**.

4 Rate of rise heat sensor/detection system should be provided in Electrical Vehicles (EV) parks and charging areas. Smoke sensor/detectors should be provided in all basements in all areas other than internal combustion engine (ICE) vehicles parks as part of the fire alarm system. ICE vehicle parks should be provided with carbon monoxide sensors as part of fire alarm system to activate ventilation system.

5 If the building height exceeds 60 m the hydraulic calculations meeting recommended system architecture with multi-level pumping and storage with gravity redundant down comer may be considered. The pumps considered should not exceed 12 bar shutoff pressure.

6 Pump pressure and quantity should be supported by hydraulic calculations.

7 2,500 lpm at 10 bar common pumping and water storage of 2,55,000 litre should be provided for a cluster of maximum 5 buildings, with or without common basement. The buildings should not be closer than 9 m. If the buildings are closer than 9 m, or the basement is used for EV parking and or charging facilities, the protection level should comply with **CL-5**.

8 Multi-level Pumping and water storage as per schematic line drawing (SLD) may be considered for cluster buildings more than 45 m; and water storage at every 45 m above should be provided for individual buildings.

9 If the cluster of buildings exceeds 5, another set of pumps and water storage of similar capacity should be provided. A maximum of two such sets is recommended, provided it satisfies the hydraulic requirements and functioning at the remotest point.

10 Table 7K and Table 7M suggesting the basis for water quantity required for fire-fighting, respectively for combined (sprinkler and hose) protection and hose protection be considered.

Table 7C Requirements for Firefighting Installations – For Institutional Buildings

[*Clauses* 4.9 (a), 4.9 (c), 4.9(e), 5.1.1 (a), 5.1.1(d), 5.1.2.1, 5.1.3 (a), D-6.1, G-2(f) *and* Table 31]

Sl No.	**Type of Building Occupancy**	**Type of Installation**							
		Fire Extinguisher	First Aid Hose Reel	Down comer	Wet Riser	Yard Hydrant	Automatic Wet Sprinkler System	Automatic Detection and Alarm System	Public Address and Voice Evacuation System
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	INSTITUTIONAL BUILDINGS (C)								
a)	**Nursing homes and sanatoria**	**Up to 500 m^2 area and up to 24 m height (both conditions to be met), self-certification by a certified and state approved building professional should be treated acceptable**							
i)	(*see* Note 1) Building height above 15 m; and, for heights up to 15 m, and area 501 m^2 and above **(HL-3)** *See* Notes 1, 2, 4, 6 and 9	R	R	R	NR	NR	NR	R	NR
b)	**Hospitals (C-I)**	**Up to 500 m^2 area and up to 24 m height (both conditions to be met), self-certification by a Certified and State Approved building professional should be treated acceptable**							
1)	For heights not exceeding 45 m in height								

Table 7C (*Continued*)

Sl No.	**Type of Building Occupancy**	**Type of Installation**							
		Fire Extinguisher	First Aid Hose Reel	Down comer	Wet Riser	Yard Hydrant	Automatic Wet Sprinkler System	Automatic Detection and Alarm System	Public Address and Voice Evacuation System
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
i)	501 m^2 to 1 000 m^2 **(CL-3)** *See* Notes 2, 4, 6, 7, 9 and 10	R	R	NR	R	R	R	R	NR
ii)	Above 1 001 m^2 **(CL-4)** *See* Notes 2, 4, 6, 7, 9 and 10	R	R	NR	R	R	R	R	R
2)	Above 45 m but not exceeding 60 m in height **(CL-5)** *See* Notes 4, 6, 7, 9 and 10	R	R	NR	R	R	R	R	R
3)	Above 60 m – *See* Note 3								
b)	**Custodial, Penal and Mental Institutions (C-II and III)**	**Up to 500 m^2 area and up to 24 m height (both conditions to be met), self-certification by a Certified and State Approved building professional should be treated acceptable**							

Table 7C (*Concluded*)

Sl No.	**Type of Building Occupancy**	**Type of Installation**							
		Fire Extinguisher	First Aid Hose Reel	Down comer	Wet Riser	Yard Hydrant	Automatic Wet Sprinkler System	Automatic Detection and Alarm System	Public Address and Voice Evacuation System
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1)	For heights not exceeding 45 m in height								
i)	501 m^2 to 1 000 m^2 **(HL-2)** *See* Notes 1, 2, 4 and 6	R	R	R	NR	NR	NR	NR	R
ii)	1 001 m^2 and above **(HL-3)** *See* Notes 1, 2, 4, 6 and 9	R	R	NR	R	R	NR	R	R
2)	Above 45 m **(HL-4)** *See* Notes 1, 2, 3, 6, 8 and 9	R	R	NR	R	R	NR	R	R

R – Required NR – Not Required

REMARK 1: Any state or area where the municipal supply caters to municipal/public yard hydrant system with hydrant outlets provided throughout the premises with adequate water supply meeting the wet riser requirement demand flow and pressure 24 × 7 uninterrupted, such states/areas/jurisdiction can replace the wet riser system and its associated pumping with water storage with a dry riser system. Dry riser system is also recommended for areas where ambient temperature below is 4 °C and has facility of connecting the yard hydrant to the dry riser in any event of fire in the building. This system is to be maintained with quarterly checks to ensure the system integrity to handle the required flow and pressure. This is applicable for buildings height only up to 24 m where HL Protection is required as per above Table**.**

REMARK 2: Sharing of water storage tank may be permitted between the adjacent neighbouring properties including industry clusters, without any loss of hydraulic effects (which is essential to fight the fire during an emergency).

NOTES

1 Basement area or storage of oxygen or any medical gases or any gas fuel, laundry or linen/waste, transformer/HT rooms within the building foot print or in basement should be protected with sprinkler and the protection level should comply with **CL-3**.

2 If the building has electrical vehicles (EV) parks in podium or basements, it should be protected with sprinklers and complying to **CL-5**.

3 If the building height exceeds 60 m the hydraulic calculations meeting recommended system architecture with multi-level pumping and storage with gravity redundant down comer may be considered. The pumps considered should not exceed 12 bar shutoff pressure.

4 Protection should comply to supplementary protection for specific hazard/critical rooms as per Table 9/ Table 10/ Table 11 as applicable.

5 Pump pressure and quantity should be supported by hydraulic calculations.

6 Rate of rise heat sensor/detection system should be provided in electrical vehicles (EV) parks and charging areas. Smoke sensor/detectors should be provided in all basements in all areas other than internal combustion engine (ICE) vehicles parks as part of the fire alarm system. ICE vehicle parks should be provided with carbon monoxide sensors as part of fire alarm system to activate ventilation system. (recommendation only for parking and podium)

7 3785/2500 lpm at 10 bar common pumping and water storage of 3,50,000/2,55,000 litre should be provided of cluster of maximum 5 building 45 m height, with or without common basement. The buildings should not be closer than 9 m. If the buildings are closer than 9 m, or the basement is used for Electric Vehicles (EV) parking and or charging facilities, the protection level should comply with **CL-5**.

8 Multi-level pumping and water storage as per schematic line drawing (SLD) may be considered for cluster buildings more than 45 m; and water storage at every 45 m above should be provided for individual buildings.

9 If the cluster of buildings exceeds 5, another set of pumps and water storage of similar capacity should be provided. A maximum of two such sets is recommended, provided it satisfies the hydraulic requirements and functioning at the remotest point.

10 If the building height exceeds 30 m it should comply hydraulic calculations meeting recommended system architecture.

11 Table 7K and Table 7M suggesting the basis for water quantity required for fire-fighting, respectively for combined (sprinkler and hose) protection and hose protection be considered.

Table 7D Requirements for Firefighting Installations – For Assembly Buildings

[*Clauses* 4.9 (a), 4.9 (c), 4.9(e), 5.1.1 (a), 5.1.1(d), 5.1.2.1, 5.1.3 (a), D-6.1, G-2(f) *and* Table 31]

Sl No.	**Type of Building Occupancy**	**Type of Installation**							
		Fire Extinguisher	First Aid Hose Reel	Down Comer	Wet Riser	Yard Hydrant	Automatic Wet Sprinkler System	Automatic Detection and Alarm System	Public Address and Voice Evacuation System
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	ASSEMBLY BUILDINGS (D) *See* Note 4								
a)	**Assembly Buildings**	**Up to 500 m^2 area and up to 9 m height (both conditions to be met), self-certification by a certified and State approved building professional should be treated acceptable**							
1)	9 m and above but not exceeding 15 m in height; and, for heights less than 9 m; and area *See* Note 6								
i)	501 m^2 to 1 000 m^2 **(HL-3)** *See* Notes 1, 2, 3, 5 and 8	R	R	NR	R	NR	NR	R	NR

Table 7D (*Concluded*)

Sl No.	Type of Building Occupancy	Type of Installation							
		Fire Extinguisher	First Aid Hose Reel	Down Comer	Wet Riser	Yard Hydrant	Automatic Wet Sprinkler System	Automatic Detection and Alarm System	Public Address and Voice Evacuation System
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
ii)	1 001 m^2 and above **(CL-4)** *See* Notes 2, 5, 8 and 9	R	R	NR	R	R	R	R	NR
2)	Above 15 m in height **(CL-4)** *See* Notes 2, 5, 6, 7, 8 and 9	R	R	NR	R	R	R	R	NR

R – Required NR – Not Required

REMARK 1: Any state or area where the municipal supply caters to municipal/public yard hydrant system with hydrant outlets provided throughout the premises with adequate water supply meeting the wet riser requirement demand flow and pressure 24×7 uninterrupted, such states/areas/ jurisdiction can replace the wet riser system and its associated pumping with water storage with a dry riser system. Dry riser system is also recommended for areas where ambient temperature below is 4 °C and has facility of connecting the yard hydrant to the dry riser in any event of fire in the building. This system is to be maintained with quarterly checks to ensure the system integrity to handle the required flow and pressure. This is applicable for buildings height only up to 24 m where HL Protection is required as per above Table**.**

REMARK 2: Sharing of water storage tank may be permitted between the adjacent neighbouring properties including industry clusters, without any loss of hydraulic effects (which is essential to fight the fire during an emergency).

NOTES

1 If the building has basement to be protected with sprinklers, the protection level should comply with **CL-3**.

2 If the building has electrical vehicles (EV) parks in podium or basements, it should be protected with sprinklers and complying to **CL-5**.

3 Live cooking kitchens, boiler/furnace rooms, laundry or linen/waste rooms, transformer/HT rooms within the building foot print or in basement the area should be protected with sprinkler protection and should comply with **CL-4**.

4 Pump pressure and quantity should be supported by hydraulic calculations.

5 Rate of rise heat sensor/detection system should be provided in electrical vehicles (EV) parks and charging areas. Smoke sensor/detectors should be provided in all basements in all areas other than internal combustion engine (ICE) vehicles parks as part of the fire alarm system. ICE vehicle parks should be provided with carbon monoxide sensors as part of fire alarm system to activate ventilation system. (recommendation only for parking and podium).

6 2,500 lpm at 10 bar common pumping and water storage of 2,55,000 litre should be provided for a cluster of maximum 5 buildings, with or without common basement. The buildings should not be closer than 9 m. If the buildings are closer than 9 m, or the basement is used for EV parking and or charging facilities, the protection level should comply with **CL-5**.

7 Multi-level pumping and water storage as per schematic line drawing (SLD) may be considered for cluster buildings more than 45 m; and water storage at every 45 m above should be provided for individual buildings.

8 If the cluster of buildings exceeds 5, another set of pumps and water storage of similar capacity should be provided. A maximum of two such sets is recommended, provided it satisfies the hydraulic requirements and functioning at the remotest point.

9 Table 7K and Table 7M suggesting the basis for water quantity required for fire-fighting, respectively for combined (sprinkler and hose) protection and hose protection be considered.

Table 7E Requirements for Firefighting Installations – For Business Buildings

[*Clauses* 4.9 (a), 4.9 (c), 4.9(e), 5.1.1 (a), 5.1.1(d), 5.1.2.1, 5.1.3 (a), D-6.1, G-2(f) *and* Table 31]

Sl No.	**Type of Building Occupancy**	**Type of Installation**							
		Fire Extinguisher	First Aid Hose Reel	Down Comer	Wet Riser	Yard Hydrant	Automatic Wet Sprinkler System	Automatic Detection and Alarm System	Public Address and Voice Evacuation System
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	BUSINESS BUILDINGS (E) *See* Notes 5								
a)	**Business Buildings (Human Occupied)**	**Up to 500 m^2 area and up to 15 m height (both conditions to be met), self-certification by a Certified and State approved building professional should be treated acceptable**							

Table 7E (*Continued*)

Sl No.	**Type of Building Occupancy**	**Type of Installation**							
		Fire Extinguisher	First Aid Hose Reel	Down Comer	Wet Riser	Yard Hydrant	Automatic Wet Sprinkler System	Automatic Detection and Alarm System	Public Address and Voice Evacuation System
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1)	15 m and above but not exceeding 45 m in height; and, for heights less than 15 m and area								
i)	500 m^2 to 1 000 m^2 **(CL-2)** *See* Notes 1, 2, 3, 6, 7, 9 and 11	R	R	R	NR	NR	R	R	R
ii)	1 001 m^2 to 3 000 m^2 **(CL-3)** *See* Notes 2, 3, 6, 7, 9 and 11	R	R	NR	R	R	R	R	R
iii)	3 001 m^2 and above **(CL-4)** *See* Notes 2, 3, 6, 7, 9 and 11	R	R	NR	R	R	R	R	R

Table 7E (*Continued*)

Sl No.	**Type of Building Occupancy**	**Type of Installation**							
		Fire Extinguisher	First Aid Hose Reel	Down Comer	Wet Riser	Yard Hydrant	Automatic Wet Sprinkler System	Automatic Detection and Alarm System	Public Address and Voice Evacuation System
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
2)	Above 45 m but not exceeding 60 m height **(CL-5)** *See* Notes 3, 4, 6, 7, 8, 9 and 11	R	R	NR	R	R	R	R	R
3)	For buildings over 60 m height	*See* Note 4							
b)	**Data Centres (Machine Environment)** *See* Notes 3, 12 ,13 and 15								
1)	Less than 15 m in height								
i)	Floor Area on any single floor up to 1 000 m^2	R	R	NR	R	R	R	R	R
ii)	1 001 m^2 and above	R	R	NR	R	R	R	R	R

Table 7E (*Concluded*)

Sl No.	**Type of Building Occupancy**	**Type of Installation**							
		Fire Extinguisher	First Aid Hose Reel	Down Comer	Wet Riser	Yard Hydrant	Automatic Wet Sprinkler System	Automatic Detection and Alarm System	Public Address and Voice Evacuation System
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
2)	Above 15 m in height								
i)	Floor area on any single floor up to 1 000 m^2	R	R	NR	R	R	R	R	R
ii)	1 001 m^2 and above	R	R	NR	R	R	R	R	R

R – Required NR – Not Required

REMARK 1: Any state or area where the municipal supply caters to municipal/public yard hydrant system with hydrant outlets provided throughout the premises with adequate water supply meeting the wet riser requirement demand flow and pressure 24 × 7 uninterrupted, such states/areas/jurisdiction can replace the wet riser system and its associated pumping with water storage with a dry riser system. Dry riser system is also recommended for areas where ambient temperature below is 4 °C and has facility of connecting the yard hydrant to the dry riser in any event of fire in the building. This system is to be maintained with quarterly checks to ensure the system integrity to handle the required flow and pressure. This is applicable for buildings height only up to 24 m where HL protection is required as per above table.

REMARK 2: Sharing of water storage tank may be permitted between the adjacent neighbouring properties including industry clusters, without any loss of hydraulic effects (which is essential to fight the fire during an emergency).

NOTES

1 If the building has basement to be protected with sprinklers, the protection level should comply with **CL-3**.

2 If the building has Electrical Vehicles (EV) parks in podium or basements, it should be protected with sprinklers and complying to **CL-5**.

3 Protection should comply to supplementary protection for specific hazard/critical rooms as per Table 9/ Table 10/ Table 11 as applicable.

4 If the building height exceeds 60 m the hydraulic calculations meeting recommended system architecture with multi-level pumping and storage with gravity redundant down comer may be considered. The pumps considered should not exceed 12 bar shutoff pressure.

5 Pump pressure and quantity should be supported by hydraulic calculations.

6 2500 lpm at 10 bar common pumping and water storage of 2,55,000 litre should be provided for a cluster of maximum 5 buildings, with or without common basement. The buildings should not be closer than 9 m. If the buildings are closer than 9 m, or the basement is used for EV parking and or charging facilities, the protection level should comply with **CL-5**.

7 3785 lpm at 10 bar common pumping and water storage of 3,50,000 litre should be provided of cluster of maximum 5 building, with or without common basement. The buildings should not be closer than 9 m. If the buildings are closer than 9 m, or the basement is used for Electric Vehicles (EV) parking and or charging facilities, the protection level should comply with **CL-5**.

8 Multi-level pumping and water storage as per schematic line drawing (SLD) (*see* Fig. 20) may be considered for cluster buildings more than 45 m; and water storage at every 45 m above should be provided for individual buildings.

9 If the cluster of buildings exceeds 5, another set of pumps and water storage of similar capacity should be provided. A maximum of two such sets is recommended, provided it satisfies the hydraulic requirements and functioning at the remotest point.

10 The entire building it should be protected with sprinkler and the protection level should comply with **CL-5**. IT/Data Hall should be protected with suitable clean agent gas suppression only if the racks are without BBU (not exceeding 20 kWh backup battery units).

11 All internet data centres or hyper scales or colocation data centres comply with protection level **CL6**.

12 If the IT/data hall (DC) racks are with BBUs with Lithium-ion batteries not exceeding 20 kWh/rack, wet or dry sprinkler/pre-action/water mist (3rd party tested for lithium ion BBUs) should be deployed. If the BBUs exceed 20 kWh/rack, water mist should not be installed.

13 If the cluster of data centre buildings to a maximum of 3, common pumping system and storage may be with an additional diesel engine pump, with double water storage.

14 If the any of the building houses lithium-ion energy storage systems exceeding 600 kWh/floor, the building should comply to protection level **CL-6**.

15 Lithium-ion battery energy storage systems (BESS) room should be protected with wet/single interlock pre action sprinkler only, considering entire room as “assumed area of operation”. Pump and water storage should be calculated based on maximum design and hydraulic calculations whichever is higher.

16 Table 7K and Table 7M suggesting the basis for water quantity required for fire-fighting, respectively for combined (sprinkler and hose) protection and hose protection be considered.

Table 7F Requirements for Firefighting Installations – For Mercantile Buildings

[*Clauses* 4.9 (a), 4.9 (c), 4.9(e), 5.1.1 (a), 5.1.1(d), 5.1.2.1, 5.1.3 (a), D-6.1, G-2(f) *and* Table 31]

Sl No.	**Type of Building Occupancy**	**Type of Installation**							
		Fire Extinguisher	First Aid Hose Reel	Down Comer	Wet Riser	Yard Hydrant	Automatic Wet Sprinkler System	Automatic Detection and Alarm System	Public Address and Voice Evacuation System
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	MERCANTILE BUILDINGS (F) *See* Note 4								
a)	**Mercantile Buildings (F)**	**Up to 500 m^2 area and up to 15 m height (both conditions to be met), self-certification by a certified and State approved building professional should be treated acceptable**							
1)	Above 15 m but not exceeding 30 m in height; and, for heights less than 15 m and area								
i)	501 m^2 to 1 000 m^2 **(HL-3)** *See* Notes 1, 2, 3, 5, 6 and 7	R	R	R	NR	NR	NR	R	NR
ii)	1 001 m^2 and above **(CL-4)** *See* Notes 2, 3, 5, 6, 7 and 8	R	R	NR	R	R	R	R	NR

Table 7F (*Concluded*)

Sl No.	**Type of Building Occupancy**	**Type of Installation**							
		Fire Extinguisher	First Aid Hose Reel	Down Comer	Wet Riser	Yard Hydrant	Automatic Wet Sprinkler System	Automatic Detection and Alarm System	Public Address and Voice Evacuation System
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
2)	Above 30 m	See Note 5							
b)	**Underground Shopping Complex** **(CL-5)** *See* Note 3	R	R	NR	R	R	R	R	R

R – Required NR – Not Required

REMARK 1: Any state or area where the municipal supply caters to municipal/public yard hydrant system with hydrant outlets provided throughout the premises with adequate water supply meeting the wet riser requirement demand flow and pressure 24 × 7 uninterrupted, such states/areas/ jurisdiction can replace the wet riser system and its associated pumping with water storage with a dry riser system. Dry riser system is also recommended for areas where ambient temperature below is 4 °C and has facility of connecting the yard hydrant to the dry riser in any event of fire in the building. This system is to be maintained with quarterly checks to ensure the system integrity to handle the required flow and pressure. This is applicable for buildings height only up to 24 m where HL Protection is required as per above table.

REMARK 2: Sharing of water storage tank may be permitted between the adjacent neighbouring properties including industry clusters, without any loss of hydraulic effects (which is essential to fight the fire during an emergency).

NOTES

1 If the building has basement to be protected with sprinklers, the protection level should comply with **CL-3**.

2 If the building has electrical vehicles (EV) parks in podium or basements, it should be protected with sprinklers and complying to **CL-5**.

3 Protection should comply to supplementary protection for specific hazard/critical rooms as per Table 9/ Table 10/ Table 11 as applicable.

4 Pump pressure and quantity should be supported by hydraulic calculations.

5 If the building height exceeds 30 m it should comply hydraulic calculations meeting recommended system architecture.

6 If the building height exceeds 60 m multi-level pumping and storage with gravity redundant down comer. The pumps considered should not exceed 12 bar shutoff pressure.

7 Rate of rise heat sensor/detection system should be provided in electrical vehicles (EV) parks and charging areas. Smoke sensor/detectors should be provided in all basements in all areas other than internal combustion engine (ICE) vehicles parks as part of the fire alarm system. ICE vehicles parks should be provided with carbon monoxide sensors as part of fire alarm system to activate ventilation system.

8 Table 7K and Table 7M suggesting the basis for water quantity required for fire-fighting, respectively for combined (sprinkler and hose) protection and hose protection be considered.

Table 7G Requirements for Firefighting Installations – For Industrial Buildings

(*See also* Annex N on Fire Protection for Specific Industries)

[*Clauses* 4.9 (a), 4.9 (c), 4.9(e), 5.1.1 (a), 5.1.1(d), 5.1.2.1, 5.1.3 (a), D-6.1, G-2(f), Annex N *and* Table 31]

Sl No.	Type of Building Occupancy	Type of Installation							
		Fire Extinguisher	First Aid Hose Reel	Down Comer	Wet Riser	Yard Hydrant	Automatic Wet Sprinkler System	Automatic Detection and Alarm System	Public Address and Voice Evacuation System
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Industrial Buildings (G) *See* Note 5								
a)	**Low Hazard (G-1)** *See* Notes 1 and 6								

Table 7G (*Continued*)

Sl No.	Type of Building Occupancy	Type of Installation							
		Fire Extinguisher	First Aid Hose Reel	Down Comer	Wet Riser	Yard Hydrant	Automatic Wet Sprinkler System	Automatic Detection and Alarm System	Public Address and Voice Evacuation System
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
i)	Built up area up to 1 000 m^2 (Including the MSMEs) **(HL-1)**	R	R	NR	NR	NR	NR	NR	NR
ii)	Built up area from 1 001 m^2 to 2 000 m^2 **(HL-2)**	R	R	R	NR	NR	NR	NR	NR
iii)	Built up area from 2 001 m^2 up to 3 000 m^2 **(HL-3)**	R	R	NR	NR	R	NR	R	NR
iv)	Above 3 001 m^2 **(HL-4)** *See* Note 1	R	R	NR	NR	R	NR	R	NR

Table 7G (*Continued*)

Sl No.	**Type of Building Occupancy**	**Type of Installation**							
		Fire Extinguisher	First Aid Hose Reel	Down Comer	Wet Riser	Yard Hydrant	Automatic Wet Sprinkler System	Automatic Detection and Alarm System	Public Address and Voice Evacuation System
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
b)	**Moderate Hazard (G-2)** *See* Notes 1, 4 and 6								
i)	Built up area up to 500 m^2 **(HL-2)**	R	R	R	NR	NR	NR	NR	NR
ii)	Built up area from 501 m^2 to 2 000 m^2 **(HL-3)**	R	R	NR	R	R	NR	R	NR
iii)	Built up area from 2 001 m^2 to 3 000 m^2 **(HL-4)**	R	R	NR	R	R	NR	R	NR
iv)	Built up area above 3 001 m^2 **(CL-5)**	R	R	NR	R	R	R	R	NR

Table 7G (*Continued*)

Sl No.	**Type of Building Occupancy**	**Type of Installation**							
		Fire Extinguisher	First Aid Hose Reel	Down Comer	Wet Riser	Yard Hydrant	Automatic Wet Sprinkler System	Automatic Detection and Alarm System	Public Address and Voice Evacuation System
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
c)	**High Hazard (G- 3)**								
i)	Built up area up to 250 m^2 **(CL-4)** *See* Notes 1, 2, 3 and 7	R	R	NR	R	R	R	NR	NR
ii)	Built up area from 251 m^2 to 1 000 m^2 **(CL-5)** *See* Notes 1, 2, 3, 4 and 7	R	R	NR	R	R	R	R	NR

Table 7G (*Concluded*)

Sl No.	**Type of Building Occupancy**	**Type of Installation**							
		Fire Extinguisher	First Aid Hose Reel	Down Comer	Wet Riser	Yard Hydrant	Automatic Wet Sprinkler System	Automatic Detection and Alarm System	Public Address and Voice Evacuation System
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
iii)	Built up area above 1 001 m^2 **(CL-6)** *See* Notes 2, 3, 4 and 7	R	R	NR	R	R	R	R	R

R – Required NR – Not Required

REMARK 1: Any state or area where the municipal supply caters to municipal/public yard hydrant system with hydrant outlets provided throughout the premises with adequate water supply meeting the wet riser requirement demand flow and pressure 24×7 uninterrupted, such states/areas/ jurisdiction can replace the wet riser system and its associated pumping with water storage with a dry riser system. Dry riser system is also recommended for areas where ambient temperature below is 4 °C and has facility of connecting the yard hydrant to the dry riser in any event of fire in the building. This system is to be maintained with quarterly checks to ensure the system integrity to handle the required flow and pressure. This is applicable for buildings height only up to 24 m where HL Protection is required as per above Table**.**

REMARK 2: Sharing of water storage tank may be permitted between the adjacent neighbouring properties including industry clusters, without any loss of hydraulic effects (which is essential to fight the fire during an emergency).

NOTES

1 If the building has any type of combustible storage, combustible packing, fuel storage, boilers, furnaces such areas should be protected and should comply to protection level **CL-6**.

2 Alternate suppression agent should be considered as per relevant Indian Standards if water is not a suitable agent for materials protected.

3 Oxidizing materials, ignitable liquids, water resistive chemicals, explosives, aluminium dust, or any other explosive environment should be treated separately.

4 Protection should comply to supplementary protection for specific hazard/critical rooms as per Table 9/ Table 10/ Table 11 as applicable.

5 Pump pressure and quantity should be supported by hydraulic calculations.

6 If the cluster of buildings exceeds 5, another set of pumps and water storage of similar capacity should be provided. A maximum of two such sets is recommended, provided it satisfies the hydraulic requirements and functioning at the remotest point.

7 Table 7K and Table 7M suggesting the basis for water quantity required for fire-fighting, respectively for combined (sprinkler and hose) protection and hose protection be considered.

Table 7H Requirements for Firefighting Installations – For Storage Buildings

[*Clauses* 4.9 (a), 4.9 (c), 4.9(e), 5.1.1 (a), 5.1.1(d), 5.1.2.1, 5.1.3 (a), D-6.1, G-2(f) *and* Table 31]

Sl No.	**Type of Building Occupancy**	**Type of Installation**							
		Fire Extinguisher	First Aid Hose Reel	Down Comer	Wet Riser	Yard Hydrant	Automatic Wet Sprinkler System	Automatic Detection and Alarm System	Public Address and Voice Evacuation System
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Storage Buildings (H) (*See* Note 1, 2 and 3)								
i)	Built-up area up to 500 m^2 **(HL-4)**	R	R	NR	R	NR	NR	R	NR
ii)	501 m^2 to 1 000 m^2 **(HL-5)**	R	R	NR	R	R	NR	R	NR

Table 7H (*Concluded*)

Sl No.	Type of Building Occupancy	Type of Installation							
		Fire Extinguisher	First Aid Hose Reel	Down Comer	Wet Riser	Yard Hydrant	Automatic Wet Sprinkler System	Automatic Detection and Alarm System	Public Address and Voice Evacuation System
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
iii)	1 001 m^2 to 2 000 m^2 or building ridge height up to 7.6 m **(CL-6)**	R	R	R	NR	R	R	R	NR
iv)	Above 2 001 m^2 or Building ridge height above 7.6 m and up to 9.0 m **(CL-7)**	R	R	NR	R	R	R	R	R
v)	Building of any height with rack storage	R	R	NR	R	R	R	R	R

R – Required NR – Not Required

REMARK 1: Any state or area where the municipal supply caters to municipal/public yard hydrant system with hydrant outlets provided throughout the premises with adequate water supply meeting the wet riser requirement demand flow and pressure 24×7 uninterrupted, such states/areas/ jurisdiction can replace the wet riser system and its associated pumping with water storage with a dry riser system. Dry riser system is also recommended for areas where ambient temperature below is 4 °C and has facility of connecting the yard hydrant to the dry riser in any event of fire in the building. This system is to be maintained with quarterly checks to ensure the system integrity to handle the required flow and pressure. This is applicable for buildings height only up to 24 m where HL Protection is required as per above table.

REMARK 2: Sharing of water storage tank may be permitted between the adjacent neighbouring properties including industry clusters, without any loss of hydraulic effects (which is essential to fight the fire during an emergency).

NOTES

1 Pump pressure mentioned in above table is considering minimum requirement, it should be supported hydraulic calculations. The above Table applies to the below Storage categories only, stored on ground, not exceeding 3.7 m, (12 feet) excluding tyre storage. In addition, they should also comply with supplementary protection for all hazard/critical rooms as per Table 9/Table 10/ Table 11:

a) Packaging materials stored on ground with or without pallets

b) Raw materials storage, in solid pile, shelves, pallets

c) Finished goods storage, solid pile, shelves, pallets

d) Miscellaneous storage in and around manufacturing/assembly/packaging areas

e) Retail storage in shelves other than catwalk storage

2 For rack storages, with plastic/combustible packaging (exposed/cartoned unexpanded or exposed/ cartoned expanded), water reactive solids/liquid storages, lithium battery storages, ignitable chemical storages, or retail cat walk, any other oxidizing agent storages, relevant Indian Standards should be followed, and pumping capacities and water storage should be justified by way of hydraulic calculations.

3 If the cluster of buildings exceeds 5, another set of pumps and water storage of similar capacity should be provided. A maximum of two such sets is recommended, provided it satisfies the hydraulic requirements and functioning at the remotest point

4 Table 7K and Table 7M suggesting the basis for water quantity required for fire-fighting, respectively for combined (sprinkler and hose) protection and hose protection be considered.

Table 7J Requirements for Firefighting Installations – For Hazardous Buildings

[*Clauses* 4.9 (a), 4.9 (c), 4.9(e), 5.1.1 (a), 5.1.1(d), 5.1.2.1, 5.1.3 (a), D-6.1, G-2(f) *and* Table 31]

Sl No.	**Type of Building Occupancy**	**Type of Installation**							
		Fire Extinguisher	First Aid Hose Reel	Down Comer	Wet Riser	Yard Hydrant	Automatic Wet Sprinkler System	Automatic Detection and Alarm System	Public Address and Voice Evacuation System
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Hazardous Buildings (J) (*See* Notes 1 and 2)								
1)	Up to 15 m in height								
i)	Single storey building **(CL-7)**	R	R	NR	R	R	R	R	NR

Table 7J (*Concluded*)

Sl No.	**Type of Building Occupancy**	**Type of Installation**							
		Fire Extinguisher	First Aid Hose Reel	Down Comer	Wet Riser	Yard Hydrant	Automatic Wet Sprinkler System	Automatic Detection and Alarm System	Public Address and Voice Evacuation System
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
ii)	More than one floor building but not exceeding 15 m **(CL-8)**	R	R	NR	R	R	R	R	R

R – Required NR – Not Required

REMARK 1: Any state or area where the municipal supply caters to municipal/public yard hydrant system with hydrant outlets provided throughout the premises with adequate water supply meeting the wet riser requirement demand flow and pressure 24 × 7 uninterrupted, such states/areas/ jurisdiction can replace the wet riser system and its associated pumping with water storage with a dry riser system. Dry riser system is also recommended for areas where ambient temperature below is 4 °C and has facility of connecting the yard hydrant to the dry riser in any event of fire in the building. This system is to be maintained with quarterly checks to ensure the system integrity to handle the required flow and pressure. This is applicable for buildings height only up to 24 m where HL Protection is required as per above Table.

REMARK 2: Sharing of water storage tank may be permitted between the adjacent neighbouring properties including industry clusters, without any loss of hydraulic effects (which is essential to fight the fire during an emergency).

NOTES

1 These buildings should deploy specific tailor-made systems and solutions in terms of water hydrant/sprinklers, dry chemical, dry powder, water mist, gas/ wet chemical suppression, foam or/and any other as per relevant Indian Standards and international standards (wherever Indian Standards are not available) in consultation with local fire services or Authority having Jurisdiction (AHJ).

2 Pump pressure and quantity should be supported by hydraulic calculations.

3 Table 7K and Table 7M suggesting the basis for water quantity required for fire-fighting, respectively for combined (sprinkler and hose) protection and hose protection be considered.

Table 7K Base Calculations for Combined Protection System (Sprinkler System and Hose Stream)

[*Clause* 5.1.1 (a)]

Sl No.	**Combined System**	**Hazard Classification**	**Sprinkler Demand**		**Hose Stream Flow @ 3.5 bar**	**Number of Hose Streams**	**Pump Capacity and Quantity**	**Duration** min
(1)	(2)	(3)	(4)		(5)	(6)	(7)	(8)
i)	Level of Protection – **CL-1**	Extra Low Hazard -1	2.25	84	50	2	379 lpm × 1	30 – 60
ii)	Level of Protection – **CL-2**	Extra Low Hazard -2	4.1	140	170	2	946 lpm × 1	30 – 60
iii)	Level of Protection – **CL-3**	Low Hazard	6.1	230	285	3	1 892 lpm × 1	30 – 60
iv)	Level of Protection – **CL-4**	Moderate Hazard -1	8.1	230	285	3	2 500 lpm × 1	60 – 120
v)	Level of Protection – **CL-5**	Moderate Hazard -2	12.2	230	475	3	3 785 lpm × 1	60 – 120
vi)	Level of Protection – **CL-6**	Extra Hazard -1	16.3	230	475	3	4 731 lpm × 1	60 – 120
vii)	Level of Protection – **CL-7**	Extra Hazard -2	18.3	280	670	4	7 570 lpm × 1	60 – 120
viii)	Level of Protection – **CL-8**	High Hazard	24.5	280	1050	4	4731 lpm x 2	60 – 120

Pump capacity = Total flow with 20 percent overflow and operating at 140 percent capacity. For example, for **CL-5**, capacity will be (12.2 × 230) + (475 × 3) = 4 231 litre; with overflow margin works to 5 077.2 litre; and pump selection will be 5 077.2/140*100 = 3 627 lpm (and the nearest Indian Standard pump is 3 785 lpm).

NOTES

1 'Pump' implies, providing an electric pump and 'Standby pump of equivalent capacity'. For loss in pressure, jockey pump is also to be provided.

2 The duration of firefighting may be decided from 30 min to 120 min based on the hazard, fire preparedness, local conditions, to name a few.

3 The required quantity of water may be calculated as per the respective Indian Standards (where available); or based on the Table 7K and Table 7M.

Table 7M Base Calculations for Hose Stream Protection System

[*Clause* 5.1.1 (a) *and* D-6.1]

Sl No.	Hose Stream Only	Hazard Classification	Hose Stream Flow	Number of Hose Streams	Pump Capacity and Quantity	Duration min
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	Level of Protection – **HL-1**	Extra Light -1	50	4	379 lpm × 1	30 – 60
ii)	Level of Protection – **HL-2**	Extra Light -2	170	4	946 lpm × 1	30 – 60
iii)	Level of Protection – **HL-3**	Low Hazard	270	4	1 514 lpm × 1	30 – 60
iv)	Level of Protection – **HL-4**	Moderate -1	475	4	2 839 lpm × 1	60 – 120
v)	Level of Protection – **HL-5**	Moderate -2	670	5	4 731 lpm × 1	60 – 120
vi)	Level of Protection – **HL-6**	Extra Hazard	670	6	5 677 lpm × 1	60 – 120

Pump capacity = Total flow with 40 percent overflow and operating at 140 percent capacity. For example, for **HL-3**, capacity will be 270 × 4 = 1 080 litre; together with overflow margin works to 1 512 litre; and pump selection will be 1 512/140 × 100 = 1 514 lpm (nearest Indian Standard pump).

NOTES

1 'Pump' implies, providing an Electric pump and 'Standby pump of equivalent capacity'. For loss in pressure, jockey pump is also to be provided.

2 The duration of firefighting may be decided from 30 min to 120 min based on the hazard, fire preparedness, local conditions, to name a few.

3 The required quantity of water may be calculated as per the respective Indian Standards (where available); or based on the Table 7K and Table 7M.

4.10 Fire Officer

The essential capabilities of the Fire Officer should be to maintain fire equipment, develop and implement fire safety operational plans, train occupants on fire tools and evacuation, and coordinate with the city fire brigade to ensure constant safety compliance. It is recommended that a qualified Fire Officer should be stationed on-site for large building complexes and specific high-rise or high-risk buildings.

4.11 Fire Drills and Fire Orders

Fire notices/orders should be prepared to fulfil the requirements of firefighting and evacuation from the buildings in the event of fire and other emergency. The occupants should be made thoroughly conversant with their action in the event of emergency, by displaying fire notices at vantage points and also through regular training. Such notices should be displayed prominently in bold lettering. The State/Local Authorities may also decide on the nature and frequency of fire drills to be carried out in buildings.

5 FIRE PROTECTION

5.1 Fire Extinguishers/Fixed Firefighting Installations

5.1.1 All buildings depending upon the occupancy use and height should be protected by fire extinguishers, hose reels, wet riser, down-comer, yard hydrants, automatic sprinkler installation, deluge system, high/medium velocity water spray, foam, water mist systems, gaseous or dry powder system, manual/automatic fire alarm system, etc, in accordance with the provisions of various clauses given below, as applicable:

a) These fire extinguishing equipment and their installation should be in accordance with accepted standards [F(17)]. The extinguishers should be mounted at a convenient height to enable its quick access and efficient use by all in the event of a fire incidence. The requirements of fire extinguishers/yard hydrant systems/wet riser/down-comer installation, etc, should be as specified in Table 7A to Table 7J. *See also* Table 7K and Table 7M for guidance, on base calculation for capacity of water storage tanks and fire pumps. The requirements regarding size of mains/risers should be as given in Table 8. The typical arrangements of down-comer and wet riser installations, as also the pumping system are shown in Fig. 15, Fig. 16 and Fig. 17. The wet riser should be designed for zonal distribution ensuring that unduly high pressures are not developed in risers and hose-pipes.

b) First-aid firefighting appliances should be provided and installed in accordance with good practice [F(18)]. The firefighting equipment and accessories to be installed in buildings for use in firefighting should also be in accordance with the accepted standard [F(17)] and should be maintained periodically so as to ensure their perfect serviceability at all times.

c) Valves in fixed firefighting installations should have supervisory switch with its signalling to fire alarm panel or to have chain(s), pad lock(s), label, and tamper-proof security tag(s) with serial number to prevent tampering/unauthorized operation. These valves should be kept in their intended 'open' position.

d) In addition to wet riser or down-comer, first-aid hose reels should be installed in buildings (where required under Table 7A to Table 7J) on all the floors, in accordance with accepted standard [F(19)]. The first-aid hose reel should be connected directly to the riser/down-comer main and diameter of the hose reel should not be less than 19 mm.

e) Wet risers should be interconnected at terrace level to form a ring and cut-off should be provided for each connection to enable repair/ maintenance without affecting rest of the system.

f) Pressure at the hydraulically remote hydrant and at the highest hydrant should not be less than 3.5 bar. The pressure at the hydrants should however not exceed 7.0 bar, considering the safety of operators. It may be planned to provide orifice plates for landing valves to control pressure to desired limit especially at lower levels. This could also be achieved through other suitable means of pressure reducing devices such as pressure-controlled hydrant valves.

g) Hydrants for firefighting and hose reels should be located in the lobby in firefighting shaft. Those hydrants planned to be provided near fire exit staircase on the floor should be within 5 m from fire exit door in exit access. Such hydrant cabinet may finish with doors to meet interior finishes with requirement of glass panel to provide visibility to the installations inside and inscribed with the word: 'FIRE HOSE CABINET' of letter size 75 mm in height and 12 mm in width. Such door of the fire hose cabinet need not be fire resistant rated. The location of such cabinets should be shown on floor plan and duly displayed in the landing of the respective fire exit staircase.

5.1.2 *Static Water Storage Tanks and Pump House*

5.1.2.1 *Static water storage tanks*

A satisfactory supply of water for the purpose of firefighting should always be available in the form of underground/terrace level static storage tank with capacity specified for each building with arrangements or replenishment.

Water for the hydrant services should be stored in an easily accessible surface/underground lined reservoir or above ground tanks made of steel or concrete or masonry. The effective capacity of the reservoir above the top of the pump casing (flooded suction) for various types of occupancies should be as indicated in Table 7A to Table 7J.

Water for firefighting should be stored in two or more interconnected compartments of equal size to facilitate cleaning and maintenance of the tanks without interrupting the water availability for firefighting.

To prevent stagnation of water in the static water storage tank, the suction tank of the domestic water supply should be fed only through an overflow arrangement from the fire water storage tanks to maintain the level therein at the minimum specified capacity.

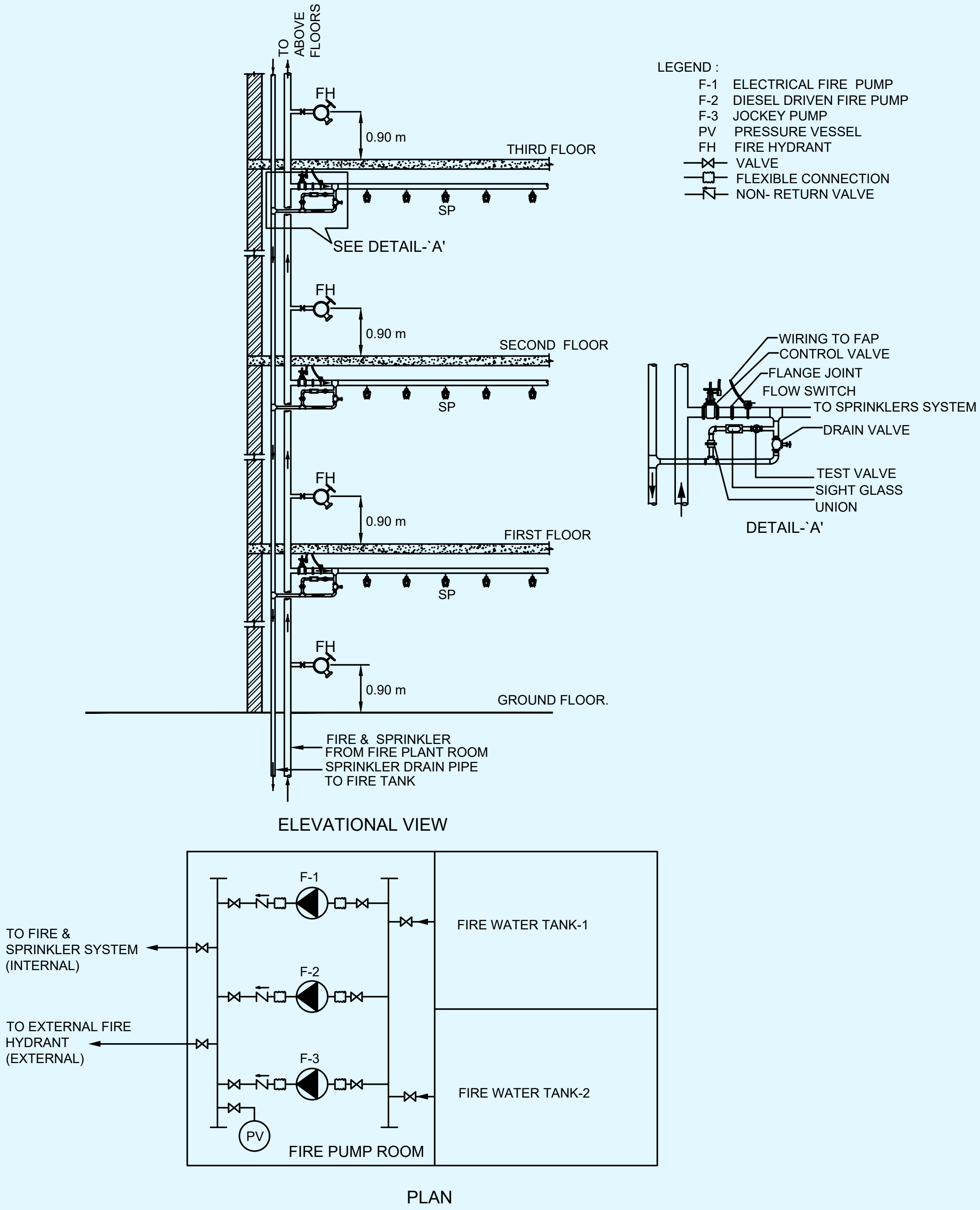
Alternatively, domestic and fire water can be stored in two interconnected compartments as mentioned above. The suction inlet(s) for the domestic water pumps should be so located at an elevation that minimum water requirements for firefighting as stated in Table 7A to Table 7J will be always available for fire pumps.

The static storage water supply required for the above-mentioned purpose should entirely be accessible to the fire engines of the local fire service. Sufficient number of manholes should be provided for inspection, repairs, insertion of suction hose, etc. As an alternative to the arrangement of manholes to allow access from the top, suitable arrangement to enable efficient access to the tank by the firemen from the adjoining fire pump room having direct access from the ground level, should be made. The underground fire water storage tank(s) should not be more than 7 m in depth from the level having fire brigade draw-out connection, while the draw-out connection should not be more than 5 m away from the tank wall.

The covering slab and its supporting wall/supporting system should be able to withstand a total vehicular load of 45 tonnes (or higher as applicable) equally divided as a four-point load when the slab forms a part of fire apparatus pathway/driveway.

The static water storage tank should be provided with a fire brigade collecting head with 4 number 63 mm diameter (2 number 63 mm diameter for pump with capacity 1 400 litre/min) instantaneous male inlets arranged in a valve box at a suitable point at street level. The same should be connected to the static tank by a suitable fixed galvanized iron pipe not less than 150 mm in diameter to discharge water into the tank when required at the rate of 2 250 litre/min if tank is in the basement or not approachable for the fire engines.

Each of the static water storage tanks should also be provided with a fire brigade draw out collecting head with 63 mm diameter instantaneous male draw out arranged in a valve box at a suitable point at street level. This draw out should be connected to galvanized iron pipe of 100 mm diameter with foot valve arrangement in the tank.



TO ABOVE FLOORS
LEGEND :
F-1 ELECTRICAL FIRE PUMP
F-2 DIESEL DRIVEN FIRE PUMP
F-3 JOCKEY PUMP
PV PRESSURE VESSEL
FH FIRE HYDRANT
VALVE
FLEXIBLE CONNECTION
NON- RETURN VALVE
FH
0.90 m
THIRD FLOOR
SP
SEE DETAIL-`A'
FH
0.90 m
SECOND FLOOR
SP
FH
0.90 m
FIRST FLOOR
SP
FH
0.90 m
GROUND FLOOR.
FIRE & SPRINKLER FROM FIRE PLANT ROOM
SPRINKLER DRAIN PIPE TO FIRE TANK
ELEVATIONAL VIEW
WIRING TO FAP
CONTROL VALVE
FLANGE JOINT
FLOW SWITCH
TO SPRINKLERS SYSTEM
DRAIN VALVE
TEST VALVE
SIGHT GLASS
UNION
DETAIL-`A'
F-1
F-2
F-3
TO FIRE & SPRINKLER SYSTEM (INTERNAL)
TO EXTERNAL FIRE HYDRANT (EXTERNAL)
FIRE WATER TANK-1
FIRE WATER TANK-2
PV
FIRE PUMP ROOM
PLAN

Fig. 15 Typical System of Pumping with One Electric, One Diesel Fire Pump

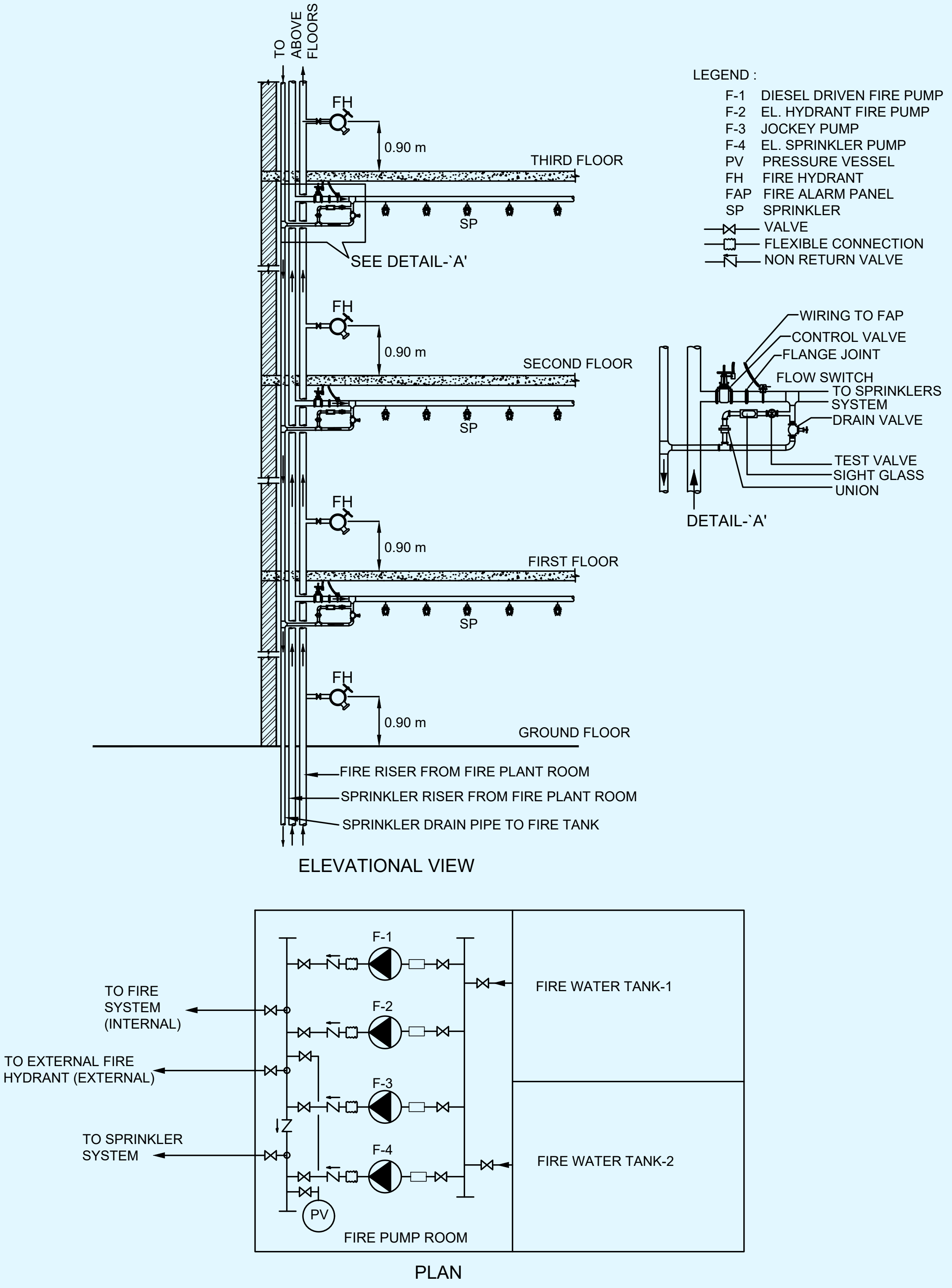

TO ABOVE FLOORS
LEGEND :
F-1 DIESEL DRIVEN FIRE PUMP
F-2 EL. HYDRANT FIRE PUMP
F-3 JOCKEY PUMP
F-4 EL. SPRINKLER PUMP
PV PRESSURE VESSEL
FH FIRE HYDRANT
FAP FIRE ALARM PANEL
SP SPRINKLER
VALVE
FLEXIBLE CONNECTION
NON RETURN VALVE
FH
0.90 m
THIRD FLOOR
SP
SEE DETAIL-`A'
FH
0.90 m
SECOND FLOOR
SP
FH
0.90 m
FIRST FLOOR
SP
FH
0.90 m
GROUND FLOOR
FIRE RISER FROM FIRE PLANT ROOM
SPRINKLER RISER FROM FIRE PLANT ROOM
SPRINKLER DRAIN PIPE TO FIRE TANK
ELEVATIONAL VIEW
WIRING TO FAP
CONTROL VALVE
FLANGE JOINT
FLOW SWITCH
TO SPRINKLERS SYSTEM
DRAIN VALVE
TEST VALVE
SIGHT GLASS
UNION
DETAIL-`A'
F-1
F-2
F-3
F-4
TO FIRE SYSTEM (INTERNAL)
TO EXTERNAL FIRE HYDRANT (EXTERNAL)
TO SPRINKLER SYSTEM
PV
FIRE PUMP ROOM
FIRE WATER TANK-1
FIRE WATER TANK-2
PLAN

FIG. 16 TYPICAL SYSTEM OF PUMPING WITH TWO ELECTRIC, ONE DIESEL FIRE PUMP

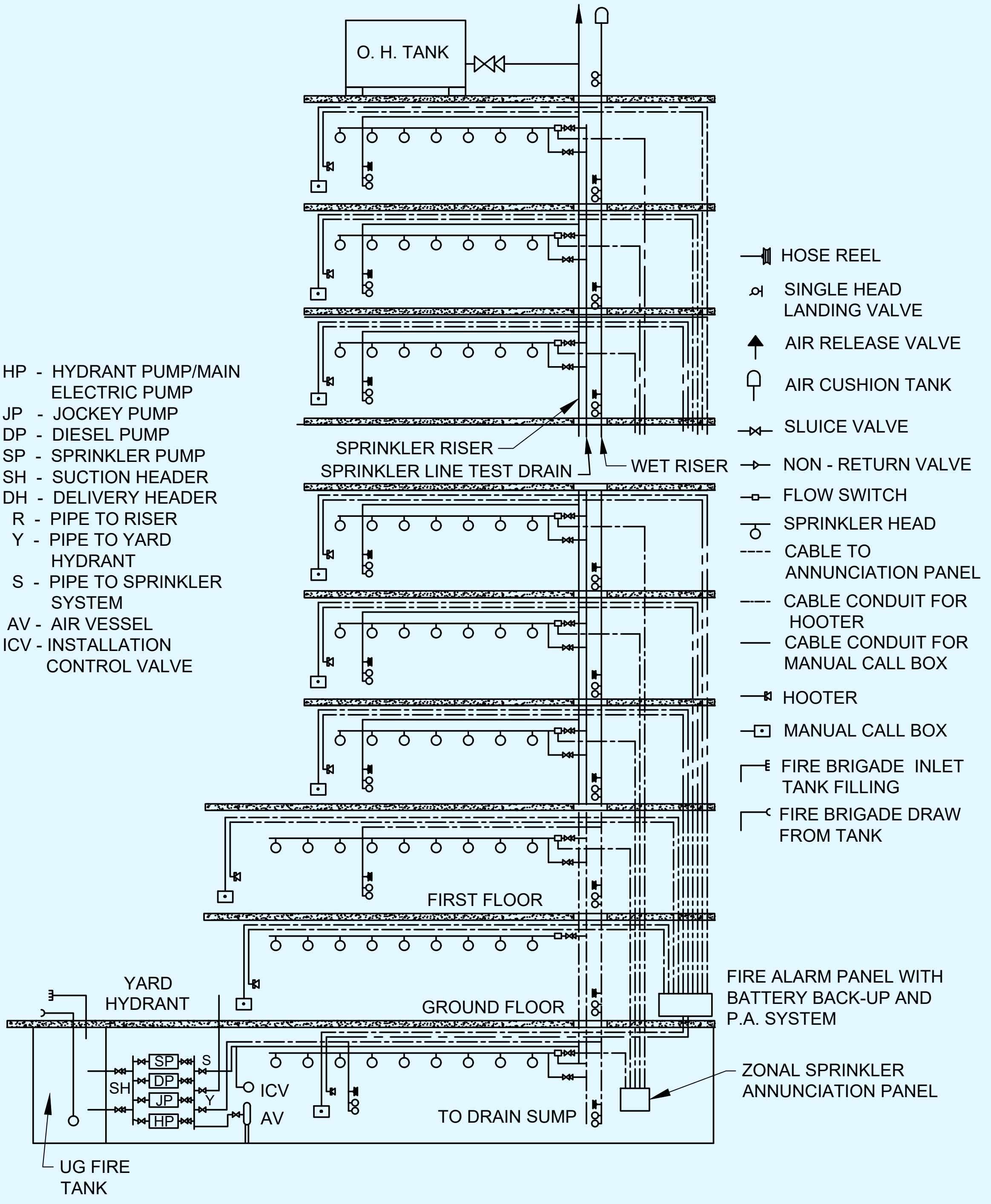

O. H. TANK
HP - HYDRANT PUMP/MAIN ELECTRIC PUMP
JP - JOCKEY PUMP
DP - DIESEL PUMP
SP - SPRINKLER PUMP
SH - SUCTION HEADER
DH - DELIVERY HEADER
R - PIPE TO RISER
Y - PIPE TO YARD HYDRANT
S - PIPE TO SPRINKLER SYSTEM
AV - AIR VESSEL
ICV - INSTALLATION CONTROL VALVE
SPRINKLER RISER
SPRINKLER LINE TEST DRAIN
WET RISER
HOSE REEL
SINGLE HEAD LANDING VALVE
AIR RELEASE VALVE
AIR CUSHION TANK
SLUICE VALVE
NON - RETURN VALVE
FLOW SWITCH
SPRINKLER HEAD
CABLE TO ANNUNCIATION PANEL
CABLE CONDUIT FOR HOOTER
CABLE CONDUIT FOR MANUAL CALL BOX
HOOTER
MANUAL CALL BOX
FIRE BRIGADE INLET TANK FILLING
FIRE BRIGADE DRAW FROM TANK
FIRST FLOOR
YARD HYDRANT
GROUND FLOOR
FIRE ALARM PANEL WITH BATTERY BACK-UP AND P.A. SYSTEM
SP
DP
JP
HP
S
SH
Y
ICV
AV
TO DRAIN SUMP
ZONAL SPRINKLER ANNUNCIATION PANEL
UG FIRE TANK

FIG. 17 TYPICAL ARRANGEMENT OF WET RISER AND TOTAL SPRINKLER SYSTEM OF BUILDING

Table 8 Size of Mains

[*Clause* 5.1.1(a)]

Sl No.	**Minimum Size of the Mains** mm	**Type of Building**		**Building Height** m
(1)	(2)	(3)		(4)
i)	100 mm with single outlet 63 mm landing valve	a)	Residential buildings (A)	
			1) Dormitories	–
			2) Apartments	Up to 15 m
			3) Hotels	Up to 15 m
		b)	Educational buildings (B)	Up to 15 m
		c)	Institutional buildings (C)	Up to 15 m
		d)	Assembly buildings (D)	Up to 15 m
		e)	Business buildings (E)	Up to 15 m
		f)	Mercantile buildings (F)	Up to 9 m
		g)	Industrial buildings (G)	Up to 9 m
ii)	150 mm with single outlet 63 mm landing valve	a)	Hotels	Above 15 m
		b)	Starred hotels	–
		c)	Institutional buildings (C)	Above 15 m
		d)	Business buildings (E)	Above 15 m
		e)	Industrial buildings (G)	Up to 15 m
		f)	Storage buildings (H)	Up to 15 m
		g)	Hazardous buildings (J)	Up to 15 m

5.1.2.2 *Firefighting pump house*

The requirements should be as given below:

a) Pump house should be situated so as to be directly accessible from the surrounding ground level. In the case of industrial occupancies, it is preferable to install the pump house at ground level.

b) When located below ground, the pump house is much preferred in the first basement and should not be installed lower than the second basement (in which case the pumping efficiency should be ascertained). When installed in the basement, staircase with direct accessibility (or through enclosed passageway with 120 min fire rating) from the ground, should be provided. Access to the pump room should not require to negotiate through other occupancies within the basement.

c) Pump house need to be separated by fire walls all around and doors to be protected by fire doors (120 min rating).

d) Pump house should be well ventilated and due care should be taken to avoid water stagnation.

e) No other utility equipment should be installed inside fire pump room.

f) Insertions like flexible couplings, bellows, etc, in the suction and delivery piping should be suitably planned and installed.

g) Installation of negative suction arrangement and submersible pumps should not be allowed.

h) Pump house should be sufficiently large to accommodate all pumps, and their accessories like pressure reducing valves (PRVs), installation control valves (ICVs), diesel tank and electrical panel. ICV for the towers (superstructure) is allowed to be installed in the first basement, in a duly protected room of 120 min fire resistance rating.

j) Battery of diesel engine operated fire pump should have separate charger from emergency power supply circuit.

k) Exhaust pipe of diesel engine should be insulated as per best engineering practice and taken to a safe location at ground level, considering the back pressure.

m) Fire pump is to be provided with soft starter or variable frequency drive starter.

5.1.3 *Automatic Sprinkler Installation*

The requirements should be as given below:

a) Automatic sprinklers should be installed wherever required in terms of Table 7A to Table 7J throughout the building, for uses as specified in, and in accordance with good practice [F(20)].

b) If selective sprinklering is adopted, there is a real danger of a fire starting in one of the unsprinklered area gathering momentum spreading to other areas and reaching the sprinklered areas as a fully developed fire. In such an event, the sprinklers can be rendered useless or ineffective.

c) Automatic sprinklers should be installed in false ceiling voids exceeding 800 mm in height.

d) Installation of sprinklers may be excluded in any area to be used for substation and DG set.

e) In areas having height 17 m or above such as in atria, sprinkler installations may be rendered ineffective and hence may be avoided.

f) Pressure in sprinkler system should not exceed 12 bar or else high pressure sprinkler to be installed for above 12 bar operations.

g) The maximum floor area on any one floor to be protected by sprinklers supplied by any one sprinkler system riser from an installation control valve should be based on system protection area limitations considering maximum floor area on any one floor to be 4 500 m^2 for all occupancies except industrial and hazardous occupancies, where Authorities should be consulted for advice based on type and nature of risk.

h) Sprinkler installation control valves, should be installed inside the fire pump room.

j) For industrial buildings, such installation control valves may be installed outside the building and Authorities should be consulted in situations where it is not possible to locate them inside the buildings. It is advisable to provide electrically operated siren for each valve outside the buildings in addition to water gongs in such case.

k) The sprinkler flow switches provided should be monitored by fire alarm panel.

m) It is essential to make provisions for avoiding water from sprinkler/hydrant operation entering lifts and electrical rooms.

n) Ramps at all levels should be protected with sprinklers.

p) The water based sprinkler systems are not suited for specific buildings for example, areas manufacturing electronic equipment, in which case alternate type of protection should only be provided.

q) Colour of the sprinkler piping may be matched to suit the interiors; however, in such case, the piping should be provided with red colour band of about 100 mm wide, every 3 m along the length of the pipe. In no case, the sprinkler heads should be painted.

r) Based on interior design or interior requirements where it is necessary to provide pendent sprinkler with no false ceiling, to achieve the sprinkler response/activation, it is required to provide about 250 mm diameter circular plate around the sprinkler.

5.1.4 *Automatic High Velocity and Medium Velocity Water Spray Systems*

Automatic high velocity water spray or emulsifying system should be provided for protection of outdoor and/or indoor oil-cooled transformers as applicable in accordance with good practice [F(21)] where applicable (*see* Annex D). Also, medium velocity water spray system should be provided for tankage (where applicable), conveyors, cable galleries and other occupancies listed in good practice [F(21)].

5.1.5 *Fixed Foam Installation*

Fixed foam generating system should be provided for protection of oil storage area for boilers with its ancillary storage of furnace oils in basement. Fixed foam installations can be low, medium, or high expansion types, which can be provided based on the type of fire hazards identified in the facility. High expansion foams are used for cable tunnels and other confined areas. Design and installation of foam systems should be governed by good practice [F(22)].

5.1.6 *Gas Based Suppression System*

Gas based fire extinguishing installation should be provided in accordance with good practice on premises where water or foam cannot be used for fire extinguishing because of the special nature of the contents of the buildings/areas to be protected where either the building(s) have very limited manpower or unmanned. The protection design for fixed carbon dioxide fire extinguishing system should conform to good practice [F(23)] in all respects. For some special fire risk/essential applications, carbon dioxide may not be suitable and alternate provisions should be made as per relevant standards (*see* **5.1.9**).

NOTE — Hypoxic air technology should not be used in occupiable areas (considering the tenability aspects), and specific caution should be exercised in consultation with the Authority, regarding its applicability.

5.1.7 Firefighting equipment should be suitably located and clearly marked by luminous signs.

5.1.8 *Automatic Water Mist Systems*

These systems involve the use of fine water sprays for the efficient extinguishment of fires. These systems may be provided to protect areas in buildings for the uses as specified in good practice [F(24)].

5.1.9 *Extinguishing Systems with Clean Agents*

Alternative systems for halon gas protection systems should be provided where necessary as prescribed in this Part. These should be in accordance with the accepted standards [F(25)].

5.2 Fire Detection and Alarm System

See also **4.9**.

5.2.1 *Automatic Detection System*

5.2.1.1 *Pneumatic linear high-sensitivity heat detection*

Pneumatic linear high-sensitivity heat detection is a gas-pressure-based linear detector. The tube material (copper/steel/Teflon) is selected based on the environmental and operational needs, copper for fast response and standard indoor use, steel for rugged corrosive areas, and Teflon for chemically aggressive or electrically sensitive spaces.

5.2.1.2 *Flame/gas/spark detection*

A flame detector works by sensing the electromagnetic radiation and, through algorithms and filters, discriminates it from false sources (sunlight, hot machinery). The following are the characteristic radiation emitted by the flames/gas/spark:

a) Ultraviolet (UV) 180 nm to 260 nm, from most hydrocarbon and hydrogen flames;

b) Infrared (IR) 2 µm to 6 µm, from hot CO_2/H_2O in the flame; and

c) Some systems also use visible light (VIS).

5.2.1.3 *Video detection*

Video-based fire detection (VFD) is an advanced fire detection technology that uses CCTV cameras combined with image-processing software to automatically detect visible signs of fire, such as smoke, flames, or heat distortions, and alert emergency systems for early fire response. The system is capable of simultaneous fire detection and visual verification. The system can use infrared (IR) or thermal imaging cameras for low-light or dusty conditions.

5.2.1.4 *Gas detection*

To detect accumulation of combustible gases or vapours (for example, methane, propane, jet fuel vapours) or toxic gases (for example, carbon monoxide, hydrogen sulphide, ammonia) before they ignite or endanger personnel**.** Common sensor types used are: catalytic, infrared (IR), electrochemical, or semiconductor.

5.2.1.5 *Spark detection*

To detect ignition sources (sparks, hot particles, embers) transported by air or material flow before they enter dust collectors, filters, or silos and ignite an explosion.

This detection uses infrared photo-sensors tuned to glowing particle radiation (approx. 0.8 µm to 1.1 µm). The same is installed in dark ducts or pneumatic conveying lines. The system should detect sparks within milliseconds (≤ 10 ms). The system should be integrated with automatic extinguishing systems (for example, water spray or deluge system) in industrial processes.

5.2.1.6 *Fuel leak detection*

Fuel leak detection (FLD) is a safety and monitoring system designed to identify and alert operators to the accidental release of fuel or flammable liquids from storage tanks, pipelines, or equipment. The system helps prevent fires, explosions, environmental contamination, and operational hazards by detecting leaks early.

5.2.1.7 *High ceiling beam detector*

The beam detector works like an electronic eye and keeps watching a clear light path; when smoke blocks the beam, it raises the alarm. A high-ceiling beam detection system is a projected or reflected IR smoke detection technology designed for large, tall spaces where spot detectors are ineffective. The system works works by sensing reduction in light intensity caused by smoke particles in the beam path and provides early warning for fast-developing fires in high-volume spaces.

5.2.1.8 *Linear heat sensing cable*

A linear heat sensing cable (digital/analogue) is a wire-type, continuous heat detector that triggers an alarm when it gets hot at any point, making it ideal for protecting long or irregular spaces where many spot-type heat detectors would otherwise be needed.

5.2.1.9 *Probe type heat detector*

A probe type heat detector is essentially a temperature-sensing probe that extends into the area to detect fire or abnormal heat early, especially in confined, harsh, or high-risk industrial environments. The probe is usually metallic (steel, copper) for good thermal conduction. Its length allows it to reach inside equipment, ducts, or confined spaces where smoke detectors may not work effectively.

5.2.1.10 *Aspiration high-sensitivity smoke detection*

Aspiration high-sensitivity smoke detection is a pipe-based, actively sampled smoke detection system that can detect smoke at very low concentrations, giving earliest possible warning of fire, especially in high-value, high-ceiling, or challenging environments. It continuously samples air from the protected area through a network of pipes and detects smoke at very low concentrations, providing early warning of fire before visible smoke accumulates.

5.2.2 *Automatic Fire Suppression Systems*

5.2.2.1 *Water spray system*

A water spray system is a fixed fire protection system that delivers water through a network of piping and specially designed spray nozzles to cool surfaces, control, or extinguish a fire. It is similar to a sprinkler system but is designed to protect specific equipment or areas, rather than an entire room, by spraying water in a predetermined pattern and density.

5.2.2.2 *Wet/Dry pre-action*

A pre-action system is a special hybrid system used in areas where accidental water discharge would cause serious damage, such as data centres, archives, museums, cleanrooms. A wet sprinkler system is the simplest and most common type of sprinkler system. The pipes are always filled with water under pressure up to each sprinkler head**.** A dry sprinkler system is used in areas subject to freezing temperatures (for example, unheated warehouses, loading docks). The pipes are filled with pressurized air or nitrogen, and not water.

5.2.2.3 *Modular panel/rack suppression system*

A modular panel/rack suppression system with heat-sensitive tubing is a self-contained automatic fire protection system that uses a pressurized agent cylinder and flexible heat-sensitive tubing. The tube detects heat, ruptures at the fire spot, and releases the agent directly, providing fast, localized suppression for sensitive enclosures.

5.2.2.4 *Nitrogen injection*

The system is used for oil filled transformer system in which an overheating triggering the nitrogen gas displaces air/oxygen above the oil surface, preventing further combustion. The increased pressure helps to seal the transformer tank and suppress vapour formation, thereby preventing transformer fires and minimizing damage.

5.2.2.5 *Water mist system*

A water mist system is a specialized fire suppression system that uses very fine water droplets (mist) – typically less than 1 000 μ in diameter – to control, suppress, or extinguish fires. A water mist firefighting system suppresses fire by discharging a fine spray of water droplets that cools the fire, displaces oxygen, and reduces radiant heat, offering effective protection with minimal water use.

5.2.2.6 *Foam sprinkler system*

A foam sprinkler system automatically discharges a water-foam mixture through sprinkler heads to cool, smother, and suppress flammable liquid fires, providing effective fire protection for high-risk liquid storage and handling areas. It operates like a conventional sprinkler system; sprinkler heads open when heat rises above a preset temperature. It is primarily designed to suppress flammable liquid (Class B) fires, such as oil, fuel, or chemical storage, by cooling the fire and forming a foam blanket that smothers vapours.

5.2.2.7 *Wet chemical kitchen suppression system*

A wet chemical kitchen suppression system is a specialized fire suppression system designed to extinguish fires in commercial cooking areas, especially those involving cooking oils and grease (Class K fires). It uses a liquid wet chemical agent that reacts with hot grease to form a soapy foam layer (saponification), which cools and smothers the fire.

5.2.2.8 *Dry powder flooding system*

A dry powder flooding system is a fixed fire suppression system that floods a hazard area with dry chemical powder, quickly extinguishing flammable liquid, combustible metal, or electrical fires by interrupting the combustion reaction and isolating fuel from oxygen.

The dry chemical powder (for example, sodium bicarbonate, potassium bicarbonate, or special metal powders) is stored in pressurized vessels or storage tanks. Upon activation, the powder is discharged through a network of piping and nozzles into the protected space.

5.2.2.9 *Clean agent total flooding*

A clean agent total flooding system is a fixed fire suppression system that protects an enclosed space by discharging a gaseous extinguishing agent (clean agent) to rapidly suppress fire without leaving any residue. The term “total flooding” indicates that the agent fills the entire protected volume to extinguish the fire. The agent absorbs heat and/or interrupts the chemical reaction of the fire.

5.2.2.10 *Carbondioxide flooding*

A carbon dioxide flooding firefighting system is a fixed system that rapidly floods an enclosed area with carbon dioxide, extinguishing fire by removing oxygen and cooling while leaving no residue, but it requires evacuation of personnel due to asphyxiation risk. It is fast-acting and effective for flammable liquid and electrical fires.

5.2.2.11 *Aerosol-based fire suppression system*

An aerosol-based fire suppression system is a fixed or modular fire protection system that extinguishes fires by releasing a fine particulate aerosol a mixture of solid microscopic particles suspended in inert gas which interrupts the chemical reactions of combustion. When triggered, it rapidly vapourizes and condenses into ultra-fine particles (1 microns to 10 microns) suspended in gas. It is highly effective for enclosed spaces.

5.3 The fixed firefighting installations and systems should be maintained in accordance with good practice [F(26)]. *See also* the ‘Handbook on Asset and Facility Management’.

5.4 Fire Detection and Suppression Systems Based on the Specific Type and Intensity of Industrial Hazards

Table 9 serves as a guiding tool for designers, fire safety engineers, and facility managers in selecting appropriate fire detection and suppression systems based on the specific type and intensity for G to J occupancy hazards. Table 9 supports a risk-based approach, recognizing that fire protection requirements vary with operational processes, materials handled, and business continuity considerations. It moves away from a one-size-fits-all model and promotes hazard-specific fire safety planning to ensure enhanced protection, system reliability, and life safety in special industrial occupancies.

5.5 Supplementary Protection for Specific Areas/Hazards

Table 10 provides a guide for the structured classification of automatic detection systems, and Table 11 provides for automatic fire suppression systems, based on the specific type and intensity for G to J occupancy hazards. The tables serve as a reference for designers, fire safety engineers, and regulatory authorities to determine the appropriate supplementary protection measures based on the specific fire risks present in a building or facility.

The automatic detection systems covered in the table include high-sensitivity pneumatic linear (or tubing) heat detection, aspiration high-sensitivity smoke detection, gas/flame/visual detection, fuel leak detection, and linear heat detection (LHS). The automatic fire suppression systems include water mist, clean agent gas suppression, wet/dry pre-action sprinkler systems, water spray protection, carbon dioxide flooding, etc.

Each system is marked as either ‘S’ (Suitable) or ‘NS’ (Not Suitable) depending on its effectiveness for a given hazard scenario. The selection of a special protection system should be based on a comprehensive fire risk assessment, considering factors such as fuel type, occupancy, fire growth rate, and critical infrastructure protection. These tables provides essential guidance for ensuring compliance with fire safety regulations and enhancing fire protection strategies in buildings.

Table 9 Fire Detection and Suppression Systems

(Based on the Specific Type and Intensity of A to F Occupancies)

(*Clauses* 3.5.5.4 *and* 5.4)

		Types of Special Protection System											
Sl No.	**Type of Risk/ Hazard**	**Automatic Detection System**					**Automatic Fire Suppression Systems**						
		Pneumatic Linear (Copper/ Steel/ Teflon Tubing) High Sensitivity Heat Detection	Aspiration High Sensitivity Smoke Detection	Gas/ Flame/ Video Detection	Fuel Leak Detection	Linear Heat Sensing Cable (LHS)	Water Mist Low/High Pressure	Clean Agent Gas Suppression	Water Pre-Action Sprinkler	Modular Panel/ Rack Suppression with Heat Sensitive Tubing	Water Spray Protection	Wet Chemical Kitchen Suppre-ssion	Aerosol Based Fire Suppre-ssion
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
i)	UPS room without batteries	NS	S	S	NS	NS	S	S	S	NS	NS	NS	NS
ii)	UPS room with batteries (except Lithium ion)	NS	S	S	NS	NS	S	S	S	NS	NS	NS	NS
iii)	Battery room with Lithium ion	S	S	S	NS	NS	NS	NS	S	NS	S	NS	NS
iv)	Server room/data halls	NS	S	NS	NS	NS	S	S	S	NS	NS	NS	NS
v)	Kitchen with any type of fuel, (live cooking)	NS	NS	S	NS	S	S	NS	NS	NS	NS	NS	NS
vi)	Network/ Electrical rooms	NS	S	NS	NS	NS	S	S	S	NS	NS	NS	NS

Table 9 (*Continued*)

		Types of Special Protection System											
Sl No.	**Type of Risk/ Hazard**	**Automatic Detection System**					**Automatic Fire Suppression Systems**						
		Pneumatic Linear (Copper/ Steel/ Teflon Tubing) High Sensitivity Heat Detection	Aspiration High Sensitivity Smoke Detection	Gas/ Flame/ Video Detection	Fuel Leak Detection	Linear Heat Sensing Cable (LHS)	Water Mist Low/High Pressure	Clean Agent Gas Suppression	Water Pre-Action Sprinkler	Modular Panel/ Rack Suppression with Heat Sensitive Tubing	Water Spray Protection	Wet Chemical Kitchen Suppre-ssion	Aerosol Based Fire Suppre-ssion
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
vii)	Electrical/ MCC panels	NS	S	NS	NS	NS	NS	S	NS	S	NS	NS	S
viii)	Cable cellar and trenches and trays over 1.5 m wide	S	NS	NS	NS	S	S	NS	NS	NS	S	NS	S
ix)	Dry transformer indoor	S	NS	S	NS	NS	NS	NS	NS	NS	NS	NS	NS
x)	Oil transformer outdoor more than 2.0 MVA or 2 000 litre oil	S	NS	S	NS	NS	NS	NS	NS	NS	S	NS	NS
xi)	DG rooms	S	NS	S	S	S	S	NS	NS	NS	S	NS	S
xii)	Cold/freezer rooms	S	S	NS	NS	NS	NS	NS	S	NS	NS	NS	NS

Table 9 (*Concluded*)

		Types of Special Protection System											
Sl No.	**Type of Risk/ Hazard**	**Automatic Detection System**					**Automatic Fire Suppression Systems**						
		Pneumatic Linear (Copper/ Steel/ Teflon Tubing) High Sensitivity Heat Detection	Aspiration High Sensitivity Smoke Detection	Gas/ Flame/ Video Detection	Fuel Leak Detection	Linear Heat Sensing Cable (LHS)	Water Mist Low/High Pressure	Clean Agent Gas Suppression	Water Pre-Action Sprinkler	Modular Panel/ Rack Suppression with Heat Sensitive Tubing	Water Spray Protection	Wet Chemical Kitchen Suppre-ssion	Aerosol Based Fire Suppre-ssion
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
xiii)	MRI/ scanning rooms	NS	S	NS	NS	NS	S	NS	NS	NS	NS	NS	NS
xiv)	Operation theatres	NS	S	NS	NS	NS	S	NS	S	NS	NS	NS	NS
xv)	Tunnel protection	S	NS	S	NS	S	S	NS	NS	NS	S	NS	NS

NS = Not Suitable

S = Suitable

NOTES

1 Wet sprinklers are acceptable for all areas where pre-action sprinklers or closed water mist is suitable.

2 DG rooms should be protected with total flooding open nozzles where water mist is being deployed.

3 Spray system should be supplemented with suitable foam, if ignitable liquids or water miscible liquids are involved.

4 Water mist system should be selected based on 3rd party independent test carried out for the specific application, flow rate, density, etc. The products in terms of functionality and the performance should be based on actual test results and certifications, and should NOT be prescriptive.

5 Water mist solution selected, total flooding with sprinklers, total flooding with open nozzles, wet system, pre-action system should comply based on actual test results, and certifications.

Table 10 Special Protection Systems — Automatic Detection Systems for G to J Occupancies

(*Clause* 5.5)

Sl No. (1)	**Type of Risk/Hazard** (2)	**Pneumatic Linear (Copper/Steel/Teflon Tubing) High Sensitivity Heat Detection** (3)	**Flame/Gas/ Spark Detection** (4)	**High Ceiling Beam Detection System** (5)	**Linear Heat Sensing Cable** (6)	**Probe Type Heat Detector** (7)	**Aspiration High Sensitivity Smoke Detection** (8)
i)	Generator room	S	S	NS	S	S	NS
ii)	Water reactive chemical store	S	S	NS	S	S	NS
iii)	Chemical store	S	S	NS	S	S	NS
iv)	Paint booth	S	S	NS	S	S	NS
v)	Paint/varnish storage	S	S	NS	S	S	NS
vi)	Warehouse	NS	S	S	NS	NS	S
vii)	Above ground fuel oil storage	S	S	NS	S	NS	NS
viii)	Oil transformers	S	S	NS	NS	NS	NS
ix)	Diesel/HSD tanks	S	S	NS	S	NS	NS
x)	LPG bullets/Benzene, Xylene, Toulene tanks	NS	NS	NS	NS	NS	NS
xi)	Airport hanger	S	S	S	S	S	S
xii)	Hydrogenation rooms	NS	S	NS	S	S	S
xiii)	Sulphur storage	S	S	NS	S	S	NS
xiv)	Tanker loading/unloading bay	NS	S	NS	NS	NS	NS
xv)	Kitchen	S	S	NS	S	S	NS
xvi)	Conveyors	S	S	NS	S	NS	NS

Table 10 (*Concluded*)

Sl No. (1)	Type of Risk/Hazard (2)	Pneumatic Linear (Copper/Steel/Teflon Tubing) High Sensitivity Heat Detection (3)	Flame/Gas/ Spark Detection (4)	High Ceiling Beam Detection System (5)	Linear Heat Sensing Cable (6)	Probe Type Heat Detector (7)	Aspiration High Sensitivity Smoke Detection (8)
xvii)	QA/QC labs	S	S	NS	S	S	NS
xviii)	Open large atriums	NS	NS	NS	NS	NS	S
xix)	Floating roof tanks	S	S	NS	S	NS	NS
xx)	Oil fire boiler room, oil quenching tank	S	S	NS	S	S	NS
xxi)	Cooling tower	NS	NS	NS	S	NS	NS
xxii)	MCC room	S	NS	NS	S	S	S
xxiii)	Cable cellar/trenches	S	NS	NS	S	S	NS
xxiv)	Electrical panels	S	NS	NS	S	NS	NS

NOTE

NS = Not Suitable

S = Suitable

Table 11 Special Protection Systems — Automatic Fire Suppression Systems for G to J Occupancies

(*Clause* 5.5)

Sl No. (1)	Type Of Risk/Hazard (2)	Water Spray System (3)	Wet/Dry Pre-action (4)	Nitrogen Injection (5)	Water Mist (6)	Foam Sprinkler System (7)	Dry Powder Flooding System (8)	Clean Agent Total Flooding (9)	Carbon-Dioxide Flooding (10)
i)	Generator room	S	NS	NS	S	NS	NS	NS	NS
ii)	Water reactive chemical store	NS	NS	NS	NS	NS	S	NS	S
iii)	Chemical store	S	NS	NS	S	S	NS	NS	NS
iv)	Paint booth	S	NS	NS	S	NS	NS	NS	NS
v)	Paint/varnish storage	S	NS	NS	S	S	S	NS	NS
vi)	Warehouse	NS	NS	NS	NS	NS	NS	NS	NS
vii)	Above ground fuel oil storage	S	NS	NS	NS	S	NS	NS	NS
viii)	Oil transformers	S	NS	S	S	NS	NS	NS	NS
ix)	Diesel / HSD tanks	S	NS	NS	NS	S	NS	NS	NS
x)	LPG bullets/Benzene, Xylene, Toulene tanks	S	NS	NS	NS	NS	NS	NS	NS
xi)	Airport hanger	NS	NS	NS	NS	S	NS	NS	NS
xii)	Hydrogenation rooms	S	NS	NS	S	NS	NS	NS	NS
xiii)	Sulphur storage	NS	NS	NS	S	NS	NS	NS	NS
xiv)	Tanker loading/unloading bay	S	NS	NS	NS	NS	NS	NS	NS
xv)	Kitchen	NS	NS	NS	S	NS	NS	NS	NS
xvi)	Conveyors	S	NS	NS	S	NS	NS	NS	NS
xvii)	QA/QC labs	NS	S	NS	S	S	S	S	NS
xviii)	Open large atriums	NS	NS	NS	S	NS	NS	NS	NS
xix)	Floating roof tanks	S	NS	NS	NS	S	NS	NS	NS

Table 11 (*Concluded*)

Sl No. (1)	Type Of Risk/Hazard (2)	Water Spray System (3)	Wet/Dry Pre-action (4)	Nitrogen Injection (5)	Water Mist (6)	Foam Sprinkler System (7)	Dry Powder Flooding System (8)	Clean Agent Total Flooding (9)	Carbon-Dioxide Flooding (10)
xx)	Oil fire boiler room, oil quenching tank	S	NS	NS	S	S	NS	NS	NS
xxi)	Cooling tower	S	NS	NS	NS	NS	NS	NS	NS
xxii)	MCC room	NS	S	NS	S	NS	NS	S	S
xxiii)	Cable cellar/trenches	S	NS	NS	S	NS	NS	NS	S
xxiv)	Electrical panels	NS	NS	NS	NS	NS	NS	S	S

NS = Not Suitable

S = Suitable

NOTES

1 Spray system should be supplemented with suitable foam, if ignitable liquids or water miscible liquids are involved.

2 Chemical material safety data sheet (MSDS) as per manufacture should be referred to select the right suppression agent.

3 Water mist system should be selected based on third party independent test carried out for the specific application, flow rate, density, etc. The products in terms of functionality and the performance should be based on actual test results and certifications, and should not be prescriptive.

4 Water mist solution selected, total flooding with sprinklers, total flooding with open nozzles, wet system, pre-action system should comply based on actual test results, and certifications.

5 Oxygen-reduction systems, which is not listed but area proactive fire prevention solutions by maintaining the oxygen percentage below the threshold needed for ignition and sustained combustion but suitable for human occupancy. These systems should be carefully evaluated and used for normally unoccupied areas with proper monitoring of oxygen levels. Fully enclosed very sensitive and critical high valve equipment rooms, rooms in heritage buildings for storing archives or ancient manuscripts, areas where no other fire protection system are effective and feasible are a few areas where it can be implemented. The implementer should ensure all 3rd party product/system accreditations certifications for specific applications and approval from local statutory bodies and AHJs in place before use.

6 SPECIFIC OCCUPANCY WISE REQUIREMENTS

Apart from the general requirements on fire prevention given in **3**, the life safety requirements given in **4**, and the fire protection requirements given in **5**, the following specific requirements should also be complied with for each type of occupancy.

For specific requirements for high rise buildings, the provisions as given in Annex D should apply.

Atriums in building occupancies should comply with the provisions as given in Annex E.

For specific requirements for data centres, the provisions as given in Annex F should apply.

For fire protection requirements of commercial kitchen, cooking facilities with or without restaurants, the provisions of good practice [F(30)] should be referred.

6.1 Residential Buildings (Group A)

6.1.1 *Life Safety*

6.1.1.1 *Subdivision A*-I

a) All locking devices, which would impede or prohibit exit, such as chain type bolts, limited opening sliding type locks and burglar locks, which are not disengaged easily by quick- releasing catches, should be prohibited.

b) All bathroom door locks or fasteners should be designed to permit the opening of the locked or closed door from the outside in an emergency without the use of a special key.

c) No lodging or rooming house should have its sole means of egress pass through any non-residential occupancy in the same building.

d) Rooming and lodging houses having floor area of 500 m^2 on any one or more floors should have access to minimum two separate means of exits, at least one of which should be so arranged as to have direct exit discharge.

6.1.1.2 *Subdivision A*-II

a) Requirements of **6.1.1.1** should be applicable.

b) All sleeping rooms having occupancy of more than 10 persons should have two separate and distinct exit access in different directions.

6.1.1.3 *Subdivision A*-III

In case of high-rise apartments, of the minimum exits as specified in **4.4.2.4.3.1**, the naturally ventilated/cross-ventilated exit staircases may not require the provision of fire door. However, fire door should be provided for all other staircases and pressurized staircases.

6.1.1.4 *Subdivision A*-IV

a) Panic bars should be provided in the fire exits. Panic bars should be located at a height between 865 mm and 1 220 mm from the floor level.

b) All guest rooms and suites should be protected by extended throw or quick response type sprinklers only. Also, these areas should be provided with audio-based detectors, having a sound level of at least 75 dB.

c) Horizontal-sliding doors should not be used for door openings across corridors.

6.1.1.5 *Additional Precautions*

a) Flammable liquids for household purposes should be kept in tightly stoppered or sealed containers. For the limits of quantities of flammable liquids to be allowed in various occupancies, reference may be made to appropriate regulations.

b) No stove or combustion heater should be located directly under or immediately at the foot of stairs or otherwise so located as to block escape in case of malfunctioning of the stove or heater.

c) All kitchen exhaust fans, where provided, should be fixed to an outside wall or to a duct of non-combustible material, which leads directly to the outside. The ducts should not pass through areas having combustible materials. However, in case of centralized ducting, the duct should be provided with adequate protection to limit the spread of fire.

d) Stores, engineering workshops, areas of high hazard, etc used for storage of substantial amount of flammable liquids should be of 120 min fire resistance rated wall. Such areas should be provided with fire doors, to be kept closed and should be posted with a sign on each side of the door prominently in block letters stating — 'FIRE DOOR — KEEP CLOSED'.

6.2 Educational Buildings (Group B)

6.2.1 *Fire Prevention*

a) Buildings intended for educational occupancy should not be used for storage of any hazardous material.

b) Gymnasiums, indoor stadiums, and similar occupancies are permitted to have floors/running tracks of wood, cinder, synthetic or the like.

6.2.2 *Life Safety*

a) Every room with a capacity of over 45 persons in area should have at least two doorways. Exit doors should be operated by panic bars except that doors leading from classrooms directly to the outside may be equipped with the same type of lock as is used on classroom doors leading to corridor, with no provision whatsoever for locking against egress from the classroom.

b) A building, which will have only the first floor and is accessible to not more than 20 pupils at any time, may be used for school purposes with the following exceptions:

   1) Exterior walls or parts of walls which are less than 900 mm from adjacent property lines should have no openings therein.

   2) Classrooms may have only one exit not less than 900 mm wide.

c) Rooms or areas for use by the preschool, kindergarten, Class/Grade 1 students should be located on ground floor/level of exit discharge. Rooms or areas occupied by Class/Grade II students should be located not above one floor higher than ground floor/level of exit discharge.

d) Of the minimum exits as specified in **4.4.2.4.3.1**, the naturally ventilated exit staircases, may not require provision of fire door. However, fire door should be provided for all other staircases and pressurized staircases.

6.2.3 *Special Precautions*

a) Storage of volatile flammable liquids should be prohibited and the handling of such liquids should be restricted to science laboratories only; and

b) All exterior openings in a boiler room or rooms containing central heating equipment, if located below an opening in another storey or if less than 3 m from other doors or windows of the same building, should be protected by a fire assembly as in **3.5.4**. Such assemblies should be of fixed, automatic, or self-closing type.

6.3 Institutional Buildings (Group C)

6.3.1 *Fire Prevention*

No combustible material of any kind should be stored or used in any building or section thereof used for institutional occupancy, except as necessary to normal occupancy and use of the building.

6.3.2 *Life Safety*

a) The common path of travel should be up to 30 m. The maximum dead end of corridor distance should not exceed 6 m;

b) Principle of progressive horizontal evacuation is of paramount consideration for hospital patients particularly those lacking self-preservation. This calls for moving occupants from a fire affected area to an adjoining area at the same level through a fire resistant wall, to protect them from the immediate dangers of fire and smoke (*see* Fig. 18);

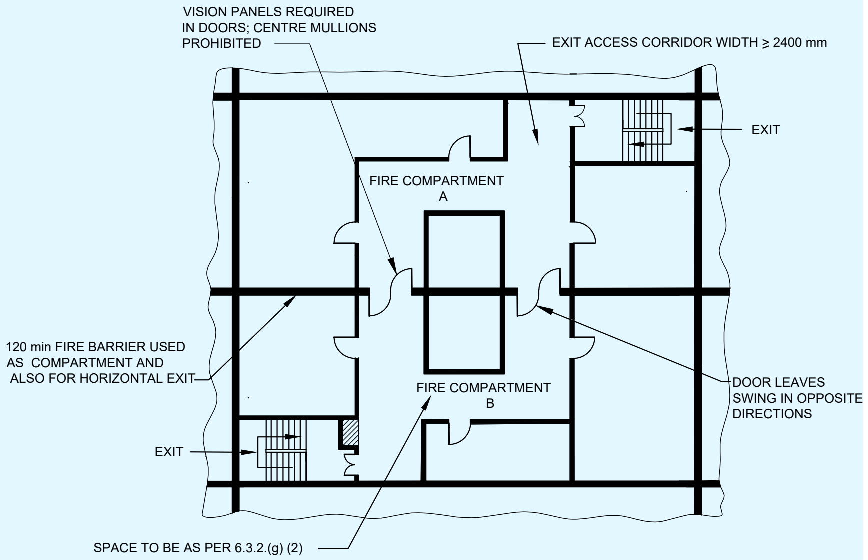

VISION PANELS REQUIRED IN DOORS; CENTRE MULLIONS PROHIBITED
EXIT ACCESS CORRIDOR WIDTH ≥ 2400 mm
EXIT
FIRE COMPARTMENT A
120 min FIRE BARRIER USED AS COMPARTMENT AND ALSO FOR HORIZONTAL EXIT
FIRE COMPARTMENT B
DOOR LEAVES SWING IN OPPOSITE DIRECTIONS
EXIT
SPACE TO BE AS PER 6.3.2.(g) (2)

FIG. 18 PART PLAN INDICATING CONCEPT OF HORIZONTAL EXIT IN HOSPITAL

c) Progressive horizontal evacuation operates on the basis of evacuation from compartment to compartment and on use of adjacent compartments as temporary means of refuge. All compartments should be divided with self-closing (door closers) fire doors with electromagnetic hold open. A coordinator should be provided to sequence the closing of double leaf in case of emergency;

d) Doors in fire resistant walls should be so installed that these may normally be kept in open position, but will close automatically. Corridor door openings should be not less than 2.0 m in width of double swing double leaf type door. A coordinator should be provided as above, for closing of double leaf in case of emergency;

e) Exits and other features for penal and mental institutions, and custodial institutions should be the same as specified for hospitals [*see* **6.3.2** (g)], in so far as applicable. Reliable means should be provided to permit the prompt release of inmates from any locked section in case of fire or other emergency;

f) All buildings or sections of buildings in penal and mental institution used for manufacturing, storage or office purposes should have exits in accordance with the provisions of this Part for those occupancies;

g) For hospitals (Subdivision C-I), the following should also be complied with:

   1) Compartmentation should meet the requirement as per **4.5.2**.

   2) Each compartment (*see* **4.5.3**) should be able to accommodate, in addition to its own, the patients from adjoining compartment also considering 3.5 m^2 per person. If patients are not bed-ridden, a factor of 0.6 m^2 per person is recommended. This is towards achieving horizontal evacuation.

   3) All critical patients incapable of self-preservation and those having physical impairment should preferably be housed within 45 m height. For hospitals exceeding 45 m in height, where such occupants are located above this level, the following non-exhaustive additional provisions should be complied with in consultation with local fire authorities:

      i) The general life safety and protection aspects and fire protection features, as in heights up to 45 m should be provided to the entire height, including progressive horizontal evacuation.

    - ii) Further, the alternate floors (particularly those housing all such patients) should have refuge terraces (basically a covered area with place of safety directly exposed to atmosphere at least one side) of sufficient area (as prescribed by the local authorities) with provisions for medical gases to support patients on ventilators temporarily during evacuation during the staging/evacuation period, to ensure uninterrupted care. The refuge terraces should have:
        - a) direct access to the fire-fighting shaft/fire tower,
        - b) access through fire rated door having a minimum 2 h fire resistant rating,
        - c) automatic sprinkler system, public announcement system, fire detection and alarm system, dedicated and separate shaft for medical gas pipelines, utility services and for electrical services,
        - d) dedicated emergency power supply back up (UPS and DG), particularly for all life-saving equipment, and
        - e) washroom facility within it or directly accessible.
    - iii) A dedicated firefighting team should be available round the clock, and having relevant qualification, competence and necessary experience, as may be required by the competent authority.
  - 4) Basement should not be used to store flammables or for pathological or other laboratories particularly those involving usage of inflammable chemicals. Medical health care services involving radiation facilities may be housed in the basements as per medical planning along with radiation therapy allied services like bunkers, SIM CT, brachytherapy, nuclear medicine, hot lab, patient hold and waiting area, consultant room, mould room, TPS room, subject to compliance of all requirements for fire safety.
  - 5) Operation theatres, delivery rooms, intensive care units, recovery rooms, etc, that containing patients lacking self-preservation in case of emergencies should be fire/smoke separated (120 min minimum rating) from all the adjoining areas.
  - 6) Aisles, corridors, ramps, etc, through which patients are moved, should have a minimum width of 2.4 m throughout. Aisles, corridors, and ramps in other areas not intended for the housing, treatment, or use of inpatients should be not less than 1.5 m in width.
  - 7) All exits from hospital or infirmary sections should be not less than 2.0 m in width.
  - 8) Minimum width of door of single or double occupancy patient room should be 1.25 m, while for the wards for 3 to 5 patient beds should be 1.50 m, to enable movement of patients. The minimum width of door for wards for more than 5 patient beds and for areas necessarily requiring patient evacuation on bed (such as ICU, recovery units, delivery rooms, etc), should have door width of 2.0 m. The width of 2.0 m may be reduced to minimum of 1.5 m where two such doors are provided in such areas.
  - 9) Any sleeping accommodation or suite exceeding 100 m^2 in area should have at least two doorways leading to the exit access corridors.
  - 10) Exit access corridors from a compartment to another compartment should be divided at the compartment intersection by a fire door of 120 min fire rating in the fire compartment wall.
  - 11) Rooms designated for laboratory and the like should not exceed 100 m^2 in area, and if additional space is required, fire separation of 120 min should be provided.
  - 12) A stretcher lift in a lift bank should also act as fireman's lift meeting the requirements of Part D 'Building Services, Section 5 Installation of Lifts, Escalators, Moving Walks and Power Driven Parking Systems, Subsection 5A Lifts' of this NBCS.
- h) *Progressive evacuation strategy* — *See* Fig. 19, in which, as an example, the exit calculations at two locations should be based on requirements of total occupancy for area (A, B and C) divided by 2 considering progressive evacuation strategy.

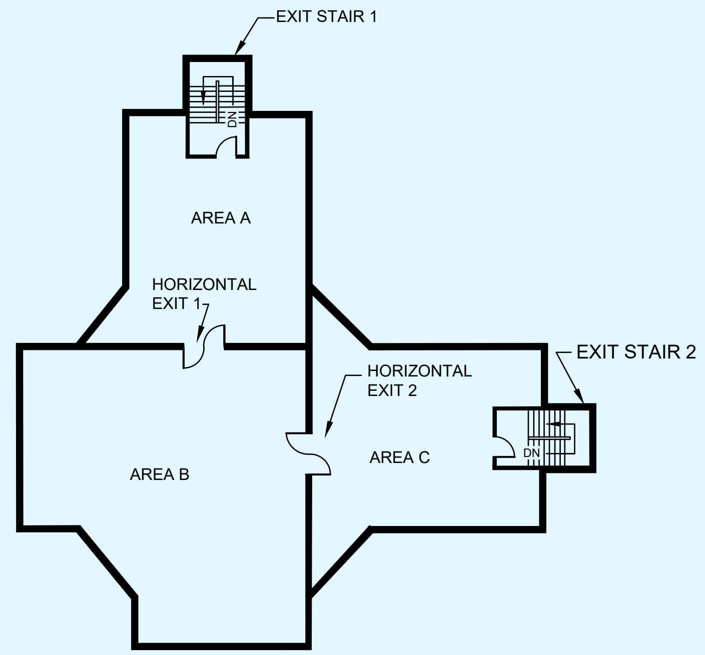


FIG. 19 MINIMUM OF TWO EXITS ACCESSIBLE FROM ALL PARTS OF FLOOR

6.3.3 *Exception and Deviation*

It is recognized that in institutions or part of buildings housing various types of psychiatric patients, or used as mental institutions and penal institutions, it is necessary to maintain locked doors and barred windows; and to such extent the necessary provision in other sections of this Part requiring the keeping of exits unlocked may be waived. It is also recognized that certain type of psychiatric patients are not capable of seeking safety without adequate guidance. In buildings where this situation prevails, reliable means for the rapid release of occupants should be provided, such as remote control of locks, or by keying all locks to keys commonly used by attendants.

6.4 Assembly Buildings (Group D)

6.4.1 *Fire Prevention*

6.4.1.1 The following should be applicable*:*

a) Decorations of places of assembly should be of non-flammable materials. Fabrics and papers used for such purpose should be treated with an effective flame-retardant material. Stage settings made of combustible materials should likewise be treated with fire retardant materials of Class 1 flame spread; and

b) Gymnasiums, indoor stadiums, and similar occupancies are permitted to have floors/running tracks of wood, cinder, synthetic or the like.

6.4.1.2 *Additional fire prevention requirements for mixed use assembly buildings* (*including malls*)

Buildings provided with multiple services/facilities like shopping, cinema theatres, multiplexes, restaurants/food court as part of mixed use assembly/mercantile occupancy should preferably limit the height of the assembly/ mercantile occupancy portion of the buildings to 30 m. Above this height the buildings may be used for business or residential occupancies with 240 min separation. Independent exits should be provided for such occupancy above 30 m and should not interface with exits of assembly/mercantile occupancy.

6.4.2 *Life Safety*

6.4.2.1 The following should be applicable:

a) Exit door width for assembly buildings should not be less than 2.0 m.

b) At least four separate exits as remote from each other as practicable are required from every place of assembly in buildings primarily meant for theatrical or operatic performances and which has a stage, proscenium curtain, fixed or portable scenery or scenery loft, lights, mechanical appliances or other theatrical accessories and equipment for example, theatres, motion picture houses, auditoria, concert halls, television and radio studios admitting an audience and which are provided with fixed seats for over 1 000 persons.

c) At least two separate exits as remote from each other as practicable are required in buildings primarily meant for or theatrical or operatic performances and which has a stage, proscenium curtain, fixed or portable scenery or scenery loft, lights, mechanical appliances or other theatrical accessories and equipment for example, theatres, motion picture houses, auditoria, concert halls, television and radio studios admitting an audience and which are provided with fixed seats. Those building having a capacity from 600 and up to 1 000 persons, at least three exits should be provided with each exit not less than of 2.0 m width.

d) Clear aisles not less than 1.2 m in width should be formed at right angles to the line of seating in such number and manner that no seat should be more than seven seats away from an aisle. Rows of seats opening on to an aisle at one end only should have not more than seven seats. Under the conditions, where all these aisles do not directly meet the exit doors, cross-aisles should be provided parallel to the line of seating so as to provide direct access to the exit, provided that not less than one cross aisle for every 10 rows should be required. The width of cross-aisles should be minimum of 1 m. Steps should not be placed in aisles to overcome differences in levels unless the gradient exceeds 1 in 10.

e) The fascia of boxes, balconies and galleries should have substantial railings not less than 1 000 mm high above the floor. The railings at the end of aisles extending to the fascia should be not less than 1 100 mm high for the width of the aisle or 1.2 m high at the foot of steps.

f) Cross-aisles, except where the backs of seats on the front of the aisle project 600 mm or more above the floor of the aisle, should be provided with railings not less than 900 mm high.

g) Turnstiles or other devices to restrict the movement of persons should not be installed in any place of assembly in such a manner as to interfere in any way with the required exit facilities.

h) In theatres and similar places of public assembly where persons are admitted to the building at a time when seats are not available for them and are allowed to wait in a lobby or similar space until seats are available, such use of lobby or similar space should not encroach upon the required clear width of exits. Such waiting should be restricted to areas separated from the required exit ways by substantial permanent partitions or fixed rigid railing not less than 1 050 mm high. Exit should be provided for such waiting spaces on the basis of maximum capacity of two largest screen of multiplex (considering the staggered movie timings). Such exits should be in addition to the exits specified for the main auditorium area and should conform in construction and arrangement to the general rules of exits given above.

j) Display or exhibit should not be so installed or operated as to interfere in any way with access to any required exit, or with any required exit sign.

k) All displays or exhibits of combustible material or construction and all booths and temporary construction in connection therewith should be so limited in combustibility or protected as to avoid any undue hazard of fire which might endanger occupants before they have opportunity to use the available exits, as determined by the authority.

m) Places of assembly in buildings of other occupancy may use exits common to the place of assembly and the other occupancy, provided the assembly area and the other occupancy are considered separately, and each has exits sufficient to meet the requirements of this Part.

n) Exits should be sufficient for simultaneous occupancy of both the places of assembly and other parts of the building.

p) For detailed information regarding cinema buildings, reference may be made to good practice [F(27)].

q) Seats in places of public assembly, accommodating more than 300 persons, should be securely fastened to the floor, except as permitted in (r) below. All seats in balconies and galleries should be securely fastened to the floor, except that in nailed-in enclosures, boxes with level floors and having not more than 14 seats, the seats need not be fastened.

r) Chairs not secured to the floor may be permitted in restaurants, night clubs and other occupancies where the fastening of seats to the floor may not be practicable, provided that in the area used for seating, excluding dance floor, stage, etc, there should be not more than one seat for each 1.4 m^2 of floor area and adequate aisles to reach exits should be maintained at all times. The arrangements should be as follows in general:

    1) Rows of seats between aisles should have not more than 14 seats.
    2) Rows of seats opening on to an aisle at one end only should have not more than 7 seats.
    3) Seats without dividing arms should have their capacity determined by allowing 450 mm per person.

s) The spacing of rows of seats from back to back should be neither less than 850 mm nor less than 700 mm plus the sum of the thickness of the back and inclination of the back. There should be a space of not less than 350 mm between the back of one seat and the front of the seat immediately behind it as measured between plumb lines.

t) *Lighting* — No open flame lighting devices should be used in any place of assembly, except in the following cases:

    1) Where necessary for ceremonial purposes, the enforcing Authority may consider permiting open flame lighting under such restrictions as are necessary to avoid danger of ignition of combustible materials or injury to occupants.
    2) Candles may be used on restaurant tables if securely supported on non-combustible bases and so located as to avoid danger of ignition of combustible materials.
    3) Open flame devices may be used on stages where they are a necessary part of theatrical performance, provided adequate precautions, satisfactory to the Authority are taken to prevent ignition of combustible materials.

6.4.2.2 *Life safety provisions for mall-like* (*Assembly*, *Mercantile*, *Cinema hall*, *Restaurant*) *occupancy*

The following additional requirements should be applicable:

a) Assembly occupancies of theatres, cinema halls and multiplexes should be so located in the mall building that their exits will be separate and lead the occupant directly to exit discharge.

b) The common path of travel should be 30 m. The maximum dead end of corridor distance should not exceed 6 m.

c) The minimum width of an exit passageway should be 2.0 m.

d) Where wheeled carts or buggies are used by customers, adequate provision should be made for the transit and parking of such carts to minimize the possibility that they might obstruct means of egress. Any other storage or hindrances causing obstruction in exits should be avoided.

e) Car parking facilities should comply with Annex G. Car parking areas at upper levels adjacent to shops, food courts or multiplex should be separated by 120 min fire rated construction and building elements;

f) 50 percent lifts in common areas in the mal-like occupancies should be with features and requirement of fireman's lift.

g) The manual call points should be break glass and not pull stations.

h) Photoluminescent markings should be done along the width and length of treads in all enclosed exits staircases. Exit directional arrow on the wall (in the direction of egress) should be 175 mm × 50 mm in size.

j) Refuge area to be provided on the floor at or immediately above 18 m should be not less than 10 percent of gross area of floor. Next refuge area to be at/on the floor immediately above 24 m. The refuge area should be 10 percent of the respective floor, which may be divided into two or more separate refuge areas at each of the respective floors, with each being not less than 100 m^2. Refuge area should also meet all the requirements of life safety as per **4**.

k) When refuge spaces are resorted to, every floor should be provided with space for 20 percent of the respective occupants of that floor.

6.4.3 *Fire Protection*

a) Every stage equipped with fly galleries, grid irons and rigging for movable theatre type scenery, should have a system of automatic sprinklers over and under such stage areas or spaces and auxiliary spaces, such as dressing rooms, store rooms and workshops, and the proscenium opening should be provided with a fire resisting curtain, capable of withstanding a lateral pressure of 4 kN/m^2 over the entire area. The curtain should have an emergency closing device capable of causing the curtain to close without the use of power and when so closed, it should be reasonably tight against the passage of smoke.

b) The stage roof of every theatre using movable scenery or having a motion picture screen of highly combustible construction should have a ventilator or ventilators in or above it, openable from the stage floor by hand and also opening by fusible links or some other approved automatic heat/smoke actuated device, to give a free opening equal to at least one-eighth the area of the floor of the stage.

c) The proscenium wall of every theatre using movable scenery of decorations should have, exclusive of the proscenium opening, not more than two openings entering the stage, each not to exceed 2 m^2 and fitted with self-closing fire resistant doors.

d) Every place of assembly in which projection of motion pictures by light is made should have the projection apparatus enclosed in a fire resisting fixed booth in accordance with good practice [F(27)], except that such booth should not be required where no nitrocellulose motion picture film is used.

6.4.4 *Fire Protection and Firefighting System for Metro Stations and Metro Trainways Occupancy*

Fire and life safety requirements for metro stations and metro trainways should be in accordance with Annex H and Annex J, respectively. In case of any ambiguity with respect to provisions in Part F or any other Part of this NBCS, the respective provisions given in Annex H and Annex J should be applicable.

6.5 Business Buildings (Group E)

6.5.1 *Life Safety*

Not less than two exits should be provided for every floor, including basements occupied for office purposes or uses incidental thereto.

6.5.2 *Fire Protection*

a) For business buildings (namely laboratories, outpatient clinics, research establishments, libraries, and test houses) the requirement should be provision of automatic fire detection alarm system, while for fire protection, CO_2 and/or foam-based installation to be planned based on the requirements; and

b) For business buildings (namely electronic data processing centres, computer installations, information technology parks and call centres, telephone exchanges, broadcasting stations, T.V. stations, and air traffic control towers) the requirement should be provision of automatic fire detection alarm system, while for fire protection, any or combination of clean agents, mist technologies, etc, may be planned for appropriate/special situations/locations. Electrical panels may be provided with CO_2/inert gas flooding system based on the requirement and reliability of power for the functional requirement and performance.

6.6 Mercantile Buildings (Group F)

6.6.1 *Life Safety*

6.6.1.1 Open air mercantile operations, such as open air markets, petrol filling stations, roadside stands for the sale of a farm produce and other outdoor mercantile operations should be so arranged and conducted as to maintain free and unobstructed ways of travel at all times to permit prompt escape from any point of danger in case of fire or other emergency, but having no dead-ends in which persons might be trapped due to display stands, adjoining buildings, fences, vehicles or other obstructions.

6.6.1.2 If such mercantile operations are conducted in roofed-over areas, these should be treated as mercantile buildings, provided canopies over individual small stands to protect merchandise from the weather should not be construed to constitute buildings for the purpose of this Part.

6.6.2 *Exception and Deviation*

Any mercantile occupancy, where goods of a highly hazardous nature are predominant, should be considered under Group J occupancy for the purpose of this Part.

6.7 Industrial Buildings (Group G)

6.7.1 *Fire Prevention*

6.7.1.1 *Fire separating walls, fire separating floors and fire partitions*

Fire separating walls should be provided between two buildings or between two blocks inside a building, having different fire hazards in accordance with the provisions of this Part. The areas having storage, manufacturing, hazardous activities such as paint store, oil storage, spray booths, etc, should be separated from non-hazardous areas like administrative office, staff canteen, etc by fire rated walls/doors of 120 min fire resistance rating. The fire resistance rating of high hazardous areas like petrochemical, explosives should be 240 min.

The fire separating wall where provided should comply with the following requirements:

a) The separating wall should be carried through the roof. This portion of the wall extending above the roof, known as 'screen wall' should be of such a height (in no case less than 600 mm) that the horizontal distance at the level of the top of the screen wall between the roofs of the buildings/compartments being segregated is at least 6 m.

b) The screen wall should be of not less than 230 mm in thickness if it is an extension of a masonry wall, and not less than 150 mm in thickness if it is an extension of a reinforced concrete wall.

c) The separating wall need not be extended as a screen wall if the roof of one or both of the buildings/blocks being segregated is of reinforced concrete construction (RCC).

d) In the case of buildings of unequal height, windows, or other openings in the wall of the higher building overlooking the roof of the lower building and within 6 m, thereof, should be protected by fire resistant glass assembly or by approved type fire doors unless the roof of the lower building is of reinforced concrete.

e) In case the eaves of the higher building fall within 6 m of the roof of the lower building such eaves should be cut-off and the screen wall raised as a parapet, 600 mm high over the roof of the higher building, unless the roof of the lower building is of RCC construction.

f) Fire separating walls should also be extended outwards on both sides by at least 450 mm.

g) Doors and window openings in external walls within 3 m of the fire separating walls should be protected by fire doors having a rating of at least 60 min and window openings may be protected by fire resistant glass assembly having same fire rating.

h) In the case of buildings/compartments having north-light roofs when a separating wall runs parallel to the axis of the north-light opening, the screen wall should be carried through and 600 mm above the ridge of the north light. If, however, the separating wall is at right angles to the axis of the north-light opening, the saw tooth gaps should be bricked up and the screen wall extended 600 mm above the ridge of the north light as well as beyond the extreme north-light opening.

j) Similarly, the thickness of the floor slabs in case of buildings having upper levels should be designed to provide fire rating as mentioned above.

k) Storage areas should be separated from the remainder of the building/block by fire walls. Moderate and high hazard areas in industries should have two fire doors each having 180 min fire resistance rating.

6.7.2 *Life Safety*

6.7.2.1 In buildings used for aircraft assembly or other occupancy requiring undivided floor areas so large that the distances from points within the area to the nearest outside walls where exit doors could be provided are in excess of 45 m, requirements for distance to exits may be satisfied by providing stairs leading to exit tunnels or to overhead passageways. In cases where such arrangements are not practicable, the Authority may, by special ruling, permit other exit arrangements for single storeyed buildings with distances in excess of the maximum distances specified in 4, if completely automatic sprinkler protection is provided and if the heights of ceiling curtain boards and roof ventilation are such as to minimize the possibility that employees will be overtaken by the spread of fire or smoke within 1.8 m of the floor level before they have time to reach exits, provided, however, that in no case may the distance of travel to reach the nearest exit exceed 65 m where smoke venting is required as a condition for permitting distances of travel to exits in excess of the maximum otherwise allowed.

6.7.2.2 The following applies to special purpose industrial occupancies:

a) Exits need be provided only for the persons actually employed; spaces not subject to human occupancy because of the presence of machinery or equipment may be excluded from consideration.

b) Where unprotected vertical openings are necessary to manufacturing operations, these may be permitted beyond the limits specified for industrial occupancy, provided every floor level has direct access to one or more enclosed stairways or other exits protected against obstruction by any fire in the open areas connected by the unprotected vertical openings or smoke therefrom.

6.7.2.3 The following applies to high hazard industrial occupancies:

a) From every point in every floor area, there should be at least two exits accessible in different directions; where floor areas are divided into rooms, there should be at least two ways of escape from every room, however small rooms, except toilet rooms, so located that the points of access thereto are out of or suitably shielded from areas of high hazard.

b) In addition to types of exits for upper floors specified for Group G occupancies, slide escapes may be used as required exits for both new and existing buildings.

NOTE — All high hazard industrial occupancies should have automatic sprinkler protection or such other protection as may be appropriate to the particular hazard, including explosion venting for any area subject to explosion hazard, designed to minimize danger to occupants in case of fire or other emergency before they have time to utilize exits to escape.

6.7.3 *Additional Precautions*

a) In any room in which volatile flammable substances are used or stored, no device generating a glow or flame capable of igniting flammable vapour should be installed or used, such a room should be provided with a suitably designed exhaust ventilation system (*see* Annex K).

b) For detailed information on fire safety of certain individual (specific) industrial occupancies, reference may be made to good practice [F(28)].

c) Fire protection considerations for venting industrial occupancies should be as in Annex K.

6.8 Storage Buildings (Group H)

6.8.1 *Life Safety*

6.8.1.1 Every area used for the storage of hazardous commodities should have an exit within 30.0 m (*see* Table 4) of any point in the area where persons may be present or 35 m where automatic sprinkler protection is provided.

6.8.1.2 Every storage area or space exceeding 1 400 m^2 gross area, or where more than 10 persons may be normally present should have at least two exit access doors leading to the corridors in exit access, which can be readily opened. This should not be subject to locking so long as any persons are inside and should not depend on power operation. Exits in such cases should be as remote from each other as practicable.

For warehouses, natural draft smoke venting should utilize roof vents or vents in walls at or near the ceiling level; such vents should be normally open, or, if closed, should be designed for automatic opening in case of fire, by release of smoke sensitive devices.

6.8.1.3 The following special provisions should apply to aircraft hangers:

a) Exits from aircraft hangers (storage or servicing areas) should be provided at intervals of not more than 45 m on all exterior walls of aircraft hangers. There should be a minimum of two exits serving each aircraft storage or servicing areas. Horizontal exits through interior fire walls should be provided at intervals of not more than 30 m. 'Dwarf' or 'Smash' doors accommodating aircraft may be used to comply with these requirements. All doors designated as exits should be kept unlocked in the direction of exit travel while the area is occupied; and

b) Exits from mezzanine floors in aircraft storage or servicing areas should be so arranged that the maximum travel to reach the nearest exits from any point on the mezzanine should not exceed 22.5 m. Such exits should lead directly to a properly enclosed stairwell discharging directly to the exterior or to a suitably cut-off area or to outside fire escape stairs.

6.8.1.4 The following special provisions should apply to grain elevators:

a) There should be at least one stair tower from basement to first floor and from the first floor to the top floor of workhouse which is enclosed in a dust tight non-combustible shaft.

b) Non-combustible doors of self-closing type should be provided at each floor landing.

c) An exterior fire escape of the stair or basket ladder type should be provided from the roof of the workshop to ground level or the roof of an adjoining annexe with access from all floors above the first.

d) An exterior fire escape of either the stair or basket ladder type should be provided from the roof of each storage annexe to ground level.

6.8.1.5 For provisions relating to car parking facilities, *see* Annex G.

6.8.2 *Additional Precautions*

Requirements specified in **6.7.3 (a)** should apply to Group H occupancies also.

6.9 Hazardous Uses (Group J)

6.9.1 *Life Safety*

Requirements specified in **6.7.2.3** should apply to Group J occupancies also.

6.9.2 *Additional Precautions*

The following requirements should apply to all Group J occupancies, as applicable:

a) Hazardous buildings should have vapour/flame/ember/spark detectors and explosion suppression systems depending on the type of fire hazard involved;

b) Each building where gas is employed for any purpose should be provided with an approved outside gas shut-off valve conspicuously marked. The detailed requirements regarding safe use of gas should be as specified in Part E ‘Plumbing Services, Section 4 Gas Supply’ of this NBCS;

c) Each boiler room or room containing a heating plant should be separated from the rest of the building by a separating wall;

d) In any room in which volatile flammable substances are used or stored, no device generating a spark, or glow flame capable of igniting flammable vapour should be installed or permitted unless it is enclosed in a flameproof enclosure;

e) The use, handling, storage and sale of gasoline, fuel oil and other flammable liquids should not be permitted in Group J occupancies unless such use, handling, storage, and sale is in accordance with appropriate legislation in force;

f) All openings in exterior walls except wall vents should be protected by a fire stop assembly as in **4** and they should be fixed, automatic or self-closing. Wall vents having an area of not less than 100 cm^2 each should be placed in the exterior walls near the floor line, not more than 1 800 mm apart horizontally. Each building should be provided with a power driven fan exhaust system of ventilation which should be arranged and operated so as to produce a complete change of air in each room every 3 min;

g) Each machine in dry-cleaning establishments which uses flammable liquid should have an adequate steam line or any other suitable extinguishing agent directly connected to it, so arranged as to have the agent automatically released to the inside of each machine should an explosion occur in the machine; and

h) Equipment or machinery which generates or emits combustible or explosive dust or fibres should be provided with an adequate dust collecting and exhaust system.

ANNEX A

(*Clause* 3.1.8)

CALORIFIC VALUES OF COMMON MATERIALS

A-1 The calorific values of some common materials are given in Table 12 for guidance.

Table 12 Calorific Values of Common Materials

(*Clause* A-1)

Sl No.	Material	Calorific Value (10^3 kJ/kg)[1)]	Wood Equivalent (kg/kg)
(1)	(2)	(3)	(4)
i)	**Solid Fuels**		
	a) Anthracite	28.6	1.66
	b) Bituminous coal	30.8	1.75
	c) Charcoal	28.4	1.61
	d) Coke (average)	27.5	1.56
	e) Peat	20.9	1.19
	f) Sub-bituminous coal	22.0	1.25
	g) Woods (hard or softwood)	17.6	1.00
ii)	**Hydrocarbons**		
	a) Benzene	39.6	2.25
	b) Butane	47.1	2.68
	c) Ethane	49.1	2.79
	d) Ethylene	47.7	2.71
	e) Fuel oil	41.6	2.36
	f) Gas oil	42.9	2.44
	g) Hexane	44.9	2.55
	h) Methane (natural gas)	52.8	3.00
	j) Octane	45.3	2.58
	k) Paraffin	39.6 to 44.0	2.3 to 2.5
	m) Pentane	46.0	2.61
	n) Propane	47.3	2.69
	p) Propylene	46.2	2.63
iii)	**Alcohols**		
	a) Ethyl alcohol	28.4	1.61
	b) Methyl alcohol	21.1	1.20

Table 12 (*Continued*)

Sl No.	**Material**	**Calorific Value** (10^3 kJ/kg)[1)]	**Wood Equivalent** (kg/kg)
	c) Propyl alcohol	31.9	1.81
iv)	**Polymers**		
	a) Casein	23.1	1.31
	b) Cellulose	16.5	0.94
	c) Cellulose acetate	17.8	1.01
	d) Polyethylene	48.4	2.75
	e) Polypropylene	48.4	2.75
	f) Polystyrene	41.8	2.38
	g) Polyvinylchloride	20.9	1.19
	h) Polymethyl methacrylate	24.6	1.40
	j) Polyurethane	35.2	2.00
	k) Polyamide (nylon)	22.0	1.25
	m) Polyester	22.0	1.25
v)	**Common Solids**		
	a) Asphalt	38.3	2.13
	b) Bitumen	33.4	1.90
	c) Carbon	32.1	1.83
	d) Cotton (dry)	15.8	0.90
	e) Flax	14.3	0.81
	f) Furs and skins	18.7	1.06
	g) Hair (animal)	20.9	1.19
	h) Leather	17.6	1.00
	j) Ozokerite (wax)	43.5	2.46
	k) Paper (average)	15.4	0.88
	m) Paraffin wax	40.9	2.33
	n) Pitch	33.0	1.88
	p) Rubber	37.4	2.13
	q) Straw	13.2	0.75
	r) Tallows	37.6	2.14
	s) Tan bark	20.9	1.19

Table 12 (*Concluded*)

Sl No.	Material	Calorific Value (10^3 kJ/kg)[1]	Wood Equivalent (kg/kg)
	t) Tar (bituminous)	35.2	2.00
	u) Wool (raw)	21.6	1.23
	w) Wool (scoured)	19.6	1.11
vi)	**Foodstuffs**		
	a) Barley	14.1	0.80
	b) Bran	11.0	0.63
	c) Bread	9.9	0.56
	d) Butter	29.5	1.68
	e) Cheese (Cheddar)	18.1	1.03
	f) Corn meal	14.1	0.80
	g) Flour	14.1	0.80
	h) Margarine	29.5	1.68
	j) Oatmeal	15.8	0.90
	k) Rice	13.9	0.79
	m) Soya bean flour	16.1	0.91
	n) Sugar	15.4	0.88
	p) Whole wheat	14.3	0.81
vii)	**Miscellaneous**		
	a) Acetone	29.7	1.69
	b) Acetaldehyde	25.1	1.43
	c) Formaldehyde	17.6	1.00
	d) Hydrogen	134.2	7.63
	e) Magnesium	24.0	1.36

[1] 1 kJ is approximately equal to 1 Btu, so the figures in the tables are also equivalent to Btu/kg.

ANNEX B

(*Clause* 3.1.8)

BROAD CLASSIFICATION OF INDUSTRIAL OCCUPANCIES INTO DIFFERENT DEGREE OF FIRE HAZARD

G1 – Low Hazard	G2 – Moderate Hazard	G3 -High Hazard
Abrasive Manufacturing Premises Aerated Water Factories Agarbatti Manufacturing Areca nut slicing and/or Betel nut Factories Analytical and/or Quality Control Laboratories Athletic Equipment manufacturing Asbestos Steam Packing and Lagging Manufacturing Auto mobiles and other motor vehicles Breweries Brick Works Canning Factories Cardamom Factories Cement Factories and/or Asbestos or Concrete Products Manufacturing Ceramic Factories and Crockery and Stoneware Pipe Manufacturing Clay Works Clock and Watch Manufacturing Coffee Curing Roasting and grinding Premises Condensed Milk Factories, Milk Pasteurizing Plant and Dairies Confectionery Manufacturing Cooling Towers Electric Generating Houses (Hydroelectric)	Aluminium Factories Atta and Cereal Grinding units Auto Components (excluding plastics and foam components) manufacturing Bakeries and Biscuit Factories Beedi Factories Bobbin Factories Bookbinders, Envelopes and Paper bag Manufacturing Cable manufacturing Camphor Boiling facilities Candle Works Carbon Paper/Typewriter Ribbon Manufacturing Cardboard Box Manufacturing Carpenters, Wood wool and Furniture Manufacturing Carpet and Durries Factories Cashewnut Factories Chemical Manufacturing using raw materials having flash points above 23 ºC Chemical Store (non-water reactive) Cinema Films and T.V. Production Studios Cigar and Cigarette Factories Coal and/or Coke and/or Charcoal Ball and Briquettes Manufacturing Coir Factories	**SUB-CATEGORY (A)** Aircraft Hangers units Aluminium/Magnesium Powder Plants Auto Components (including Plastics and Foam Components) Auto Mobiles and other Motor Vehicles powered by Lithium or Lithium-Ion Batteries manufacturing Battery Charging/Battery Service Stations Battery Manufacturing Bituminized Paper and/or Hessian Cloth/Tar Felt Manufacturing Chemical Store (water reactive) Cotton Waste Factories Celluloid Goods Manufacturing Chemical Manufacturing using raw materials having flash points below 23 °C Cigarette Filter Manufacturing Diesel Generator Room Fire-works Manufacturing Foam Plastics Manufacturing and/or Converting Plants Godowns and Warehouses (storing combustible/flammable goods) Grass, Hay, Fodder and Bhoosa (chaff) Pressing Factories Hydrogenation rooms (involving Flammable Hydrogen) Industrial Gas Manufacturing (other than Inert/Halogenated Hydrocarbon Gases)

G1 – Low Hazard	G2 – Moderate Hazard	G3 -High Hazard
Incandescent and Fluorescent and TV Picture Tube Manufacturing Electro-plating Works Engineering Workshops Fruits and Vegetables Dehydrating and Drying Factories Fruit Products and Condiment Factories Garages Glass and Glass Fibre Manufacturing Godowns and Warehouses storing non-combustible goods only Green houses Gold Thread/Gilding Factories Gum and/or Glue and Gelatine Manufacturing Ice, Ice Candy, and Ice-cream Manufacturing Ink (excluding Printing Ink) Factories Mica Products Manufacturing Multiple block apartment buildings Open Large Atriums Pottery Works Poultry Farms QA/QC Laboratories Salt Crushing Factories and Refineries Stables Sugar Candy Manufacturing Tanneries/Leather Goods Manufacturers Umbrella Assembling Factories Vermicelli Factories	Coir Carpets, Rugs, Tobacco, Hides and Skin Presses Cold storage premises Cold Freezer Room Collieries Conveyors Cork products manufacturing Cotton Seed Cleaning or De-linting Factories Distilleries Dry Cleaning, Dyeing and Laundries Duplicating/Stencil Paper Manufacturing Electric substations/Distribution stations Electric Generating stations (other than Underground power houses) Electric Lamps Manufacturing Electrical Appliances Manufacturing Electrical/Motor Control Centre (MCC) Panel Rooms Electronic Products Manufacturing Enamelware Factories Filter and Wax paper Manufacturing Flour Mills Food Processing establishments Garment Makers Ghee Factories (other than vegetable) Godowns and Warehouses (other than those under light and high hazard A categories)	Jute mills and jute presses Linoleum Factories Lithium Ion Battery Manufacturing Plants LPG Bottling Plants (Mini) Man-made Fibres (Acrylic fibres/yarn manufacturing) Match Factories Metal or Tin Printers (where more than 50 percent of floor area is occupied as Engineering Workshop; this may be taken as Ordinary Hazard Risk) Oil Mills Oil Extraction Plants Oil Fire Boiler Room/ Oil Quenching Tank Oil Terminals/Depots handling flammable liquids having flash point of 23 °C and below Oil Transformer Room Paints and Varnish Factories Paint Booths Paint/Varnish Storage Paper and Cardboard Mills having raw material yards Piers, Wharfs and Jetties – Handling Extra Hazardous Materials Printing Ink Manufacturing. Rosin Lamp black and Turpentine Factories Saw Mills Spray painting facilities Server room Surgical Cotton Manufacturing Tanker Loading/Unloading Bay Tarpaulin and Canvas Proofing Factories

G1 – Low Hazard	G2 – Moderate Hazard	G3 -High Hazard
Water Treatment/Filtration Plants and Water Pump Houses Zinc/Copper Factories	Grain and/or Seeds Disintegrating and/or Crushing Factories Grease Manufacturing Hosiery, Lace, Embroidery and Thread Factories Incandescent Gas Mantle Manufacturing Indoor Dry Transformer Room Industrial Gas Manufacturing (Inert/halogenated hydrocarbon gases) Kitchen with any type of fuel (Live cooking) MRI/scanning room Man-made Yarn/Fibre Manufacturing (other than acrylic fibres/yarn Manufacturing) Manure and Fertilizer Works (Blending, Mixing, and granulating) Mattress and Pillow Making Mineral Oil Blending and Processing Multiple block business buildings Multiple block star hotel buildings Musical Instruments Manufacturing Network/electrical room Oil and Leather Cloth Factories Oil Terminals/Depots other than those categorized under High hazard A Open storage of flammable liquids in drums, cans, etc Operation Theatre Rooms Optical Goods facilities Oxygen Plants Paper and Cardboard Mills without Raw Material Yards	Turpentine and Rosin Distilleries Tyre Retreading and Resoling Factories Tunnel Protection UPS Room with batteries Battery Room with Lithium-ion batteries **SUB-CATEGORY (B)** Ammonia and Urea Synthesis Plants Benzene/ Xylene/ Toluene Tanks CNG Compressing and Bottling Plants Coal based methane plants LPG bullets Explosive Factories Oil Storage (above ground) Outdoor Oil Transformer Room NOTE — In case of complexes having separate plants having varying degrees of hazard, authority having jurisdiction should be consulted to decide on level of protection to be provided.

G1 – Low Hazard	G2 – Moderate Hazard	G3 -High Hazard
	Pharmaceuticals Piers, Wharves, Jetties and Dockyards other than those categorized under High hazard A Plastic Goods Manufacturing Plywood/Wood Veneering Factories Printing Press Premises Pulverising and Crushing Mills Rice Mills Rope Works Rubber Goods Manufacturing Rubber Tyres and Tubes Manufacturing Semiconductors Manufacturing Sulphur Storage Sugar Factories and Refineries Shellac Factories Silk Filatures Soaps and Glycerine Factories Solar Cells and Modules manufacturing Sponge Iron Steel Plants (Gas Based) Starch Factories Tea Factories Textile Mills Tobacco (Chewing) and Pan-Masala Making facilities Tobacco Grinding and Crushing Tobacco Redrying Factories UPS Room without batteries Woollen Mills	

NOTES

1 Any occupancy that is not covered in this Annex should be classified in the most appropriate class which resembles the proposed occupancy.

2 For classification of industries based on 'chemical hazard', pollution, etc, the respective state/central guidelines/documents/rules may be referred.

ANNEX C

(*Clauses* 3.4.2, 3.4.3 *and* F-2.1)

AVAILABLE DATA REGARDING FIRE RESISTANCE RATING OF VARIOUS BUILDING COMPONENTS

C-1 The following tables (*see* Table 13 to Table 29) may be used, in the absence of any validated/certified rating regarding the materials used in the structural and/or non-structural element/component.

Table 13 Masonry Walls: Solid (Required to Resist Fire from One Side at a Time)

(*Clause* C-1)

Sl No.	**Nature of Construction and Materials**	**Minimum Thickness** (mm)**, Excluding any Finish, for a Fire Resistance** (*min*) **of**									
		Load Bearing					Non-Load Bearing				
		60	90	120	180	240	60	90	120	180	240
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
i)	Reinforced cement concrete1)	120 (25)2)	140 (25)2)	160 (25)2)	200 (25)2)	240 (25)2)	–	–	–	–	–
ii)	Unreinforced cement concrete	150	175	–	–	–	–	–	–	–	–
iii)	No-fines concrete with: a) 13 mm cement/ sand or gypsum/ sand	–	–	–	–	–	150	150	150	150	150
	b) 13 mm light weight aggregate gypsum plaster	–	–	–	–	–	150	150	150	150	150
iv)	Bricks of clay: a) Without finish	90	100	100	170	170	75	90	100	170	170
	b) With 13 mm light weight aggregate gypsum plaster	90	90	90	100	100	75	90	90	90	100
v)	Bricks of sand lime: a) Without finish	90	100	100	190	190	75	90	100	170	170
	b) With 13 mm light weight aggregate gypsum plaster	90	90	90	100	100	75	90	90	90	100
vi)	Blocks of concrete:										
	a) Without finish	90	100	100	–	–	75	90	100	140	150

Table 13 (*Concluded*)

Sl No.	**Nature of Construction and Materials**	**Minimum Thickness** (mm), **Excluding any Finish, for a Fire Resistance** (*min*) **of**									
		Load Bearing					Non-Load Bearing				
		60	90	120	180	240	60	90	120	180	240
	b) With 13 mm light weight aggregate gypsum plaster	90	90	90	100	100	75	75	75	90	100
	c) With 13 mm cement/sand or gypsum/sand	–	–	–	–	–	75	90	90	100	140
vii)	Blocks of light weight concrete: a) Without finish	90	100	100	140	150	75	75	75	125	140
	b) With 13 mm light weight aggregate gypsum plaster	90	90	90	100	100	50	63	75	75	75
	c) With 13 mm cement/sand or gypsum/sand	–	–	–	–	–	75	75	75	90	100
viii)	Blocks of aerated concrete: a) Without finish	90	100	100	140	180	50	63	63	75	100
	b) With 13 mm light weight aggregate gypsum plaster	90	90	100	100	150	–	–	–	–	–

[1] Walls containing at least 1 percent of vertical reinforcement.

[2] Minimum thickness of actual cover to reinforcement.

Table 14 Masonry Walls: Hollow (Required to Resist Fire from One Side at a Time)

(*Clause* C-1)

Sl No.	**Nature of Construction and Materials**	**Minimum Thickness** (mm), **Excluding any Finish, for a Fire Resistance** (*min*) **of**										
		Load Bearing						Non-load Bearing				
		60	90	120	180	240	30	60	90	120	180	240
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
i)	Bricks of clay: a) Without finish	170	170	170	200	200	75	75	90	100	170	170

Table 14 (*Concluded*)

Sl No.	Nature of Construction and Materials	Minimum Thickness (mm), Excluding any Finish, for a Fire Resistance (*min*) of										
		Load Bearing						Non-load Bearing				
		60	90	120	180	240	30	60	90	120	180	240
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	b) With 13 mm lightweight aggregate gypsum plaster	170	170	170	200	200	75	75	90	100	170	170
ii)	Blocks of concrete:											
	a) Without finish	–	–	–	–	–	90	125	125	140	140	150
	b) With 13 mm cement/sand or gypsum/ sand	–	–	–	–	–	90	125	125	140	140	140
	c) With 13 mm lightweight aggregate gypsum plaste	190	200	200	–	–	75	90	90	100	125	125
iii)	Blocks of lightweight concrete:											
	a) Without finish	100	100	100	–	–	75	90	90	100	140	150
	b) With 13 mm cement/sand or gypsum/sand	–	–	–	–	–	75	75	75	100	140	140
	c) With 13 mm lightweight aggregate gypsum plaster	–	–	–	–	–	63	63	63	75	90	100

Table 15 Framed Construction, Load Bearing (Required to Resist Fire from One Side at a Time)

(*Clause* C-1)

Sl No.	Nature of Construction and Materials/Timber Studs at Centres not Exceeding 600 mm, Faced on Each Side with	Minimum Thickness (mm) of Protection for a Fire Resistance of 60 min
(1)	(2)	(3)
i)	Plasterboard layers with joints staggered, joints in outer layer taped and filled — Total thickness for each face	25
ii)	One layer of 12.7 mm plasterboard with a finish of lightweight aggregate gypsum plaster	13
iii)	Metal lath and plaster, thickness of plaster:	
	a) Sanded gypsum plaster (metal lathing grade)	22
	b) Lightweight aggregate gypsum plaster	13

Table 16 Framed Construction, Non-Load Bearing (Required to Resist Fire from One Side at a Time)

(*Clause* C-1)

Sl No.	Nature of Construction and Materials/Steel or Timber Frame at Centres not Exceeding 600 mm, Facings on Both Sides of	Stud Construction	Minimum Thickness (mm) of Protection for a Fire Resistance (min)			
			30	60	90	120
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	Dry lining with materials fixed direct to studs, without plaster finish					
	a) One layer of plasterboard with taped and filled joints	Timber or steel	12.7	–	–	–
	b) Two layers of plasterboard with joints staggered, joints in outer layer taped and filled – Total thickness for each face	Timber or steel	19	25	–	–
	c) One layer of asbestos insulating board with transverse joints backed by fillers of asbestos insulating board not less than 9 mm thick, or by timber	Timber or steel	9	12	–	–
	d) One layer of wood wool slabs	Timber	25	–	–	–
	e) One layer of chipboard or of plywood	Timber or steel	18	–	–	–
ii)	Lining with materials fixed direct to suds, with plaster finish					
	a) Plasterboard of thickness:					
	1) With not less than 5 mm gypsum plaster finish	Timber or steel	9.5	–	–	–
	2) With not less than 13 mm gypsum plaster finish	Timber or steel	–	12.7	–	–
iii)	Wet finish					
	a) Metal lath and plaster, thickness of plaster:					
	1) Sanded gypsum plaster	Timber or steel	13	–	–	–
	2) Lightweight aggregate gypsum plaster	Timber	–	13	19	25
		Steel	–	13	–	–

Table 17 Framed External Walls Load Bearing (Required to Resist Fire from One Side at a Time)

(*Clause* C-1)

Sl No.	Nature of Construction and Materials	Minimum Thickness (mm) of Protection for a Fire Resistance of 60 min
(1)	(2)	(3)
i)	Timber studs at centres not exceeding 600 mm with internal linings of: Plasterboard layers with joints in outer layer taped and filled, total thickness of plasterboard	31

Table 18 Framed External Walls Non-Load Bearing [Required to Resist Fire from Inside the Building (A)]

(*Clause* C-1)

Sl No.	Nature of Construction and Materials	Minimum Thickness (mm) of Protection for a Fire Resistance (min) of					
		30	60	90	120	180	240
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	Steel frame with an external cladding of non-combustible sheets (excluding sheet steel), with a steel supporting framework and internal lining of:						
	a) Metal lath and plaster, thickness of plaster:						
	1) Sanded gypsum plaster (metal lathing grade)	13	13	–	–	–	–
	2) Lightweight aggregate gypsum plaster	10	13	15	15	15	19
	b) Two layers of plasterboard with joints staggered joints in outer layer taped and filled — Total thickness	21	32	–	–	–	–
	c) Plasterboard of thickness:						
	1) With not less than 5 mm gypsum plaster finish	12.7	–	–	–	–	–
	2) With not less than 13 mm gypsum plaster finish	9.5	–	–	–	–	–
	3) With not less than 10 mm lightweight aggregate gypsum plaster	9.5	–	–	–	–	–
	d) One layer of asbestos insulating board with transverse joints backed by fillers of asbestos insulating	9	9	12	12	12	12

Table 18 (*Concluded*)

Sl No.	Nature of Construction and Materials	Minimum Thickness (mm) of Protection for a Fire Resistance (min) of					
		30	60	90	120	180	240
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	board not less than 9 mm thick, or by timber						
	e) One layer of wood/wool slabs without finish	–	50	–	–	–	–
	f) One layer of compressed straw building slabs :						
	1) Without finish	50	–	–	–	–	–
	2) With not less than 5 mm gypsum plaster finish	–	50	–	–	–	–
	g) Aerated concrete blocks	50	50	63	63	75	100
	h) Bricks of clay:						
	1) Without finish	75	75	90	90	100	100
	2) With not less than 13 mm lightweight aggregate gypsum plaster	–	–	75	75	90	90

Table 19 Framed External Walls Non-Load Bearing [(Required to Resist Fire from Inside the Building (B)]

(*Clause* C-1)

Sl No.	Nature of Construction and Materials	Minimum Thickness (mm) of Protection to Provide Sufficient Insulation to Achieve a Modified Fire Resistance of Up to 240 min
(1)	(2)	(3)
i)	Steel frame with an external cladding of sheet steel fully lapped, steel bolted and fixed to steel sheeting rails, with timber or steel supporting framework and internal lining of:	
	a) Metal lath and plaster, thickness of plaster:	
	1) Sanded gypsum plaster (metal lathing grade)	13
	2) Lightweight aggregate gypsum plaster	10

Table 19 (*Concluded*)

Sl No.	Nature of Construction and Materials	Minimum Thickness (mm) of Protection to Provide Sufficient Insulation to Achieve a Modified Fire Resistance of Up to 240 min
(1)	(2)	(3)
	b) One layer of plasterboard with joints taped and filled	12.7
	c) Plasterboard of thickness with not less than 5 mm gypsum plaster finish	9.5
	d) One layer of asbestos insulating board with transverse joints backed by fillers of asbestos insulating board not less than 9 mm thick, or by timber	9
	e) One layer of wood/wool slabs	25
	f) One layer of compressed straw building slabs	50
	g) One layer of chipboard or of plywood	18
	h) Aerated concrete blocks	50
	j) Bricks of clay	75
	k) Any internal decorative lining with a cavity fill independently supported and retained in position of mineral fibre insulating material (excluding glass) at a density of 48 kg/m3	50

Table 20 Framed Walls Non-Load Bearing [Required to Resist Fire from Inside the Building (C)]

(*Clause* C-1)

Sl No.	Nature of Construction and Materials	Minimum Thickness (mm) of Protection for a Fire Resistance of 90 min
(1)	(2)	(3)
i)	Timber frame with external cladding of weather boarding or external plywood, 9.5 mm with an internal lining of :	
	a) Plasterboard not less than 9.5 mm thick, finished with:	
	1) Gypsum plaster	13
	2) Lightweight aggregate gypsum plaster	10
	b) Plasterboard not less than 12.7 mm thick, finished with:	
	1) Gypsum plaster	10

Table 20 (*Concluded*)

Sl No.	**Nature of Construction and Materials**	**Minimum Thickness (mm) of Protection for a Fire Resistance of 90 min**
(1)	(2)	(3)
	2) Lightweight aggregate gypsum plaster	10
	c) One layer of asbestos insulating board with transverse joints backed by fillers of asbestos insulating board not less than 9 mm thick, or by timber	9 12

Table 21 Reinforced Concrete Columns

(*Clause* C-1)

Sl No.	**Nature of Construction and Materials**		**Minimum Dimensions (mm) Excluding any Finish, for a Fire Resistance (min) of**					
			30	60	90	120	180	240
(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)
i)	Fully exposed	a) Width	150	200	250	300	400	450
		b) Cover	40	40	40	40	40	40
ii)	50 percent exposed	a) Width	125	160	200	200	300	350
		b) Cover	40	40	40	40	40	40
iii)	One face exposed	a) Thickness	100	120	140	160	200	240
		b) Cover	40	40	40	40	40	40

Table 22 Concrete Beams

(*Clause* C-1)

Sl No.	**Nature of Construction and Materials**		**Minimum Dimensions (mm) Excluding any Finish, for a Fire Resistance (min) of**					
			30	60	90	120	180	240
(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)
i)	Reinforced concrete (simply supported)	a) Width	200	200	200	200	240	280
		b) Cover	20	20	20	40	60[1]	70[1]
ii)	Reinforced concrete (continuous)	a) Width	200	200	200	200	240	280
		b) Cover	20	20	20	30	40	50[1]
iii)	Prestressed concrete (simply supported	a) Width	100	120	150	200	240	280
		b) Cover	25	40	55[1]	70[1]	80[1]	90[1]

Table 22 (*Concluded*)

Sl No.	Nature of Construction and Materials		Minimum Dimensions (mm) Excluding any Finish, for a Fire Resistance (min) of					
			30	60	90	120	180	240
(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)
iv)	Prestressed concrete (continuous)	a) Width	80	100	120	150	200	240
		b) Cover	20	30	40	55[1]	70[1]	80[1]

[1] Require attention to the additional measures necessary to reduce the risk of spalling.

Table 23 Concrete Floors

(*Clause* C-1)

Sl No.	Nature of Construction and Materials		Minimum Dimensions (mm) Excluding any Finish, for a Fire Resistance (min) of					
			30	60	90	120	180	240
(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)
i)	Reinforced concrete (simply supported)	a) Thickness	75	95	110	125	150	170
		b) Cover	20	20	25	35	45[1]	55[1]
ii)	Reinforced concrete (continuous)	a) Thickness	75	95	110	125	150	170
		b) Cover	20	20	20	25	35	45[1]

[1] Require attention to the additional measures necessary to reduce the risk of spalling.

Table 24 Concrete Floors: Ribbed Open Soffit

(*Clause* C-1)

Sl No.	Nature of Construction and Materials		Minimum Dimensions (mm) Excluding any Finish, for a Fire Resistance (min) of					
			30	60	90	120	180	240
(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)
i)	Reinforced concrete (simply supported)	a) Thickness of floor	75	95	110	125	150	170
		b) Rib width	125	125	125	125	150	175
		c) Cover	20	20	35	45[1]	55[1]	65[1]
ii)	Reinforced concrete (continuous)	a) Thickness	75	95	110	125	150	170
		b) Width	125	125	125	125	150	175
		c) Cover	20	20	20	35	45[1]	55[1]

[1] Require attention to the additional measures necessary to reduce the risk of spalling.

Table 25 Encased Steel Columns, 203 mm × 203 mm

(*Clause* 3.4.3 *and* C-1)

Sl No.	Nature of Construction and Materials	Minimum Dimensions (mm) Excluding any Finish, for a Fire Resistance (min) of				
		60	90	120	180	240
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	Hollow protection (without an air cavity over the flanges):					
	a) Metal lathing with trowelled lightweight aggregate gypsum plaster[1]	13	15	20	32	–
	b) Plasterboard with 1.6 mm wire binding at 100 mm pitch, finished with lightweight aggregate gypsum plaster not less than the thickness specified:					
	1) 9.5 mm plaster board	10	15	–	–	–
	2) 19 mm plaster board	10	13	20	–	–
	c) Asbestos insulating boards, thickness of board:					
	1) Single thickness of board, with 6 mm cover fillets at transverse joints	–	19	25	–	–
	2) Two layers of total thickness	–	–	–	38	50
	d) Solid bricks of clay, composition, or sand lime, reinforced in every horizontal joint, ulastered	50	50	50	75	100
	e) Aerated concrete blocks	60	60	60	–	–
	f) Solid blocks of lightweight concrete Hollow protection (with an air cavity over the flanges)	50	50	50	60	75
ii)	Asbestos insulating board screwed to 25 mm asbestos battens	12	19	–	–	–
iii)	Solid protections					
	a) Concrete, not leaner than 1 : 2 : 4 mix (unplastered):					
	1) Concrete not assumed to be load bearing, reinforced[2]	25	25	25	50	75
	2) Concrete assumed to be load bearing	50	50	50	75	75
	b) Lightweight concrete, not leaner than 1 : 2 : 4 mix (unplastered): concrete not assumed to be load bearing, reinforced[2]	25	25	25	40	60

[1] So fixed or designed, as to allow full penetration for mechanical bond.

[2] Reinforcement should consist of steel binding wire not less than 2.3 mm in thickness, or a steel mesh weighing not less than 0.5 kg/m^2. In concrete protection, the spacing of that reinforcement should not exceed 200 mm in any direction.

Table 26 Encased Steel Beams, 406 mm × 176 mm

(Protection Applied on Three Sides)

(*Clause* 3.4.3 *and* C-1)

Sl No.	Nature of Construction and Materials	Minimum Thickness (mm) of Protection for a Fire Resistance (min) of					
		30	60	90	120	180	240
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	Hollow protection (without an air cavity beneath the lower flange):						
	a) Metal lathing with trowelled lightweight aggregate gypsum plaster1)	13	13	15	20	25	–
	b) Plasterboard with 1.6 mm wire binding2) at 100 mm pitch, finished with lightweight aggregate gypsum plaster not less than the thickness specified:						
	1) 9.5 mm plaster board	10	10	15	–	–	–
	2) 19 mm plaster board	10	10	13	20	–	–
	c) Asbestos insulating boards, thickness of board :						
	1) Single thickness of board, with 6 mm cover	–	–	19	25	–	–
	2) Two layers of total thickness	–	–	–	–	38	50
ii)	Hollow protection (with an air cavity below the lower flange):						
	a) Asbestos insulating board screwed to 25 mm asbestos battens	9	12	–	–	–	–
iii)	Solid protection :						
	a) Concrete, not leaner than 1 : 2 : 4 mix (unplastered):	25	25	25	25	50	75
	1) Concrete not assumed to be load bearing, reinforced3)	50	50	50	50	75	75
	2) Concrete assumed to be load bearing						
	b) Lightweight concrete4), not leaner than 1 : 2 : 4 (mix) unplastered	25	25	25	25	40	60

1) So fixed or designed, as to allow full penetration for mechanical bond.

2) Where wire binding cannot be used, expert advice should be sought regarding alternative methods of support to enable the lower edges of the plasterboard to be fixed together and to the lower flange, and for the top edge of the plasterboard to be held in position.

3) Reinforcement should consist of steel binding wire not less than 2.3 mm in thickness or a steel mesh weighing not less than 0.5 kg/m^2. In concrete protection, the spacing of that reinforcement should not exceed 200 mm in any direction.

4) Concrete not assumed to be load bearing, reinforced.

Table 27 Timber Floors — Tongued and Grooved Boarding, or Sheets of Tongued and Grooved Plywood or Wood Chipboard, of not Less than 21 mm Finished Thickness

(*Clause* C-1)

Sl No.	Nature of Construction and Materials	Minimum Thickness (mm) of Protection for a Fire Resistance (min) of		
		30	60	120
(1)	(2)	(3)	(4)	(5)
i)	37 mm (minimum) timber joists with a ceiling of:			
	a) Timber lathing and plaster, plaster of thickness	15	–	–
	b) Metal lathing and plaster, thickness of plaster:			
	1) Sanded gypsum plaster (metal lathing grade)	15	–	–
	2) Lightweight aggregate gypsum plaster	13	13	25
	c) One layer of plasterboard with taped and filled joints	12.7	–	–
	d) Two layers of plasterboard with joints staggered, joints in outer layer taped and filled total thickness	19	31	–
	e) One layer of plasterboard not less than 9.5 mm thick, finished with:			
	1) Gypsum plaster	5	–	–
	2) Sanded gypsum plaster	13	–	–
	3) Lightweight aggregate gypsum plaster	13	–	–
	f) One layer of plasterboard not less than 12.7 mm thick, finished with:			
	1) Gypsum plaster	5	–	–
	2) Lightweight aggregate gypsum plaster	10	–	–
	g) One layer of asbestos insulating board with any transverse joints backed by fillets of asbestos insulating board not less than 9 mm thick, or by timber	9	12	–

Table 28 Timber Floors — Tongued and Grooved Boarding, or Sheets of Tongued and Grooved Plywood or Wood Chipboard, of not Less than 15 mm Finished Thickness

(*Clause* C-1)

Sl No.	Nature of Construction and Materials	Minimum Thickness (mm) of Protection for a Fire Resistance (min) of		
		30	60	120
(1)	(2)	(3)	(4)	(5)
i)	37 mm (minimum) timber joists with a ceiling of:			
	a) Timber lathing and plaster, plaster of thickness	15	–	–

Table 28 (*Concluded*)

Sl No.	Nature of Construction and Materials	Minimum Thickness (mm) of Protection for a Fire Resistance (min) of		
		30	60	120
(1)	(2)	(3)	(4)	(5)
	b) Metal lathing and plaster, thickness of plaster for:			
	1) Sanded gypsum plaster (metal lathing grade)	15	–	–
	2) Lightweight aggregate gypsum plaster	13	13	25
	c) One layer of plasterboard with taped and filled joints	12.7	–	–
	d) Two layers of plasterboard with joints staggered, joints in outer layer taped and filled total thickness	22	31	–
	e) One layer of plasterboard not less than 9.5 mm thick, finish with:			
	1) Gypsum plaster	5	–	–
	2) Sanded gypsum plaster	15	–	–
	3) Lightweight aggregate gypsum plaster	13	–	–
	f) One layer of plasterboard not less than 12.7 mm thick, finished with:			
	1) Gypsum plaster	5	–	–
	2) Lightweight aggregate gypsum plaster	10	–	–
	g) One layer of asbestos insulating board, with any transverse joints backed by fillets of asbestos insulating board not less than 9 mm thick, or by timber	9	12 1)	–

1) Finished on top with 25 mm minimum thick glass fibre or mineral wool laid between joints.

Table 29 Timber Floors — Any Structurally Suitable Flooring of Timber or Lignocelluloses Boards

(*Clause* C-1)

Sl No.	Nature of Construction and Materials	Minimum Thickness (mm) of Protection for a Fire Resistance (min) of	
		30	60
(1)	(2)	(3)	(4)
i)	37 mm (minimum) timber joists with a ceiling of:		
	a) Timber lathing and plaster, plaster of thickness	15	–

Table 29 (*Concluded*)

Sl No.	Nature of Construction and Materials	Minimum Thickness (mm) of Protection for a Fire Resistance (min) of	
		30	60
(1)	(2)	(3)	(4)
	b) Metal lathing and plaster, thickness of plaster for :		
	1) Sanded gypsum plaster (metal lathing grade)	15	–
	2) Lightweight aggregate gypsum plaster	13	19
	c) One layer of plasterboard with joints taped and filled and backed by timber	12.7	–
	d) Two layers of plasterboard with joints staggered, joints in outer layer taped and filled total thickness	25	–
	e) Two layers of plasterboard, each not less than 9.5 mm thick, joints between boards staggered and outer layer finished with gypsum plaster	5	–
	f) One layer of plasterboard not less than 9.5 mm thick, finish with :		
	1) Sanded gypsum plaster	13	–
	2) Lightweight aggregate gypsum plaster	15	–
	g) One layer of plasterboard not less than 12.7 mm thick, finished with :		
	1) Sanded gypsum plaster	15	–
	2) Lightweight aggregate gypsum plaster	13	–
	h) One layer of asbestos insulating board with any transverse joints backed by fillets of asbestos insulating board not less than 9 mm thick, or by timber	12	–

ANNEX D

(*Clauses* 5.1.4 *and* 6)

ADDITIONAL REQUIREMENTS FOR HIGH RISE BUILDINGS

D-1 GENERAL

High rise buildings should receive special attention with respect to fire and life safety particularly with regard to planning, design, execution, maintenance and training so that the intended provisions of this NBCS are well implemented. These get further accentuated as the buildings go taller; some of the key aspects are as follows:

- a) Staging and evacuation requirements of occupants;
- b) Stack effect posing challenges towards pressurization and smoke exhaust;
- c) Zoning of firefighting system to meet functional requirements of hydraulic pressure and flow; and
- d) Challenges experienced by fire personnel in reaching the place of fire and towards evacuation.

Aspects to mitigate these challenges require innovative approach, interaction with local fire authorities and meaningful strategic planning towards maintenance and fire drills.

D-2 EGRESS AND EVACUATION STRATEGY

One firefighting shaft should be planned for each residential building/tower, in an educational building/block, and for each compartment of institutional, assembly, business and mercantile occupancy types. In buildings/floors having three or more compartments, there should be at least two firefighting shafts to serve the compartments.

For other occupancy types, requirement of firefighting shaft should be ascertained in consultation with the local fire authority. The firefighting shaft should necessarily have connectivity directly to exit discharge or through exit passageway (having 120 min fire resistance walls) to exit discharge.

Staircase and fire lift lobby of a firefighting shaft should be smoke controlled as per **4.4.2.5** and Table 5.

It is recommended that the pressurization requirement for staircase in firefighting shaft and for other fire exit staircases in buildings greater than 60 m in height be evaluated to limit the force required to operate the door assembly (in the direction of door opening) to not more than 133 N to set the door leaf in motion. The aspect of pressurization, door area/width and door closure should be planned in consideration to the above.

D-3 FIRE SAFETY REQUIREMENTS FOR LIFTS

The provisions as given in **7.1** to **7.2.4** under fire safety requirements of lifts in high rise buildings in Part D 'Building Services, Section 5 Installation of Lifts, Escalators, Moving Walks and Power-Driven Parking Systems, Subsection 5A Lifts' of this NBCS should be applicable.

D-4 HORIZONTAL EXITS AND REFUGE AREA

D-4.1 Horizontal Exit

A horizontal exit should be through a fire door of 120 min rating in a fire resistant wall. Horizontal exit require separation with the adjoining compartment through 120 min fire barrier. The adjoining compartment of the horizontal exit should allow unlocked and ease of egress and exits for the occupants using defend in place strategy.

Requirements of horizontal exits are as under:

- a) Width of horizontal exit doorway should be suitable to meet the occupant load factor for egress;
- b) Doors in horizontal exits should be openable at all times from both sides; and
- c) All doors should swing in the direction of exit travel. For horizontal exits, if a double leaf door is used, the right hand door leaf should swing in the direction of exit travel.

D-4.2 Refuge Space/Area

a) Refuge spaces and refuge areas are provided for occupants staging requirements and also enabling assisted evacuation. The aspect of staging and refuge requirements should be planned in the building for people with disabilities and ailments, including specific assistance required for certain section of occupants based on their age and other challenges for self-evacuation.

b) Refuge spaces should be achieved by adequate planning and consideration of space provided in the lift lobby of firefighting shaft, enabling the staging for such occupants and further assisted evacuation through fireman lift in the firefighting shaft. This should enable these occupants to be assisted evacuated by the lift and further to be brought to exit discharge through the well-planned evacuation strategy through exit passageway on the ground or level of exit discharge. Provision for such staging of the occupants should be minimum 12 m^2 or 5 percent of calculated occupants of the floor (served by that firefighting shaft) with a refuge area space of 0.45 m^2 per person in the firefighting shaft lift lobby, whichever is higher.

c) Alternate to refuge spaces, refuge areas should be provided in buildings of height more than 24 m. Refuge area provided should be planned to accommodate the occupants of two consecutive floors (this should consider occupants of the floor where refuge is provided and occupants of floor above) by considering area of 0.3 m^2 per person for the calculated number of occupants and should include additionally to accommodate one wheelchair space of an area of 0.9 m^2 for every 200 occupants and portion thereof, based on the occupant load served by the area of refuge or a minimum of 15 m^2, whichever is higher, should be provided as under:

   1) The refuge area should be provided on the periphery of the floor and open to air at least on one side protected with suitable railings.

   2) Refuge area(s) should be provided at/or immediately above 24 m and thereafter at every 15 m or so.

   The above refuge area requirement for mall-like (mix of assembly, mercantile, cinema screen and restaurant) occupancy requirement should however be in accordance with 6.4.2.2.

   3) A prominent sign bearing the words 'REFUGE AREA' should be installed at the entry of the refuge area, having height of letters of minimum 75 mm, and also containing information about the location of refuge areas on the floors above and below this floor. The same signage should also be conspicuously located within the refuge area.

   4) Each refuge area should be ventilated and provided with first aid box, fire extinguishers, public address speaker, fire man talk back, and adequate emergency lighting as well as drinking water facility.

   5) Refuge areas should be approachable from the space they serve by an accessible means of egress.

   6) Refuge areas should connect to firefighting shaft (comprising fireman's lift, lobby and staircase) without having the occupants requiring to return to the building spaces through which travel to the area of refuge occurred.

   7) The refuge area should always be kept clear. No storage of combustible products and materials, electrical and mechanical equipment, etc should be allowed in such areas.

   8) Refuge area should be provided with adequate drainage facility to maintain efficient storm water disposal.

   9) Entire refuge area should be provided with sprinklers.

   10) Where there is a difference in level between connected areas for horizontal exits, ramps of slope not steeper than 1 in 12 should be provided (and steps should be avoided).

   NOTE — Refuge area provided in excess of the requirements should be counted towards FAR.

High rise apartment buildings with apartments having balcony, need not be provided with refuge area; however, apartment buildings without balcony should provide refuge spaces or refuge areas as given above. When refuge areas are preferred over refuge spaces in apartment buildings of height above 60 m (and having balconies), the same should be provided around 60 m level and thereafter at levels around every 30 m. The refuge area should be an area equivalent to 0.3 m^2 per person for accommodating occupants of two consecutive floors, where occupant load should be derived on basis of 12.5 m^2 of gross floor area and additionally 0.9 m^2 for accommodating wheelchair requirement or should be 15 m^2, whichever is higher.

D-5 ELECTRICAL SERVICES

The specific requirements for electrical installations in multi-storeyed buildings given in Part D 'Building Services, Section 2 Electrical and Allied Installations' of this NBCS and Section 7 of National Electrical Code of India 2023 should be followed.

Wherever transformers are planned at higher floors, the HT cables should be routed through a separate shaft having its own fire resistance rating of 120 min. Wherever HT generators are planned centrally at ground or first basement level, redundant transformers and HT cables should be planned for buildings above 60 m in height.

D-6 FIRE PROTECTION

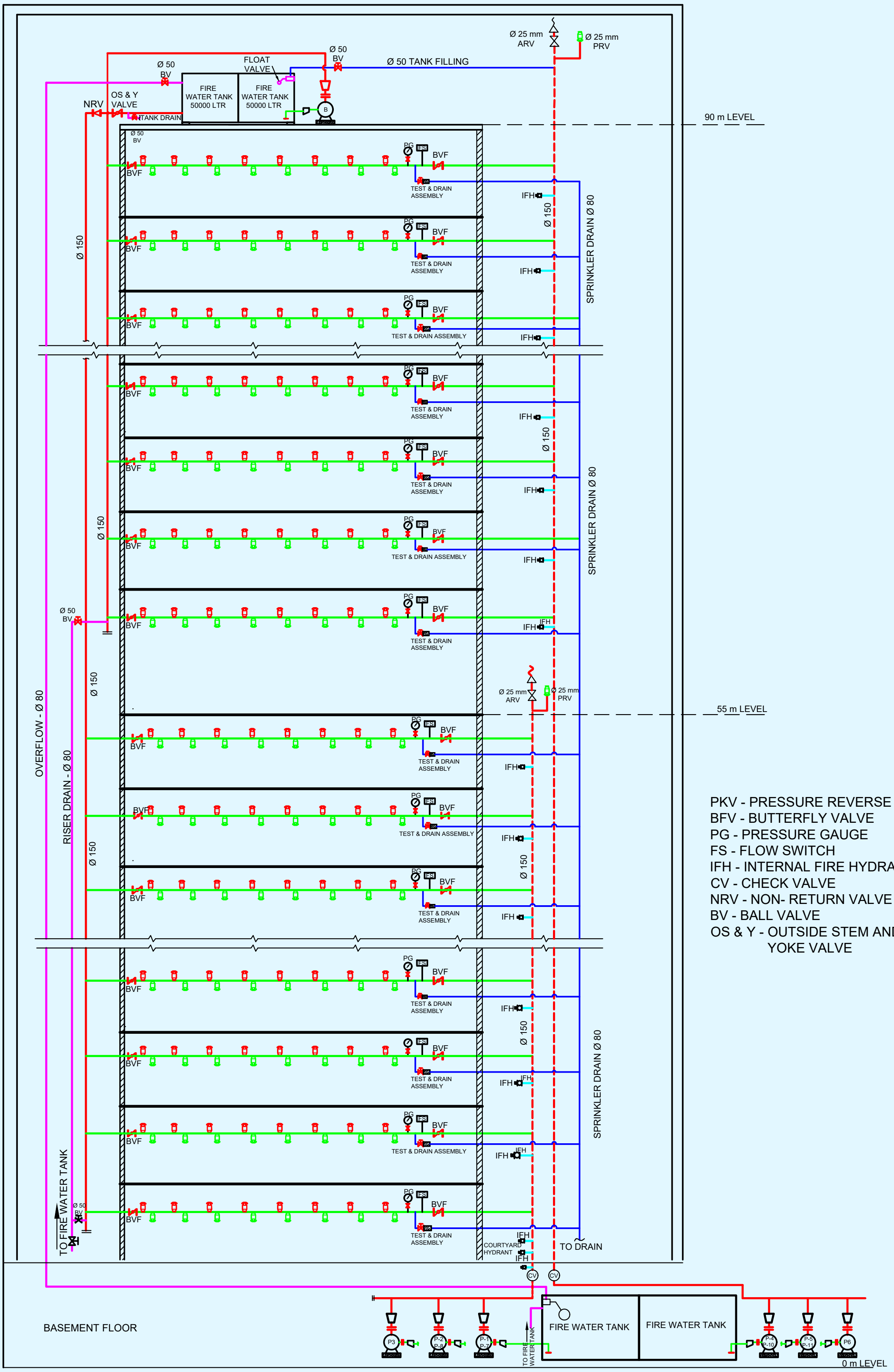
D-6.1 For residential occupancies above 120 m in height and other occupancies above 60 m in height, the sprinklers should be fed from the main and an alternate/standby riser with suitable isolation valves. The entire sprinkler system should be designed in accordance with good practice [F(20)].

D-6.2 Where the height of the building exceeds 150 m to 175 m, fire water static storage and pumps should be required to be provided at 160 m to 180 m and thereafter at intermediate floors at higher levels enabling efficient and functional firefighting installations. The static fire water storage tanks located at such levels should have capacity at minimum half of the storage of underground static water storage tank as in. Such tanks should be supplemented with water supplies through one working and one standby pump of capacity 2 850 litre/min with two risers at alternate locations feeding to such fire water static storage tanks. The fire pump's requirement and capacity should also be derived for occupancy type as per Table 7A and Table 7J substituting the diesel pump with electrical pump. The fire pump room at such level should have dedicated connectivity through passageway (with 120 min integrity) from the firefighting shaft. Such fire pump room should have 120 min fire resisting wall and provided with adequate ventilation with talk-back connectivity to the main fire pump room and Fire Command Centre.

D-6.3 As an alternative to bottom-fed and standpipe and sprinkler that rely on pumps, in high rise buildings, water can be fed by gravity based tanks located at such levels along the height of the building designed to cater to the stories located 55 m to 60 m below. *See* Fig. 20 and Fig. 21 for guidance/details regarding sizing of pipes and achieving the desired pressure and capacity/volume {as suggested in [F(29)]} to cater respectively to the hydrants and the sprinklers. It is recommended to have the top-most tank having dual risers each connecting to different tank. A cross connection with isolation valve at the top and bottom of the dual risers is recommended.

Repeater tanks provided at higher stories can also be designed to fill the tank below, should the need arise. The top-most tank should have additional capacity (50 percent) to cater to the tank below. Overflow pipes can feed the tank below and designed accordingly. This system is particularly preferred in the case of single tower high rise building. *See* Fig. 20 and Fig. 21 for details.

D-6.4 For high rise buildings, seismic bracings should be considered for firefighting installations depending on seismic vulnerability of the region and the type of occupancy.


Ø 25 mm
ARV
Ø 25 mm
PRV
Ø 50
BV
Ø 50 TANK FILLING
FLOAT
VALVE
Ø 50
BV
FIRE
WATER TANK
50000 LTR
FIRE
WATER TANK
50000 LTR
OS & Y
VALVE
NRV
TANK DRAIN
Ø 50
BV
90 m LEVEL
PG
FS
BVF
TEST & DRAIN
ASSEMBLY
IFH
Ø 150
SPRINKLER DRAIN Ø 80
Ø 150
TEST & DRAIN ASSEMBLY
Ø 150
Ø 50
BV
Ø 150
Ø 25 mm
ARV
Ø 25 mm
PRV
55 m LEVEL
OVERFLOW - Ø 80
RISER DRAIN - Ø 80
Ø 150
Ø 150
Ø 150
SPRINKLER DRAIN Ø 80
TO FIRE WATER TANK
Ø 50
BV
COURTYARD
HYDRANT
TO DRAIN
CV
CV
BASEMENT FLOOR
P3
P-2
P-1
TO FIRE WATER TANK
FIRE WATER TANK
FIRE WATER TANK
P6
0 m LEVEL

PKV - PRESSURE REVERSE VALVE
BFV - BUTTERFLY VALVE
PG - PRESSURE GAUGE
FS - FLOW SWITCH
IFH - INTERNAL FIRE HYDRANT
CV - CHECK VALVE
NRV - NON- RETURN VALVE
BV - BALL VALVE
OS & Y - OUTSIDE STEM AND
YOKE VALVE

FIG. 20 SCHEMATIC OF GRAVITY BASED FEED FOR 55 M TO 90 M (CONTINUED)

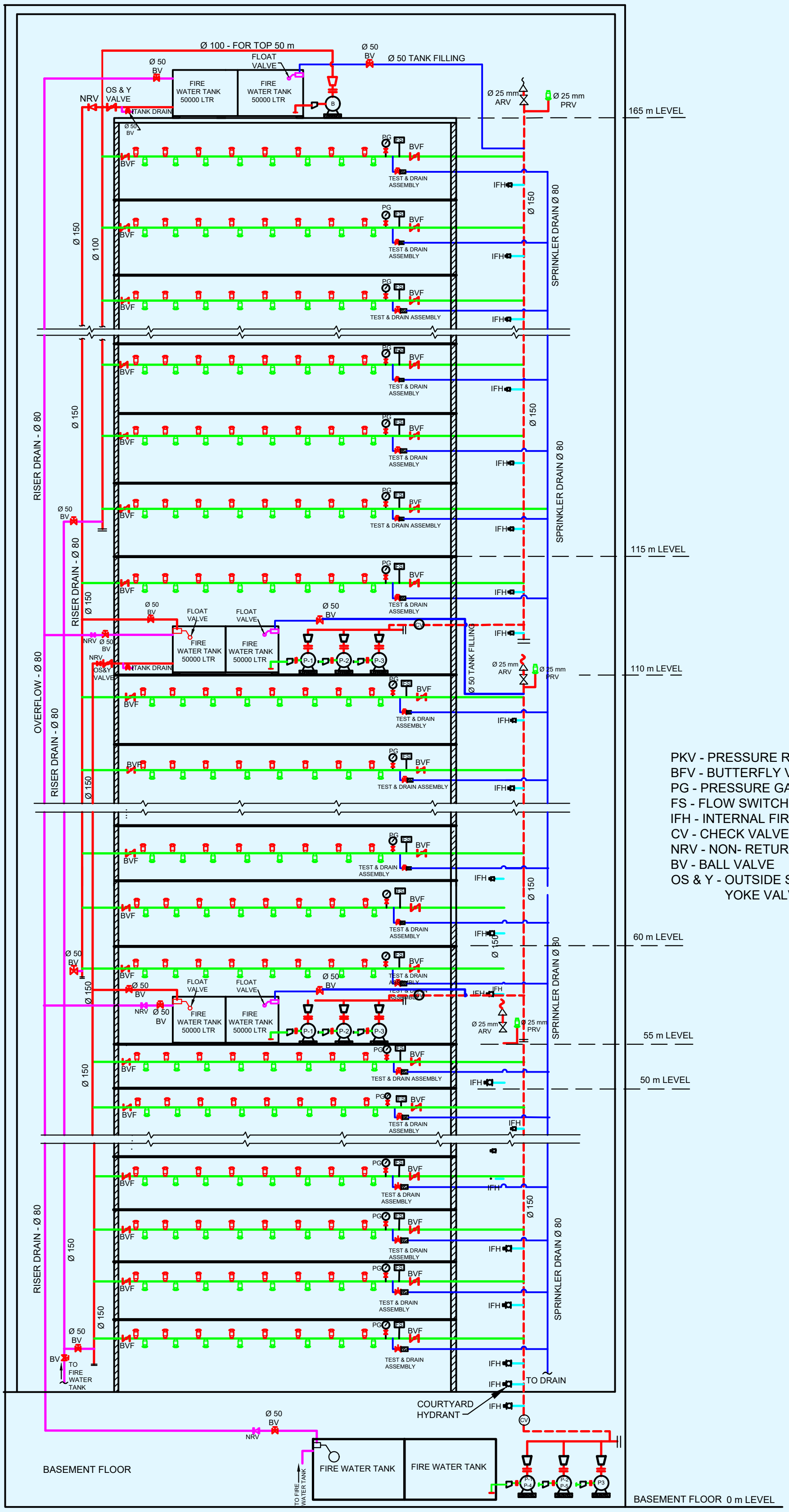
EQUIPMENT DATA:

PUMP	P-1	P-2	P-3
DESIGNATION	COMMON STANDBY PUMB	COMMON MAIN PUMP	COMMON JOCEKY PUMP
CAPACITY	2 850 lpm	2 850 lpm	180 lpm
HEAD	10 bar	10 bar	10 bar
MODE OF OPERATION	AUTO START and MANUAL START/STOP	AUTO START and MANUAL START/STOP	AUTO START/STOP
DS	DIESEL STAND BY		
SE	STAND BY ELECTRICAL PUMP		
ME	MAIN ELECTRICAL PUMP		
JE	JOCKEY ELECTRICAL		
B	BOOSTER PUMP		

PUMP	P-4	P-5	P-6
DESIGNATION	COMMON STANDBY PUMB	COMMON MAIN PUMP	COMMON JOCEKY PUMP
CAPACITY	2 850 lpm	2 850 lpm	180 lpm
HEAD	15 bar	15 bar	15 bar
MODE OF OPERATION	AUTO START and MANUAL START/STOP	AUTO START and MANUAL START/STOP	AUTO START/STOP
DS	DIESEL STAND BY		
SE	STAND BY ELECTRICAL PUMP		
ME	MAIN ELECTRICAL PUMP		
JE	JOCKEY ELECTRICAL		
B	BOOSTER PUMP		

PUMP	B
DESIGNATION	BOOSTER PUMP
CAPACITY	900 LPM
HEAD	4.5 BAR

FIG. 20 DETAILS OF EQUIPMENT FOR FIGURE 55 M TO 90 M ABOVE


Ø 100 - FOR TOP 50 m
Ø 50 BV
FLOAT VALVE
Ø 50 BV
Ø 50 TANK FILLING
FIRE WATER TANK 50000 LTR
FIRE WATER TANK 50000 LTR
OS & Y VALVE
NRV
TANK DRAIN
Ø 25 mm ARV
Ø 25 mm PRV
165 m LEVEL
PG
BVF
TEST & DRAIN ASSEMBLY
IFH
Ø 150
Ø 100
SPRINKLER DRAIN Ø 80
RISER DRAIN - Ø 80
115 m LEVEL
110 m LEVEL
OVERFLOW - Ø 80
Ø 50 TANK FILLING
P-1
P-2
P-3
OS&Y VALVE
60 m LEVEL
55 m LEVEL
50 m LEVEL
TO FIRE WATER TANK
TO DRAIN
COURTYARD HYDRANT
CV
BASEMENT FLOOR
FIRE WATER TANK
FIRE WATER TANK
TO FIRE WATER TANK
P1
P2
P3
BASEMENT FLOOR 0 m LEVEL

PKV - PRESSURE REVERSE VALVE
BFV - BUTTERFLY VALVE
PG - PRESSURE GAUGE
FS - FLOW SWITCH
IFH - INTERNAL FIRE HYDRANT
CV - CHECK VALVE
NRV - NON- RETURN VALVE
BV - BALL VALVE
OS & Y - OUTSIDE STEM AND
YOKE VALVE

FIG. 21 SCHEMATIC OF GRAVITY BASED FEED FOR 90 M AND ABOVE HIGH RISES (CONTINUED)

EQUIPMENT DATA:

PUMP	**P-1**	**P-2**	**P-3**
DESIGNATION	COMMON STANDBY PUMB	COMMON MAIN PUMP	COMMON JOCEKY PUMP
CAPACITY	2 850 lpm	2 850 lpm	180 lpm
DUTY HEAD	10 bar	10 bar	10 bar
SHUT OF HEAD	12 bar	12 bar	12 bar
MODE OF OPERATION	AUTO START and MANUAL START/STOP	AUTO START and MANUAL START/STOP	AUTO START/STOP

PUMP	**B**
DESIGNATION	BOOSTER PUMP
CAPACITY	900 LPM
HEAD	4.5 BAR

FIG. 21 SCHEMATIC OF GRAVITY BASED FEED FOR 90 M AND ABOVE HIGH RISES

D-7 FIRE AND LIFE SAFETY AUDIT

D-7.1 The following should be applicable:

a) Fire and life safety audit should be carried out for all high rise buildings;

b) Such audits should preferably be conducted by a third party auditor having requisite experience in fire and life safety inspections;

c) Frequency of such audits should be once in two years.

DI-7.2 Good practices towards fire and life safety audit should be as given below:

a) Objective is to ensure that a building's fire prevention, fire protection and life safety measures are evaluated against established Indian Standards;

b) Methodology includes: Audit planning, on-site audit execution, documentation and reporting;

c) Audit objectives to cover: compliance verification, risk identification, performance evaluation, corrective recommendations, documentation and process review;

d) Fundamental principles should be: objectivity, consistency, risk-based approach, comprehensive coverage, continuous improvement, transparency and documentation, and stakeholder involvement;

e) In the audit methodology and process the following should be adhered: planning and preparation (Pre-audit data collection, Risk assessment and prioritization techniques, Audit team composition and qualifications), Audit execution (On-site inspection procedure, documentation review and interview, checklist and performance indicators), and Audit reporting (structure and content of the report, documentation of non-compliances and recommendations, methods for risk communication);

f) Audit criteria for fire safety should be well established; covering respectively for fire prevention namely:

   1) Building design and construction features

      i) Structural fire resistance

      ii) Fire compartmentation and separation

    iii) Material selection and non-combustibility
    iv) Means of egress and access routes
    v) Integration of fire safety systems
    vi) Compliance with regulatory requirements
    vii) Documentation and verification

  2) Maintenance of fire prevention systems and housekeeping practices
    i) Regular maintenance and servicing
    ii) Housekeeping practices
    iii) Documentation and verification
    iv) Training and accountability;

g) Audit criteria for fire safety should be well established; covering respectively for fire protection systems namely:

  1) Assessment of fire detection and alarm systems
    i) Design and installation compliance
    ii) Function performance and testing
    iii) Maintenance and calibration
    iv) Integration with emergency systems
    v) Documentation and compliance verification

  2) Inspection of fire suppression systems
    i) Design and installation compliance
    ii) Operational testing and performance
    iii) Maintenance and inspection records
    iv) Integration with fire safety systems
    v) Physical condition and accessibility
    vi) Compliance with regulatory and manufacturer specifications

  3) Evaluation of emergency lighting signage
    i) Design and installation compliance
    ii) Visibility and illumination levels
    iii) Operational performance
    iv) Maintenance and inspection
    v) Integration with overall safety systems
    vi) Documentation and compliance verification

  4) Evaluation of life safety components
    i) Assessment of exit routes, corridors and stairways
      - Design and layout
      - Unobstructed passage
      - Dimensions and capacity
      - Signage and emergency lighting
      - Physical condition and maintenance

      - Special provisions
      - Documentation and verification
    - ii) Verification of occupant load, exit capacities and travel distances
      - Occupant load verification
      - Assessment of exit capacities
      - Measurement of travel distances
      - Integration and documentation
      - Assessment of portable and wheeled fire extinguisher;

h) Audit criteria for life safety should be well established to cover:
  1) Structural and environment safety
    i) Evaluation of structural fire resistance and compartmentation
    ii) Assessment of emergency communication systems and evacuation aids
  2) Accessibility and special needs
    i) Consideration for persons with disabilities
    ii) Audit of assisted evacuation procedures;

j) Performance indicators and compliance assessment – To address:
  1) Scoring and rating methodologies for audit findings
  2) Risk evaluation and prioritization of deficiencies
  3) Criteria for Compliance/Partial Compliance/Non-Compliance;

k) Corrective actions and follow-up are essential so as to provide opportunity to the building owner/resident to address the shortfall so as to make the premises safe; and

m) Reporting and record keeping – To have standard formats/templates to record observations, measurements including photographs stored in compatible formats, all with a view to enable suitable reviewing for consistency.

D-8 HELIPAD

For high rise buildings above 200 m in height, provision for helipad is recommended for specific requirements like landing of fire equipment, and support facilities or other emergencies.

Suitable fire protection is required for the helipad areas to enable their safe usage at all times. The firefighting facilities for rooftop helipad includes fire detection, fixed or portable firefighting foam system (oscillating foam monitor, deck integrated foam nozzles or portable foam units), fire hydrants and trained response team.

Low expansion aqueous film forming foam (AFFF) can be applied to the helideck from either fixed nozzles or an oscillating nozzle, particularly on the landing pad, at the rate of 10 lpm per square foot for a duration of 10 min.

Without the requirement for any additional water, buildings having helipad should use the water available for wet riser, sprinkler system, etc for foam based fire protection. This can be achieved by a suitable tee connection in the standpipe by attaching a 100 mm or 150 mm deluge valve (to control the flow of water) and extending a 100 mm or 150 mm water line from that valve, to the foam producing equipment located near (outside) the helipad area.

ANNEX E

(*Clauses* 4.5.3.4, 6 *and Table* 6)

ATRIUM

E-1 ATRIUM REQUIREMENTS

a) In order for an atrium to be permitted in buildings, the following should be complied with:

   1) Atrium should be permitted in buildings of Type 1 and Type 2 construction only.

   2) The use of combustible furnishings and decorations on the floor of the atrium should be limited and sparsely distributed.

b) Smoke detectors (preferably beam type or aspirating type) should be provided on the underside of each floor protruding into the atrium, at the atrium roof and adjacent to each return air intake from the atrium. Within atrium space, beam type or aspirating type smoke detectors should be used to ensure detection of smoke, considering factors such as stratification of smoke.

c) Where the ceiling of the atrium is more than 17 m above the floor, water based protection (automatic sprinklers) at the ceiling of atrium is not required. In such case, travel distance allowance should be as applicable for sprinkler spaces.

d) Hydrants should be available at the floor of the atrium and also at the adjoining upper spaces/floors of the atrium. Sprinklers are required to be installed for coverage of glass areas of retail, tenant and other areas adjoining the exit access corridor and atrium. Sprinklers should be at a distance of 450 mm to 600 mm enabling cooling of such glass and limiting the extent of fire and smoke to the atrium (*see* Fig. 22). This provision does not allow similar sprinkler installation arrangement to offset fire compartmentation requirements, in which case fire barrier is required as per relevant provisions of this Part.

e) Atrium in business occupancy should be planned with 6 air changes per hour (ACPH) while atrium in hotels and assembly occupancy should be planned with 8 ACPH smoke extraction system.

f) Such air changes should be planned in atrium for a height of 15 m from the top.

g) Smoke exhaust fans should be capable of operating effectively at 250 °C for 120 min.

h) Makeup air supply points should be located beneath the smoke layer and on the lower levels connected by the atrium.

j) Makeup air should be provided by fans, openings to outside to allow infiltration, or the combination thereof.

k) It is recommended that makeup air be designed at 85 percent to 95 percent of the exhaust flow rate, not including the leakage through these small paths.

m) The makeup air should not cause door-opening force to exceed allowable limits.

n) The makeup air velocity should not exceed 1.02 m/s is where the makeup air could come into contact with the plume unless a higher makeup air velocity is supported by engineering analysis;

p) Atrium smoke management system fans should be provided with emergency power.

q) If so, required by the Authority, an engineering analysis should be performed which demonstrates that the smoke system for the atrium is designed to keep the smoke layer interface 1 800 mm above the highest occupied floor level of exit access, open to the atrium, for a period equal to 1.5 times the calculated egress time or 20 min, whichever is greater.

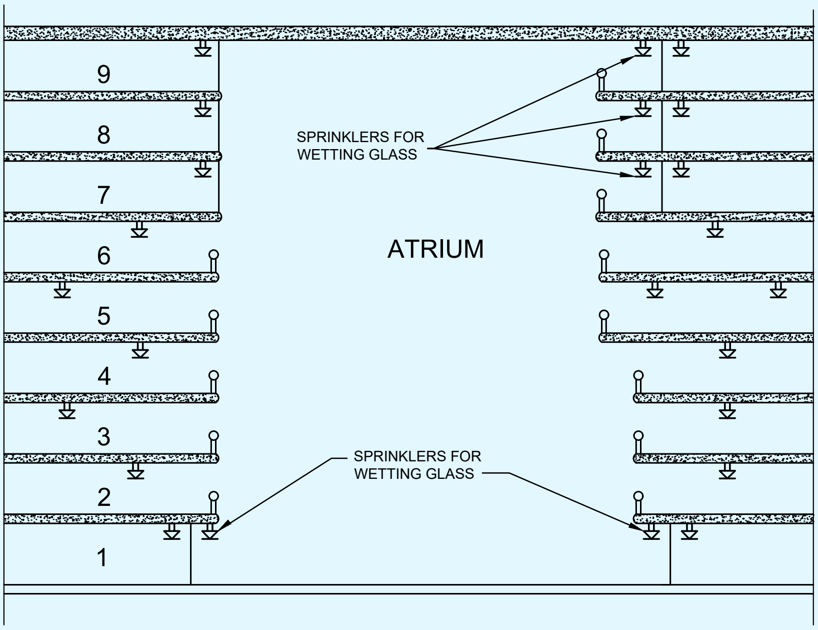


FIG. 22 SPRINKLER PROTECTION OF GLASS FOR FLOOR OPEN TO ATRIUM

ANNEX F

(*Clause* 6)

REQUIREMENTS FOR DATA CENTRES

F-1 GENERAL

Data centres are classified under Group E Business occupancy and in particular as E-II sub-occupancy considering its primary use, scale, and presence of process equipment. A comprehensive fire risk assessment should be conducted at the planning stage and periodically during operation. Assessments must include ignition sources, fire load, electrical risks, HVAC systems, etc. For guidance on the facilities and infrastructure of datacentres, refer to the following good practices.

IS/ISO/IEC 22237-1 : 2021	Information technology – Data centre facilities and infrastructures: Part 1 General concepts
IS/ISO/IEC 22237-3 : 2021	Information technology – Data centre facilities and infrastructures: Part 3 Power distribution
IS/ISO/IEC 22237-4 : 2021	Information technology – Data centre facilities and infrastructures: Part 4 Environmental control

F-2 BUILDING DESIGN AND CONSTRUCTION

F-2.1 The fire resistance rating for the structural and non-structural elements should be based on guidelines as per approved and accepted standards. The fire rating should be validated and certified with a view to meeting the requirements of Table 1. In the absence of any validated/certified rating, guidance may be obtained from the information available in Annex C.

F-2.2 An anti-static floor system is highly recommended to prevent electrostatic discharge and support cable management. The data centre must be completely isolated from dust, water, vibration, and humidity. All external openings should be sealed, and no water sources or pipelines should be routed through or above the data centre, UPS room, or communications room to eliminate risks of leakage or moisture intrusion. However, any location of chillers at higher heights be opted considering the operational efficiency and the same should be adequately considered in the structural design; Authorities may consider exempting the increased building height in such a case. Considering the sensitivity and fire hazards, such floors should have no other occupancy or else this should be considered in the calculation of floor area ratio and height.

F-2.3 Server rooms, battery banks, fuel storage, and other high-risk areas should be physically separated using fire-rated assemblies. Cable trays and ducts openings for cable trays and ducts should be sealed with materials having fire resistance rating of the compartment.

F-2.4 The number of basements should be kept as minimum and it should not be more than 2. The basement(s) should be within the building line and their total area should not exceed the area of ground floor.

F-2.5 The parking requirement should be arrived at considering the requirement for administrative building (at 1 ECS per 100 m^2). The parking requirement for the data centre/utility building should be based on the actual required number and area (of trucks) for which additional considerations of loading and unloading spaces for services, including rack placement/replacement as advised by the OEMs, DG set, utilities, etc should be made. In addition, consideration for the fire truck and its movement should be ensured in consultation with the local Fire Authority.

F-2.6 Lifts, when planned, consider respectively for administrative building as passenger lift as per Part D/ Section 5A of this NBCS should, and for the datacentre building as special goods lifts and special service lifts, for which OEMs should be consulted considering the size, speed and weight of payload; and any required special requirement.

F-2.7 Heights of stories should be arrived at based on the size of racks opted and the associated services (like cooling/ducting) and the same is effectively addressed in the structural design. The total height of the datacentre building should be arrived based on the FAR and only Type 1 construction. Ground-coverage should ideally not exceed 60 percent considering the peculiar requirements and the essential nature of these buildings which are required in the society in the current times, and the associated moment of heavy vehicles to install/maintain/repair the racks/occupant.

NOTE — Authorities to consider also the possible change of occupancy from data centre to other permitted business as well; and the ground-coverage.

F-3 FIRE DETECTION SYSTEMS

F-3.1 Use of aspirating smoke detection system in server areas is recommended for very early detection.

F-3.2 The system should incorporate heat sensitivity and high-sensitivity smoke detectors (HSSD) to enable early fire detection and prompt activation of suppression mechanisms.

F-3.3 For other requirements on fire detection and alarm system **4.9** be referred.

F-4 FIRE SUPPRESSION SYSTEMS

F-4.1 The fire suppression system in data centres should be designed to ensure both operational continuity and protection of sensitive equipment. The preferred suppression technologies and clean agent extinguishers (such as heptafluoro propane, fluorinated ketone based system or equivalent) should be available throughout data hall areas. These systems should be effective in suppressing fires without leaving any residue, making them safe for electronic and electrical installations.

F-4.2 All critical areas within the data centre, including server rooms, network rooms, UPS and battery areas, and under-floor and overhead spaces, must be covered comprehensively by the fire suppression system.

F-4.3 The suppression agents should be ozone-friendly and compliant with international environmental norms. The recharge process must be easy, with minimal downtime, and the equipment should be easy to test periodically.

F-4.4 An early warning fire detection and suppression system should be integrated with the fire alarm and building management system (BMS) for real-time monitoring and response. The system should be engineered to offer reliable and quick suppression to minimize damage and downtime.

F-5 ELECTRICAL AND HVAC FIRE SAFETY (*See also* Part D/Sec 2 and Part D/Sec 3 of this NBCS)

F-5.1 UPS, transformer, and generator rooms should be separated with fire-rated partitions/doors and have independent suppression systems. Should the need arise, the generators can be placed one over the other/stacked (suggested upto 5 numbers) parallel to the data centre building, but adequate fire safety should be ensured for which OEM's advice and specialist literature should be referred.

F-5.2 Wherever batteries are provided, the same should be segregated by 120 min fire rated construction. Ventilation to the room should be provided as per manufacturer's instructions.

F-5.3 Air conditioning and ventilating systems should be so installed and maintained as to minimize the danger of spread of fire, smoke or fumes from one floor to other or from outside to any occupied building or structure.

F-5.4 Supply air ducts, fresh air and return air ducts/passages must include fire dampers and smoke detectors (*see* 3.5.7.4).

F-5.5 Insufficient power capacity design for a data centre can result in various issues such as system downtime, data loss, increased cost, reduced performance, regulatory non-compliance, etc. Ensuring a robust power capacity design is crucial for the reliable and efficient operation of data centres.

F-6 MEANS OF EGRESS

F-6.1 Exit Access

Exits should be provided on each floor or compartment in accordance with 4.4.2. All exits should be unobstructed, illuminated, and clearly marked.

F-6.2 Staircases and Corridors

Staircases must be enclosed, fire-rated, and positively pressurized to prevent smoke ingress. Staircases should be of minimum 1.5 m in width, and 2 numbers of it will be required in the datacentre building. Staircase for administrative building should be arrived at using 4; in any case, minimum 2 staircases are required.

F-6.3 Emergency Lighting and Signage

Emergency lighting consistent with emergency system for the building should be provided. Addressable emergency exit lighting system is recommended, adaptive type exit signages can also be used.

F-7 MEP, FIREFIGHTING AND SEISMIC SUPPORT REQUIREMENT

F-7.1 Earthquakes can cause downtime, data loss, service disruptions, fire, etc. Seismic bracing is essential to secure MEP equipment and systems, safeguarding them against the threats posed by earthquakes.

F-7.2 Non-structural measures focus on protecting operational components. These include seismic-rated mounting systems for equipment racks, secure cable pathways, MEP and firefighting services to avoid disconnections, and reinforced architectural features like ceilings and raised floors. These elements must meet seismic standards to ensure systems stay operational during and after an earthquake.

F-7.3 Seismic analysis/calculations should be carried out based on Part C 'Structural Design, Section 1 Loads and Load Effects' of this NBCS and good practice [F(32)]. Each non-structural component's seismic interactions with all other connected components and with the supporting structure should be accounted for in the design. The component should accommodate drifts, deflections, and relative displacements determined in accordance with the applicable seismic requirements of standards.

F-7.4 Each straight pipe/duct/cable containment run with two or more supports requires a minimum of two transverse braces (perpendicular to the run) and one longitudinal brace (parallel to the run).

F-7.5 Wire rope angular bracing should be seismic certified/tested by third party accredited lab as per method of testing for rating seismic and wind restraints. Rigid angular bracing and modular support system should be analyzed for both tensile and compressive loads for strength and serviceability for the maximum length of element being used in worst case condition as per load combination as mentioned in standards.

F-7.6 Calculate the static and dynamic loading due to wind forces that is required to select/design vibration isolators, bases and seismic and wind restraints for outdoor and roof top equipment's/services. The calculation of wind load should be as per Part C 'Structural Design, Section 1 Loads and Load Effects' of thi NBCS. Worst case between seismic loads and wind loads should be considered for supporting and vibration isolation.

F-8 SECURITY

F-8.1 It is recommended that all doors should be access controlled or should be as per best suitable secure design requirement.

F-8.2 Doors should send an alarm if left open.

F-8.3 In line with safety requirements, access should be open for the fire affected area.

F-9 OPTIONAL PERFORMANCE INDICATORS

For guidance on the performance indicators of datacentres, the following good practices may be referred.

IS/ISO/IEC 30134-1 : 2016	Information technology — Data centres — Key performance indicators: Part 1 Overview and general requirements
IS/ISO/IEC 30134-2 : 2016	Information technology — Data centres — Key performance indicators: Part 2 Power usage effectiveness (PUE)
IS/ISO/IEC 30134-3 : 2016	Information technology — Data centres — Key performance indicators: Part 3 Renewable energy factor (REF)
IS/ISO/IEC 30134-4 : 2017	Information technology — Data centres — Key performance indicators: Part 4 IT equipment energy efficiency for servers (ITEEsv)
IS/ISO/IEC 30134-5 : 2017	Information technology — Data centres — Key performance indicators: Part 5 IT equipment utilization for servers (ITEUsv)
IS/ISO/IEC 30134-6 : 2021	Information technology — Data centres — Key performance indicators: Part 6 Energy reuse factor (ERF)
IS/ISO/IEC 30134-8 : 2022	Information technology — Data centres — Key performance indicators: Part 8 Carbon usage effectiveness (CUE)
IS/ISO/IEC 30134-9 : 2022	Information technology — Data centres — Key performance indicators: Part 9 Water usage effectiveness (WUE)

ANNEX G

[*Clauses* 6.4.2.2(e) *and* 6.8.1.5]

CAR PARKING FACILITIES

G-1 The provisions given in **G-2** to **G-5** should apply to parking structures of the closed or open type, within buildings above or below grade.

G-2 GENERAL

a) Where both parking and repair operations are conducted in the same building, the entire building should comply with the requirements for Group G occupancies, unless the parking and repair sections are effectively separated by separation walls of 120 min fire rating.

b) Floor surfaces should be non-combustible, sloping towards drains to remove accumulation of water.

c) Those parts of parking structures located within, immediately above or below, attached to, or less than

3 m away from a building used for any other purpose should be separated by fire resistant walls and floors having fire resistance rating of not less than 120 min. This should exclude those incidental spaces which are occupied by cashier, attendant booth or those spaces used for toilets, with a total area not exceeding 200 m^2.

d) Vehicle ramps should not be considered as exits unless pedestrian facilities are provided.

e) Other occupancies like fuel dispensing, should not be allowed in the building. Car repair facilities, if provided, should be separated by 120 min fire resistant construction.

f) In addition to fire protection requirements as per Table 7A to Table 7J, appropriate fire detection and suppressions systems should be provided for the protection of hydraulic oil tank and pumps located below ground level for operation of car lifts.

g) Means of egress should meet the requirements specified in **4**.

G-3 OPEN PARKING STRUCTURES (INCLUDING MULTI-LEVEL PARKING AND STILT PARKING)

a) The term open parking structure specifies the degree to which the structure's exterior walls must have openings. Parking structures that meet the definition of the term open parking structure provide sufficient area in exterior walls to vent the products of combustion to a greater degree than an enclosed parking structure.

b) A parking structure having each parking level wall openings open to the atmosphere, for an area of not less than 0.4 m^2 for each linear metre of its exterior perimeter should be construed as open parking structure. Such openings should be distributed over 40 percent of the building perimeter or uniformly over two opposing sides. Interior wall lines should be at least 20 percent open, with openings distributed to provide ventilation, else, the structure should be deemed as enclosed parking structures.

NOTE — A car park located at the stilt level of a building (not open to sky) can be considered an open or an unenclosed car park if any part of the car park is within 30 m of a permanent natural ventilation opening and any one of the following is complied with towards the permanent natural ventilation requirement:

1) 50 percent of the car park perimeter should be open to permanent natural ventilation.

2) At least 75 percent of the car park perimeter is having the 50 percent natural ventilation opening.

c) All stilt parking is required to be provided with sprinkler system where such buildings are required to be sprinklered.

d) Open parking structures are not required to be provided with compartmentation.

e) Open car parking (open to sky) within building complex having fire hydrant system should also need to be protected with yard hydrant installation system in accordance with good practice [F(29)].

G-4 ENCLOSED PARKING STRUCTURES

a) Those car parking structures which are enclosed on all sides and on top, not falling within the definition of open car parking [*see* G-3(b)] and also those situated in the basements should be known as enclosed car parking structures.

b) All sprinklers in car parking should be standard response type with minimum K-factor of 80, area coverage of 9 m^2 and designed as per good practice [F(20)].

c) For smoke ventilation requirement of car parking, *see* **4.6**.

d) All fire exit doors from the car parking to exits should be painted green and should display exit signage.

G-5 AUTOMATED CAR PARKING UTILIZING MECHANICAL OR COMPUTERIZED/ ROBOTIC MEANS

a) Automated car parking structure can be of open parking type or enclosed types.

b) Automated car parking facilities pose more hazard compared to manual parking due to following reasons:

   1) High density of cars due to close stacking one over another.

   2) Lack of provision on fire separation/compartmentation horizontal or vertical leading to rapid fire spread.

    3) Non-availability of any person to notice/control the fire in initial stages.
    4) Limited access to firefighting personnel.
    5) Extensive height and depth involved with highly combustible load.

c) All basements should deploy sprinkler system with not less than K 115 quick response sprinklers, with a minimum of 2 sprinkler for each vehicle with not more than 7.2 m^2 coverage per sprinkler. The area of operation for basement sprinkler should not be less than 230 m^2. This should be applicable to both internal combustion engines (ICE) and electric battery operated or hybrid vehicles. All the sprinklers installed should be protected with a sprinkler guard.

d) All basements that deploy stack parking with one car above the other, where 2 sprinklers cannot be installed for the car below, a quick response extended coverage horizontal side wall of K 115 should be deployed. The pressure rating for this sprinkler should be based on original equipment manufacturers (OEM) recommendation based on the length and width covered. This sprinkler coverage should be within the OEM listing and approvals. Electric or hybrid car should not be parked on stack parking at any level. All the sprinklers installed should be protected with a sprinkler guard.

e) All buildings with automated puzzle parking without human interface should deploy sprinklers as applicable for normal parking. However, the riser should be limited to 24 m height, and additional risers with isolation valves should be added for each riser of 15 m thereon. This is to facilitate maintenance and isolation in case of false activation of sprinklers. All the sprinklers installed should be protected with a sprinkler guard.

f) Fire escape staircases, at least 1 250 mm wide should be provided at appropriate locations so that no place is more than 45 m from the nearest staircase. Horizontal walkways, at least 1 000 mm wide for access to all the areas should be provided at every parking level.

g) Travel distance and means of egress should be governed by the respective sections of this NBCS.

h) The hazardous areas like DG sets, transformers, HT/LT panels for the parking lot should be suitably segregated from other areas as per requirements given in this NBCS and all such areas should be protected by suitable automatic fire suppressions systems.

G-6 REQUIREMENTS FOR ELECTRIC VEHICLES (EV) CAR PARKING

See also **10.7** of Part D 'Building Services, Section 2 Electrical and Allied Installation' of this NBCS, including regarding electrical safety and location.

EV car parking are best planned in outdoors in well ventilated condition or in separate parking building at/above ground level having naturally cross-ventilated sides. Wherever EVs are designated in the regular car parking they should be segregated from other vehicles using both passive means and active measures of fire protection. The preferred locations are in the ground level and in no case below the first basement. Charging points for EVs may not be permitted below the ground level; and when permitted the same should be restricted to first basement. To enable immediate attention, the EV charging points for the EVs should be available at the entrance/first opportunity of the basement. Isolation cut-off switches (and fireman's emergency switch) should preferably be of the automated type or when manually operated should be located at the ground level also.

Active protection measure includes one or more of: water mist sprinkler system, and smart detection/monitoring system that enables early detection of thermal runaway issues that can flare up the fire should it happen. Fire suppressing materials using vermiculite/clay/mica based encapsulating agents that provide satisfactory performance may also be used.

The passive protection measures include fire rated walls (preferred over fire curtains/smoke curtains), fire doors, etc and additional protection measures to protect the structural elements from possible rising heat due to fire/hot gases. In the case of basements, maximum sizes of such a compartment for the EV parking (and charging) stations should be 1 000 m^2.

NOTE — The above provisions may be modified based on the availability of more suitable/better extinguishing media that proves effective against such fires.

ANNEX H

(*Clause* 6.4.4)

FIRE AND LIFE SAFETY REQUIREMENTS FOR METRO STATIONS

H-1 APPLICATION AND SCOPE

The provisions of this Annex relate to the buildings constructed as part of the metro stations/metro rail systems.

H-2 TERMINOLOGY — *See* **2.46**.

H-3 GENERAL

H-3.1 Classification

Metro stations can be classified under 'Assembly occupancies'. These include any station building or part thereof, permanent or temporary, through which people transit for the duration of time required to enter the building and board the train to depart the station platform or to alight from the train and depart from the station building.

H-3.2 Sub-classification

Metro rail system buildings can be further classified under the following headings:

a) Elevated and enclosed stations,

b) Elevated and open stations,

c) Underground (enclosed) stations, and

d) Train depots.

NOTE – The above includes all open and enclosed metro stations along with their associated ancillary structures and train depots. Elevated should mean to include 'at-grade' stations as well.

H-3.3 Fire Zones

Metro stations, that is, mass rapid transit, may be constructed in any Fire Zone No. 1, 2 or 3, as per the transportation requirement/policy.

H-3.4 Type of Construction

Metro stations should conform to Type 1 or Type 2 or combinations of Types 1 and 2 non-combustible constructions, as defined in **3.4**.

H-4 LIFE SAFETY REQUIREMENTS

H-4.1 Occupant Load

a) Main occupant load in a transit station is the platform occupant load, on which basis the life safety provisions of transit stations are designed. Occupant loads in transit stations are mainly a function of the train carrying capacities rather than the areas of a station.

b) For calculating platform occupant loads for a multiline, multilevel or multiplatform station, maximum occupant load for each platform should be considered separately for determining the egress capacity from that platform.

c) At levels where egress routes from separate platforms converge, occupant loads of all platforms should be considered to calculate egress capacity from that level. Simultaneous loads should be considered for all egress routes passing through each level of that station.

d) Platform occupant load should be based on the greater of the AM or PM 'peak hour loads' generated by the system and train loads.

e) Peak hour load should be converted to peak minute loads by dividing by 60 and multiplying further by a system surge factor varying from 1.3 to 1.5, as defined by the transit system authority. Surge factor may require to be further enhanced where increased footfalls are anticipated, like stations catering to sports complex, transit oriented development, and stations serving two or more lines.

NOTE — Surge factors should be based on actual calculations by transit system authority and in no case it should be less than 1.3.

f) Platform occupant load should be determined by factoring in the peak hour entraining loads at platform edges and train loads, in emergency evacuation scenario, as defined here:

  1) *Train on Fire* – It is assumed that a train loaded to crush capacity/link load as may be decided by the transit system authority, travelling in peak direction at peak hour has caught fire, and as per the operating procedure it is brought to the next station, whereupon it should require to be evacuated.

  2) The train in this case being called the 'incident train' and the platform on which it is arriving being called 'incident platform' of the 'incident station'.

  3) Passengers waiting on all the platforms of the 'incident station' should require to be evacuated as well.

  4) Number of passengers should be determined as defined in (g) below.

  5) Only one source of fire, that is, train fire should be assumed at a time.

  6) It is assumed that the train on non-incident platform should not stop at the incident station and should stop only at previous/next station.

g) Platform occupant load for emergency evacuation scenario, should be the addition of two headway entraining loads for peak direction platform, one headway entraining load for off-peak direction platforms and one crush train load/link load.

NOTE — *See* also **H-4.1**(b) and **H-4.1**(c).

h) *Occupancy in Non-public Areas*:

  1) Use of designated non-public areas by station staff whose work assignments require their presence in the station structures should be permitted.

  2) Unmanned plant rooms and any other areas where usual occupancy is less than 10 persons at any given time should be treated as unoccupied areas.

j) *Segregation with Non-transit Occupancy*:

Non-transit (and incidental) occupancies, of area up to 300 m^2 (total area of all floors), should be permitted to be accommodated within the station building. Occupant load of areas under non-transit occupancies should be in accordance with Table 2.

H-5 EGRESS PROVISIONS

H-5.1 Evacuation Time

a) *Means of Egress–public Areas* — Egress from metro station should be designed to facilitate the evacuation of a pre-defined platform occupant load to a designated point of safety in pre-defined emergency scenario(s), as defined by the transit system authority.

b) *Evacuation Time from Platform* — Enough egress capacity should be provided to evacuate the platform occupant load within 4 min from enclosed stations and within 5.5 min from open stations.

c) *Evacuation Time to Point of Safety* — Further, station design should permit evacuation of the remotest person on platform to a point of safety within 6 min in case of enclosed stations and within 8 min in case of open stations.

NOTE – Evacuation time specified in (b) and (c) may be modified based on actual engineering analysis by evaluating material heat release rates, station geometry and emergency ventilation systems.

d) For open stations where the concourse is below or protected from the platform by distance or materials as determined by an appropriate engineering analysis, that concourse should be permitted to be defined as a point of safety.

e) For enclosed stations equipped with an emergency ventilation system and where the emergency ventilation system provides protection for the concourse from exposure to the effects of a train fire at the platform as confirmed by engineering analysis, that concourse is permitted to be defined as a point of safety.

H-5.2 General Arrangement

a) Means of egress from each station platform should be provided so that they are equally distributed as far as possible, in capacity and placement, throughout the length of platform.

b) There should be at least two means of egress remote from each other.

c) Means of egress may however, be allowed to converge at concourse or subsequent levels with sufficient capacity to achieve the required evacuation time.

d) As far as possible, all the egress capacity required for emergency evacuation should be provided with the unenclosed stairs and escalators which are used for normal circulation.

H-5.3 Travel Distance

The maximum travel distance on the platform to a point at which a means of egress route leaves the platform should not be more than 100 m. This should, however be subject to fulfilling the egress requirements specified in H-5.2.

H-5.4 Means of Egress

H-5.4.1 *Non-public Areas*

Means of egress from unoccupied non-public areas should be permitted to be merged into public means of egress.

H-5.4.2 *Non-transit Occupancies*

Separate means of egress should be provided for such non-transit occupancies which are segregated from the station’s public area to ensure independent evacuation from either occupancy. Such means of egress may be allowed to converge beyond station concourse area with the approval of the competent authority. Travel distance and other egress provisions of such non-transit occupancies should be in accordance with 4.4.

H-5.4.3 *Platform*, *Corridors*, *Ramps*

Platforms, corridors and ramps serving as means of egress should be designed as per the following criteria:

a) A minimum clear width of 1 200 mm should be provided along all platforms, corridors, and ramps serving as means of egress

b) In computing the means of egress capacity available on platforms, corridors, and ramps, 300 mm should be deducted at each side wall and 450 mm should be deducted at platform edges that are open to the trainway.

c) The maximum means of egress capacity of platforms, corridors, and ramps should be computed at 0.0820 people/mm-min.

d) The maximum means of egress travel speed along platforms, corridors, and ramps should be computed at 38.0 m/min.

e) The means of egress travel speed for concourses and other areas where a lesser pedestrian density is anticipated should be computed at 60.0 m/min.

H-5.4.4 *Stairways*

a) Unenclosed stairs and escalators should be permitted to be counted as contributing to the means of egress capacity in stations.

b) Minimum widths of such unenclosed staircases should be 1 800 mm for unidirectional stairs, and 2 400 mm for bidirectional stairs.

c) Wall or floor-mounted railings on both sides should be permitted on stairs without affecting the widths stated in (b) above by more than 300 mm.

d) Enclosed stairs in the means of egress should be minimum 1 200 mm wide.

e) Capacity and travel speed for stairs should be computed at 0.0555 people/mm-min and 14.6 m/min, respectively.

H-5.4.5 *Escalators*

a) Escalators should not account for more than one-half of the means of egress capacity at any one level.

b) In calculating the egress capacity of escalators,

  1) one escalator at each level should be considered as being out of service, and

  2) the escalator chosen should be the one having the most adverse effect upon egress capacity.

c) Where escalators are permitted as a means of egress in stations, the following criteria should be complied with:

  1) The escalators should be constructed of non-combustible materials (exceptions like rollers and handrails should be permitted with intimation to the Competent Authority).

  2) Escalators running in the direction of egress should be permitted to remain operating.

  3) Escalators running in reverse to the direction of egress should be capable of being stopped either locally by a manual stopping device at the escalator or remotely by a manual stopping device at a remote location or remotely as part of a pre-planned evacuation response. A stopped escalator should be counted as equivalent to 1 m wide staircase.

d) Where provision is made for remote stopping of escalators counted as means of egress, one of the following should apply:

The stop should be delayed until it is preceded by a minimum 15 s audible signal or warning message sounded at the escalator; wherein (1) the signal or message should have a sound intensity that is at least 15 dBA above the average ambient sound level for the entire length of the escalator, (2) the signal should be distinct from the fire alarm signal, and (3) the warning message should meet audibility and intelligibility requirements.

OR

Where escalators are equipped with the necessary controls to decelerate in a controlled manner under the full rated load, the stop should be delayed for at least 5 s before beginning deceleration, and the deceleration rate should be no greater than 0.052 m/s^2.

e) Escalators with or without intermediate landings should be acceptable as a means of egress, regardless of vertical rise.

f) Escalators exposed to the outdoor environment should be provided with slip-resistant landing and floor plates.

g) Stopped escalators should be permitted to be started in the direction of egress in accordance with the requirements for stopping of escalators described in **H-5.4.5**(c)(3) and **H-5.4.5**(d).

h) Capacity and travel speed for escalators should be computed at 120 people/min and 18.5 m/min (vertical component of travel speed), respectively.

H-5.4.6 *Lifts*

Lifts meeting the following requirements should be counted as one of the means of egress in stations.

H-5.4.6.1 *Capacity of lifts*

Where lifts are counted as contributing to the means of egress capacity;

a) lifts should have a minimum of 60 min fire resistance rating;

b) they should account for no more than 50 percent of the required egress capacity;

c) at least one lift should be considered out of service, and one lift should be reserved for fire service; and

d) the capacity of each lift should be the carrying capacity of the lifts within 30 min.

H-5.4.6.2 *Holding area for lifts*

Lifts counted as one of the means of egress from any level of a station should be accessed through holding areas or lobbies at that level, which should be designed as follows:

a) The holding areas or lobbies should be separated from the platform by a smoke-tight fire separation having a fire resistance rating of at least 60 min but not less than the time required to evacuate the holding area occupant load.

b) At least one stair should be accessible from the holding area.

c) The holding area should be sized to accommodate one person per 0.2 m^2.

d) If the holding area includes portions of the platform, the area within 600 mm of the trainway should not be considered in the calculation;

e) Upon activation of smoke control in the platform or adjacent trainway areas, the holding area should be pressurized to a minimum of 25 Pa.

f) The holding area should be provided with emergency voice alarm devices with two-way communication to the system operations control centre.

H-5.4.6.3 *Design features of lifts*

Lifts counted as one of the means of egress should be designed as follows:

a) Shaft enclosures should be constructed as fire separations having a 120 min fire resistance rating.

b) The design should limit water flow into the shaft.

c) No more than two lifts used for means of egress or fire department access should share the same machine room or lift pit.

d) Machine rooms should be separated from each other by fire separation having a minimum fire resistance rating of 120 min.

e) The lifts should be connected to back-up power supply.

f) During emergency evacuation, the lifts should travel only between the incident level and a point of safety.

H-5.4.7 *Doors and Gates*

The egress capacity for doors and gates in a means of egress serving public areas should be computed as,

a) 60 people per minute (p/min) for single leaf doors and gates;

b) 0.082 people/mm-min for bi-parting multi-leaf doors and gates measured for the clear width dimension; and

c) gates in a means of egress should be designed in accordance with the requirements for doors serving as a means of egress.

H-5.4.8 *Fare Barriers*

a) Fare barriers complying with the following provisions should be permitted in the means of egress serving the stations. Such barriers should be designed to release, permitting unimpeded travel in the direction of egress under all the following conditions:

   1) Power failure or ground fault condition;

   2) Activation of the station fire alarm signal; and

   3) Manual activation from a switch in a constantly attended location in the station or operations control centre.

b) Fare barriers that do not comply with the requirements of **H-5.4.8**(a) should be permitted in the means of egress where barriers in the equipment are designed to provide egress when a horizontal force not exceeding 66 N is applied in the egress direction.

c) Gate-type fare barriers in the means of egress should meet the following criteria:

   1) Each unit should provide a minimum of 450 mm clear width at and below a height of 1 000 mm and 530 mm clear width above that height.

   2) Each unit should be credited with a capacity of 50 p/min for egress calculations.

   3) Fare barriers should be designed so that their failure to operate properly will not prohibit the movement of passengers in the direction of emergency egress.

H-5.4.9 *Horizontal Exits*

Horizontal exits should be permitted for up to 100 percent of the number of horizontal exits and required egress capacity, provided that not more than 50 percent of the number and required capacity is into a single building and provided they comply with the following provisions:

a) Width of the horizontal exit should at least be the same as that of the exit doorways.

b) A horizontal exit should be equipped with at least one fire/smoke door of a minimum 60 min fire resistance, of self-closing type. Further, it should have direct connectivity to the egress staircase for evacuation.

c) Where there is a difference in level between connected areas for horizontal exits or ramps, slope not more than 1 in 12 should be provided.

d) Doors in horizontal exits should be able to open at all times from both sides.

H-5.4.10 *Platform Screen and Edge Door*

Horizontal sliding platform screen or platform edge doors should be permitted to separate the platform from the trainway in stations, provided that the doors permit emergency egress from the train to the platform regardless of the stopping position of the train; and the doors provide egress when a force not exceeding 220 N is applied from the train side of the doors. The doors should be designed to withstand positive and negative pressures caused by passing trains.

H-5.4.11 *Access for Fire Brigade Personnel*

A dedicated access staircase for firemen should be provided in each underground station. This access should be arranged so as to provide uninterrupted access from ground level to station concourse and platform levels. If continuous access is not feasible, smoke sealed lobbies should be provided at concourse or other intermediate levels and such lobbies should be protected with fire doors of adequate rating. Firemen staircases should be maintained under positive pressure at all times.

H-5.4.12 Emergency and escape lighting and illumination of means of all exits should comply with the various provisions under **3.5.6** and **H-9**.

H-6 FIRE SEPARATION AND COMPARTMENTATION

H-6.1 Fire compartments should be provided in transit stations in accordance with the provisions of this section. Fire ratings of various occupancies within open stations and enclosed stations should be as indicated in Table 30.

H-6.2 Further transit station should be divided into fire compartments by means of compartment walls and compartment floors by a fire separation of at least 120 min between the following occupancies:

a) Public areas and non-public areas,

b) Transit and non-transit areas, and

c) Ancillary areas located beneath and within 3 m of the trainway in open stations.

H-6.3 No fire separation should be required for occupancies like ticketing offices, toilets, other offices and the like.

H-6.4 Incidental kiosks inside stations for other purposes like commercial use, etc should be provided with detection and a suitable automatic suppression system, if areas occupied by such occupancies exceed 10 m^2.

H-6.5 Fire Doors

Fire doors should comply with the following requirements:

a) Fire doors should be constructed of non-combustible material having appropriate fire resistance, and two fire doors may be fitted in an opening if each door by itself is capable of closing the opening and the two doors together achieve the required level of fire resistance.

b) All fire doors should be fitted with an automatic self-closing device, of same fire rating as the door, which is capable of closing the door from any angle and against any latch fitted to the door.

c) Any fire door fitted within an opening which is provided as a means of escape should be capable of being opened manually or by an electromagnetic or electro-mechanical device which can be activated by the presence of smoke and/or the fire alarm system, including the case of fire doors opening into pressurised exit staircases.

H-6.6 Smoke Compartmentation

a) Smoke compartments should be created to ensure that in case of a fire scenario, the escape routes are not full of smoke and a safe passage is provided to firefighters to reach the fire location.

b) Smoke barriers should be provided within the ceiling at platform and concourse levels at locations and spacing as determined by the engineering analysis and should be designed to withstand temperatures up to 250 °C for 60 min.

c) Smoke barriers should also be provided around all openings containing staircases, escalators and lifts in public areas connecting platform to levels above or below them.

d) Multiple smoke compartments catered by a combined ductwork should be provided with fire dampers for a fire barrier.

Table 30 Fire Ratings for Mass Rapid Transit Station Occupancies

(*Clause* H-6.1)

Sl No.	Occupancies	Fire Rating of Enclosures h		Fire Rating of Doors h	
		Open Station	Enclosed Station	Open Station	Enclosed Station
(1)	(2)	(3)	(4)	(5)	(6)
i)	Auxiliary substation, electrical UPS/battery room	2	2	2	2
ii)	Signalling equipment room, telecom equipment room, S&T (signalling and train control) UPS/battery room, electrical cable shafts, S&T cable shafts	2	2	1.5	1.5
iii)	Environmental control system (ECS) plant room, tunnel ventilation room, firemen's staircase, emergency equipment store, CDMA room, GSM room, sewage ejector room, sump pump room, chiller plant room, pump room, DG panel room	2	2	1.5	1.5
iv)	Station manager room, security room, stores, cleaners room, refuse storage, plumbing shafts, staff mess rooms, distribution board room and the like.	1	2	0.5	1.5

H-7 OTHER SPECIFICS REGARDING SAFETY REQUIREMENTS

a) Materials used as interior wall and ceiling and other decorative features in enclosed stations should be non-combustible.

b) For protection against intrusion of flammable and combustible liquids and flooding of underground transit systems, any structure including emergency egress or access stairs or vent or fan shaft structure utilized for ventilation of underground system should be permitted to be terminated at grade, provided that the level at which it is terminated is at least 450 mm above the surrounding ground level/footpath level.

c) Emergency ventilation fans, their motors, and all related components exposed to the exhaust airflow should be rated for 250 °C for a minimum of 120 min. Emergency ventilation fans should be connected to a secondary power supply.

d) Operation of the emergency ventilation system components should be initiated from the central supervising station.

e) All types of kiosks like ticketing booth, information counter, commercial, if any, etc, should be constructed with non-combustible materials.

f) Stations should be provided with power supply as per **H-8**.

g) Emergency lighting should be provided throughout the station as per **3.5.6.1** and **H-9**.

h) Voice evacuation/public address system should be provided throughout the station, and ancillary buildings as per requirements.

j) Equipment rooms should be protected by fire suppression systems as per relevant standards.

k) Emergency command centres and emergency response procedures should be in place.

m) Evacuation should take place under the guidance and control of authorized, trained system employees or other authorized personnel as warranted under an emergency situation.

n) Adequate warning signs, directional signs, exit signs should be provided throughout the facility.

H-8 POWER SUPPLY SYSTEM

H-8.1 General

The auxiliary substation at metro stations can be provided at any location, for example, ground level, concourse level, platform level, etc. The access for dismantling and replacement in future and ease of operation and maintenance of the equipment are to be ensured.

H-8.2 Uninterrupted Power Supply (UPS) System

The UPS should be an online parallel redundant system with battery backup for emergency power supply. The batteries should provide backup for a minimum 90 min. If, DG set power backup to UPS is provided, the battery backup time should be suitably selected.

H-8.3 Back-up or Emergency Power Supply

a) The back-up/emergency power supply should have a capacity to cater all critical loads such as emergency lighting, protective signalling system, communication system, station control room/fire command centre, lifts providing required egress capacity, etc.

b) Power supply to these systems and equipment should be from normal and emergency (standby generator power sources with changeover facility).

c) If the power supply is taken from HT source and HT generation, the transformer should be selected with standby capacity to ensure continuity of power supply to such systems. Where parallel HV/LV supply from a separate independent source is provided with appropriate transformer for emergency, the provision of diesel generator for emergency supply may be waived off at the discretion of metro Authority. In such a scenario, in case of failure of mains power, the transfer to emergency power supply should be automatic and within 10 s for ensuring uninterrupted supply to emergency systems.

H-8.4 Cables

a) Fire resistant/survival, low smoke zero halogen, copper conductor, armoured, cross linked polyethylene (XLPE) insulated cables should be used at enclosed stations for fire and life safety equipment like fire alarm system (FAS), tunnel ventilation fans, smoke extraction fans, staircase pressurization fans, fire pumps, emergency lighting, etc.

b) All cables and wiring used for fire and life safety equipment should have a 3 h fire survival capability at 950 °C.

c) For all other essential services at enclosed stations like chillers, AHU, normal lighting, chilled water pumps etc. flame retardant, low smoke zero-halogen (LSZH), armoured, XLPE insulated aluminium/copper conductor cables should be used.

d) At open stations, flame retardant, low smoke halogen free (FRLSH), armoured, XLPE insulated aluminium/copper conductor cables should be used for power supply.

H-9 EMERGENCY LIGHTING SYSTEM

a) LED lighting fixtures should be used for lighting at metro stations.

b) Emergency illumination should include illumination of means of egress, illuminated exit signs, and all other luminaires specified as necessary to provide required illumination. Emergency lighting systems should be designed and installed so that the failure of any illumination source cannot leave in total darkness any space that requires emergency illumination. Emergency lighting should not provide less than average of 10 lux. Minimum illumination of 10 lux should be maintained on egress route.

c) Fire resistant, low smoke and zero halogen (FS) copper conductor wires should be used for wiring of emergency lighting system at underground stations. Emergency lighting system circuit should have 3 h fire survival capability at 950 °C.

d) Out of total light fixtures installed at any station, at least 30 percent of the total lights, all uniformly distributed should be connected to emergency power source, that is, UPS.

e) Emergency lighting should be powered from a source independent of that supplying the normal lighting.

H-10 FIRE PROTECTION FACILITIES

The following requirement should apply to all open (elevated and at-grade), and enclosed metro stations and depots.

H-10.1 The details of the protection and facilities required for open (elevated and at-grade) stations and depots are given hereunder.

H-10.1.1 *Pumping Arrangements*

Each station should be provided with two pumps having a minimum discharge capacity of 1 620 litre/min with different prime movers. It is possible to provide two electrically driven pumps, if assured back-up power is available for driving the pumps. Jockey pumps having a capacity of 180 litre/min should also be provided to take care of minor system leakages, (*Also refer* to **H-10.1.9**).

H-10.1.2 *Fire Extinguishers*

a) Water CO_2 type, CO_2/ABC type fire extinguisher(s) should be provided in each platform and distributed in such a way that an the extinguisher is available within a travel distance of 30 m from any point;

b) Water CO_2 type, CO_2/ABC type fire extinguisher(s) should be provided in each concourse for every 300 m^2 floor area and distributed in such a way that an extinguishers are available within a travel distance of 30 m from any point; and

c) At least one extinguisher should be provided for each equipment room and other enclosure for every 300 m^2 floor area.

H-10.1.3 *Small Bore Hose Reels*

a) One hose reel should be provided for every 1 000 m^2 floor area of station platform or part thereof, subject to a travel distance of 30 m to the nearest hose reel.

b) One hose reel should be provided for every 1 000 m^2 floor area, concourse or part thereof subject to a travel distance of 30 m to the nearest hose reel.

c) Where equipment rooms not covered by hose reel's reach from FHCs located at concourse and platform locations, additional hose reel points should be provided to ensure its coverage.

H-10.1.4 *Fire Alarm System*

a) Fire detection system should be of the addressable type. Detectors are required to be provided only in areas where there is false ceiling(s)/ false floor(s) and areas for equipment rooms. Wherever there are false ceilings/false floors with perforation less than 70 percent, the detectors should be provided both above and below false ceiling/false floor, giving due consideration to the depth of false ceiling/flooring. In open stations, in areas having high heights and cross-ventilation, detectors will not be effective and hence it can be dispensed. Detector(s) should be provided in lift shaft(s) and escalator pit(s) also.

b) Spacing of detectors and devices should be as per [4(26)].

c) Manual call stations(s) should be provided at central location(s) on each platform (near emergency stop plunger) and at least two on the concourse, on each sidewall. When the concourse is in two halves, at least one manual call station should be provided on each side.

H-10.1.5 Inert Gas/CO_2/ *based fire Suppression System*

AIS HT, Main LT and panel supplying power to UPS, DG change-over, fire pump panel and transformers at the stations should be protected with the inert gas/ CO_2 based fire suppression system in accordance with IS 15506/ IS 15525/IS 15501/IS 15528. A suitable detection mechanism should be provided for triggering the suppression system automatically.

H-10.1.6 *Provision of Hydrants and Wet Risers*

a) Minimum two hydrants should be provided at each platform with a hose box containing two lengths of hose pipes (15 m each with a nozzle) subject to a travel distance of 30 m to reach the nearest hydrant. Location of hydrants should be staggered for better coverage. The hydrants should cover the entire length of the platform when two hose pipes are coupled to the landing valves and used. If not fully covered, additional hydrant(s) should be provided.

b) Minimum two hydrants should be provided for each concourse, including commercial area, if any, with a hose box containing two lengths of hose pipes (15 m each with a nozzle), subject to a travel distance of 30 m to reach the nearest hydrant.

c) Hydrants should be provided at each entry to the station at ground and upper levels near the staircase. At least two hydrants for parking area should be provided subject to a travel distance of 30 m to the nearest hydrant.

d) In depots, fire piping should be provided along the depot boundary as ring main. The ring main should be provided with a yard hydrant every 60 m. The building should be provided with a yard hydrant, preferably at its entry, through a branch from the ring main. The inside of the building should be provided with a number of FHCs required for coverage and maintaining a maximum travel distance of 30 m to the nearest FHC. Yard hydrant in the depot should be provided as per Table 31 through branches from ring main. Other provision(s) of fire detection and suppression in the depot should be as per Table 31.

H-10.1.7 *Automatic Sprinkler System*

Sprinklers are required to be provided only in the commercial areas and any combustible storage area within the station (also refer **H-10.1.9**). Alternatively, automatic fire suppression system instead of water-based sprinkler system, as per application, is also acceptable.

H-10.1.8 *Water Requirement*

a) For stand-alone open metro stations, exclusive water requirement for the fire protection system for the installed pumping capacity, as stated in **H-10.1.1** should be at least 50 000 litre.

b) However, when commercial areas are present within open metro stations, firefighting facilities should need augmentation as in **H-10.1.9**.

H-10.1.9 In case of other types of occupancy like commercial areas inside metro stations and combustible storage areas, if any, within open stations, the pumping/water requirement should be as per Table 32.

The volume of water stated in Table 32 should be stored in more than one interconnected compartments/tanks. Wherever existing structures are upgraded to include a commercial area and additional water requirement as per Table 32 if any, may be met by additional tank or overhead tanks as permissible by structure. Size of the main header should not be less than 150 mm diameter in all cases. Entire fire protection system should be designed and installed as per the relevant Indian Standards.

Table 31 Requirement of Firefighting Installations in Depot Building

(*Clause* H-10.1.6)

Sl No.	Name/Part of the Building	Occupancy	Fire Extinguisher	First Aid Hose Reel	Wet Riser	Down Comer	Yard Hydrant	Automatic Sprinkler System Installation	Manually Operated Electronic Fire Alarm System	Automatic Detection and Alarm System	Underground Static Water Storage Tank Combined Capacity for Wet Riser, Yard Hydrant and Sprinklers per Set of Pumps	Terrace tank over Respective Tower Terrace	Pump near Underground Static Water Storage Tank (Fire Pump) with minimum pressure of 3.5 Kg/cm^2 at Remotest Location	Pump at the Terrace Tank level with minimum pressure of 3.5 Kg/cm^2	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
i)	Live OHE areas/third rail areas (like inspection bay, workshop bay, stabling lines, auto coach washing plant, covered electrical substation, etc)	Assembly	R	R	R	NR	R	NR	R	NR	2 00 000 litre	NR	2 850 lpm main and standby electric pumps, and 180 lpm jockey pump	NR	
ii)	Areas having engineering workshops and offices [Inspection offices, workshop offices, (ETU) workshop, P-way offices, depot control centre, PPIO, other administrative offices, etc]		R	R	R	NR	R	NR	R	R		NR		NR	
iii)	Storage areas (DCOS, Store rooms, scrap yards within buildings, lubricant and any other combustible storage areas)		R	R	R	R	R	R	R	R		R (10 000 litre) For main store building		NR	

Table 31 (*Concluded*)

Sl No.	**Name/Part of the Building**	**Occupancy**	**Fire Extinguisher**	**First Aid Hose Reel**	**Wet Riser**	**Down Comer**	**Yard Hydrant**	**Automatic Sprinkler System Installation**	**Manually Operated Electronic Fire Alarm System**	**Automatic Detection and Alarm System**	**Underground Static Water Storage Tank Combined Capacity for Wet Riser, Yard Hydrant and Sprinklers per Set of Pumps**	**Terrace tank over Respective Tower Terrace**	**Pump near Underground Static Water Storage Tank (Fire Pump) with minimum pressure of 3.5 Kg/cm^2 at Remotest Location**	**Pump at the Terrace Tank level with minimum pressure of 3.5 Kg/cm^2**	**Remarks**
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
iv)	Miscellaneous areas (canteen, time office, security rooms, open scrap yards, sewage treatment plants, contractor rooms, training establishments, commercial areas, etc)		(*See* Note 2)				R	(*See* Note 2)							

R – Required NR – Not Required

NOTES

1 Automatic sprinkler system is required in every storage areas and scrap yard inside the buildings. The same wet riser pumps can be used for feeding sprinkler system, if any.

2 Miscellaneous areas or any other building structure within the depot premise (separated from other depot establishments) can be considered an individual occupancy and minimum requirements for firefighting provisions for these occupancies should be adopted as given in Table 7A to Table 7J.

Table 32 Water Capacity

(*Clause* H-10.1.9)

Sl No.	Area Occupied by Commercial Occupancies m^2	Hydrant Pump Capacity (Minimum Pressure of 3.5 kg/cm^2 at the Remotest Location) litre/min	Sprinkler Pump Capacity litre/min	Jockey Pump litre/min	Common Standby Pumps litre/min	Water Capacity litre
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	Up to and including 300	2 280	Common pump	180	2 280	75 000
ii)	More than 300 and up to 1 000	2 850	Common pump	180	2 850	1 00 000
iii)	More than 1 000	2 850	2 850	180 each	2 850	2 00 000

H-10.2 Details of Protection and Facilities Required for Enclosed Metro Stations

H-10.2.1 *Hydrant System*

a) *Pumping Arrangements* — Each station should be provided with two pumps having a minimum discharge flow rate of 2 850 litre/min with different prime movers. It is possible to provide two electrically driven pumps, if assured back-up power is available for driving the pumps. Jockey pump having a capacity of 180 litre/min should also be provided to take care of minor system leakages.

b) *Flow of Hydrant Pump* — For hydrant system, having three or more hydrants on any floor, the minimum flow rate for the most demanding horizontal hydrant should be 2 850 litre/min.

c) *Requirement of Residual Pressure at Remotest Hydrant* — Hydraulically designed hydrant system should be designed to provide the water flow rate required at a minimum residual pressure of 7 bar at the remotest located hydrant.

d) *Flow of each Hydrant* — A hydraulically designed hydrant system supplying three or more hydrants on any floor, hydraulic calculations and pipe sizes should be calculated by providing 946 litre/min at the three most remote hydrants and at the minimum residual pressure of 7 bar.

e) *Water Requirement for Hydrant System* — The minimum water supply should be capable of providing the system demand for at least 60 min.

f) *Orifice plate* — Required to be installed when the static pressure at the hydrant exceeds 12.1 kg/cm^2.

g) *Distance of Fire Hydrant* (*FHC*) — FHC should be provided with hose box containing two lengths of hose pipes (15 m each with a nozzle). The travel distance to any hydrant should not exceed 30 m.

H-10.2.2 *Manual Medium Velocity Spray Nozzle Systems*

a) *Design Density* — A general range of water spray application rates that should apply to most ordinary combustible solids or liquids should be from 6.1 lpm/m^2 to 20.4 lpm/m^2 of protected surface.

b) The horizontal distance between spray nozzles/open head sprinklers should not exceed 2.5 m.

c) *Water Requirement for Spray System* — The water supply duration for an exposure protection sprinkler system should be for a minimum of 60 min.

H-10.2.3 *Water Requirement*

The enclosed station should be provided with water storage of 2 00 000 litre capacity. The underground fire water storage tanks should not be more than 7 m in depth from the level having fire brigade draw-out connection, while the draw-out connection should not be more than 5 m away from tank wall. In case any of the above criteria could not be met, one additional booster pump of suitable rating should be provided to support fire brigade vehicle for proper suction of water from the tank.

H-10.2.4 *Fire Extinguishers — See* **H-10.1.2**

H-10.2.5 *Inert Gas/CO$_2$ based Fire Suppression System — See* **H-10.1.5**

H-10.2.6 *Automatic Sprinkler System* **—** *See* **H-10.1.7**

H-10.2.7 *Station Control Room/Fire Command Centre*

a) The station control room should have the main fire alarm panel with communication system (suitable public address system) to aid floors and facilities for receiving the message from different floors.

b) Fire command centre (FCC)/station control room (SCR) should be provided with emergency lighting. All controls and monitoring of fire alarm systems, pressurization systems, smoke management systems should be done from FCC/SCR. Monitoring of integrated building management systems, CCTVs or any other critical parameters in building may also be from the FCC/SCR.

c) Details of all floor plans along with the details of firefighting equipment and installations (2 sets laminated and bound) should be maintained in fire command centre.

H-10.2.8 *Fire Alarm System*

An addressable fire detection and alarm system should be provided. Major components of fire alarm system should be as per IS 2189 and as specified herein :

a) *FACP Battery Backup*

FACP should have provision of battery for power backup in case of power failure.

The secondary power supply should have sufficient capacity to operate the system under quiescent load (system operating in a non-alarm condition) for a minimum of 24 h and, at the end of that period, should be capable of operating all alarm notification appliances used for evacuation or to direct aid to the location of an emergency for 5 min.

Battery calculations should include a minimum 20 percent safety margin above the calculated required amp-hour capacity.

In case of availability of emergency generator or two reliable sources of power supply from two separate transformers, 4 h of power backup may be taken in place of 24 h.

b) *Response Indicator*

Generally, response indicators are provided to identify the location of detectors which are installed at unapproachable/concealed locations. Response indicator should not be provided with addressable type fire alarm system.

H-11 STATION SMOKE MANAGEMENT SYSTEM

H-11.1 The subsequent clauses give the requirement of smoke extraction and smoke purging system required in enclosed metro stations. Smoke management system is not required for open (elevated and at-grade) stations.

H-11.2 Station Public Area Smoke Extraction Systems

Station public area should be provided with active smoke extraction system to maintain tenable environment for the time required for safe evacuation of passenger(s).

The smoke extraction system should be an engineered smoke control system and its design should be based on the following:

a) *Fire size*

The capacity of the engineered smoke extraction system should be calculated based on the incidence of a likely minimum baggage fire size of 1 MW.

b) *Smoke clear height*

The design smoke clear height should be above the heads of people escaping beneath it. The minimum height should be 2.0 m.

c) *Perforated ceiling*

For cases where the smoke reservoir is above the false ceiling, the ceiling should be of perforated type with at least 70 percent opening.

d) *Makeup air*

Makeup air should be drawn directly from the external space/air shaft, through inlet air ventilators or door-ways.

e) *Mode of activation*

1) *Automatic activation*

The engineered smoke extraction system should have provision of automatic activation by smoke detectors located in the fire zone. Use of smoke detectors for activation should be carefully designed, so that accidental or premature activation of smoke detectors in a non-fire zone (due to smoke spills or spread from other areas) are avoided.

2) *Manual activation*

A remote manual activation and control switches, as well as visual indication of the operation status of the smoke ventilation system, should also be provided at the station control room (SCR).

f) *Interlocking with other systems*

1) Except for smoke extraction system, all other air conditioning and mechanical ventilation systems within the areas served should be shut down automatically upon activation of the smoke extraction system.

g) *Standby fans/multiple fans*

Either a standby fan or multiple fans with excess capacity should be provided for each mechanical smoke extraction system, such that in the event the duty fan or the largest capacity fan fails, the required smoke extraction rate will still be met. The standby fan should be automatically activated in the event the duty fan fails.

h) Emergency ventilation fans, their motors, and all related components exposed to the exhaust airflow should be rated for 250 °C for a minimum of 120 min. Emergency ventilation fans should be connected to a secondary power supply.

H-11.3 Smoke Purging System

a) For extraction of cold smoke after the extinguishing of fire, smoke purging system should be provided.

b) Smoke purging system should be provided in the following areas of underground station:

1) Station control room;

2) S and T rooms;

3) Fire pump rooms;

4) UPS rooms; and

5) Auxiliary sub-station.

For other back of house rooms, normal ventilation system may be utilized to remove the cold smoke.

c) *Design of smoke purging system*

Smoke purging system, where provided in station and ancillary building, should comply with all the following requirements:

1) The smoke purging system need not be a dedicated system.
2) The purging system should have purge rate of not less than 9 air changes per hour (ACPH) or room ventilation ACPH, whichever is higher.
3) Makeup air should be drawn from adjacent area or corridor free from smoke or can be supplied by a separate mechanical system.
4) Smoke purging fans, their motors, and all related components exposed to the exhaust airflow should be fire rated and designed to operate in smoke of 250°C for a minimum of 120 min. Smoke purging fans should be connected to a secondary power supply.
5) In case of smoke/fire in entries subway, it should be rendered out of use and evacuation should be dealt procedurally.

H-11.4 Tenability Criteria

A tenable environment should be maintained in the path of egress. The tenability criteria considerations are given hereunder:

a) Smoke obstruction:
   1) Internally illuminated signage (80 lux) discernible at 30 m.
   2) Walls and doors or externally illuminated signage discernible at 10 m.
b) Heat effects:
   1) Exposure temperature (occupied zone) ≤ 60 °C for 10 min.
   2) Radiant heat exposure ≤ 2.5 kW/m^2
c) Carbon monoxide – The smoke extraction system to be designed to maintain fractional effective dose (FED) of less than 0.3. The permissible exposure to carbon monoxide should be as per following table:

Sl No. (1)	*Time* min (2)	*Maximum Carbon Monoxide Exposure* ppm (3)
i)	4	1 706
ii)	6	1 138
iii)	10	683
iv)	15	455
v)	30	228
vi)	60	114
vii)	240	28

d) Velocity – Air velocity should be greater than or equal to 0.75 m/s and less than or equal to 11 m/s along the path of egress.
e) Noise – Noise level along the path of egress should not exceed 85 dBA at any point 1.5 m above walking surface.

ANNEX J

(*Clause* 6.4.4)

FIRE AND LIFE SAFETY REQUIREMENTS FOR METRO TRAINWAYS

J-1 APPLICATION

Provisions of this Annex should apply to all portions of underground, elevated and at-grade metro trainway including tail buffer tracks and sidings not intended to be occupied by the passengers. These provisions may be amended, if required, as per the approval of the Competent Authority.

J-2 USE AND OCCUPANCY

J-2.1 Passengers should be allowed to enter the trainway only in the case it becomes necessary to evacuate a train.

J-2.2 Passenger evacuation from train onto the trainway should take place only under the guidance and control of authorized, trained system employee or other authorized personnel as warranted under an emergency situation.

J-2.3 Warning signs in accordance with **J-4.4.1** should be posted at locations where unauthorized personnel might trespass.

J-3 CONSTRUCTION

J-3.1 Construction Type

J-3.1.1 *Cut and Cover*

Where trainways are to be constructed by cut and cover method, perimeter walls, base and roof slabs and other related constructions should be of not less than Type 1 or Type 2 or combination of Types 1 and 2 non-combustible constructions as defined in this Part. The type of construction should be further determined by an engineering analysis of potential fire exposure hazards to the structure.

J-3.1.2 *Bored Tunnels*

Where trainway sections are to be constructed by a tunnelling method through earth, unprotected steel liners, reinforced concrete, shotcrete, or equivalent should be permitted to be used.

J-3.1.3 *Rock Tunnels*

Where trainway sections are to be constructed by a tunneling method through rock, steel bents with concrete liner, if lining is required, should be permitted to be used.

J-3.1.4 *Underwater Tunnels*

Underwater tunnels should be not less than Type 2 construction.

J-3.1.5 *Mid Tunnel Ventilation Shaft and Trainway Exit structures*

Mid tunnel ventilation shafts and trainway emergency egress or access stairs should not be less than Type 1 construction.

J-3.1.6 *At-Grade Construction*

Materials used for at-grade construction should not be less than Type 2 materials. The type of construction should be further determined by an engineering analysis of potential fire exposure hazards to the structure.

J-3.1.7 *Elevated Viaduct or Portals*

All elevated structures necessary for trainway support and all structures and enclosures on or under the trainway should be of not less than Type 1 or Type 2 or combination of Type 1 and Type 2 construction. The type of construction should be further determined by an engineering analysis of potential fire exposure hazards to the structure.

J-3.2 Protection against Intrusion of Flammable and Combustible Liquids and Flooding of Enclosed Trainway

Any structure including emergency egress or access stairs or vent or fan shaft structure utilized for ventilation of underground system should be permitted to be terminated at grade, provided that the level at which it is terminated is at least 450 mm above the surrounding ground level/footpath level.

J-3.3 Compartmentation

J-3.3.1 Ancillary areas should be separated from trainway areas within underwater trainway sections by construction having a minimum 180 min fire resistance rating.

J-3.3.2 Ancillary areas should be separated from trainway areas within enclosed trainway sections by construction having a minimum 120 min fire resistance rating.

J-3.4 Combustible Components

Where combustible components not specifically mentioned here are installed in a trainway, a fire hazard analysis should be conducted to determine that the level of occupant fire safety is not adversely affected by the contents.

J-3.5 Walking Surfaces

Walking surfaces designated for evacuation of passengers should be constructed of non-combustible materials.

J-4 EMERGENCY EGRESS

J-4.1 Location of Egress Routes

J-4.1.1 The system should incorporate a walking surface or other approved means for passengers to evacuate a train at any point along the trainway so that they can proceed to the nearest station or other point of safety.

J-4.1.2 Walkway continuity should be maintained at special track sections like cross over or pocket tracks. Walkway continuity should be provided by cross walks at track level.

J-4.1.3 Within enclosed trainways, the maximum distance between emergency exits/exit stairways should not exceed 750 m.

J-4.1.4 For trainways in twin bore tunnels or trainways in a tunnel divided by a minimum 120 min fire rated wall separation, cross-passageways should be permitted to be used in-lieu of emergency exit stairways.

J-4.1.5 Where cross passageways are utilized in-lieu of emergency exit stairways, the following requirements should apply:

a) First cross-passageway should be provided not farther than 500 m from the end of platform of an enclosed station or from the tunnel portal or from a mid-tunnel exit way.

b) Distance between any two cross-passageways should not be more than 250 m.

c) The crossover in an enclosed trainway should be considered as cross-passageway. The distance between crossover and subsequent cross-passageway should not be more than 250 m.

d) Cross-passageways should be separated from each trainway with separate self-closing fire door assemblies having a fire protection rating of minimum 90 min.

e) A tenable environment should be maintained in the portion of the trainway that is not involved in an emergency and that is being used for evacuation.

f) A ventilation system for the incident trainway should be designed to control smoke in the vicinity of the passengers.

g) Provisions should be made for evacuating passengers via the non-incident trainway to a nearby station or other emergency exit.

h) The provisions should include measures to protect passengers evacuating from non-incident tunnel from oncoming traffic and from other hazards.

j) Where cross-passageways are used in-lieu of emergency exit stairways, the interior of the cross-passage should not be used for any purpose other than as an area of refuge or for access/egress to the opposite tunnel, except for installation of non-combustible equipment inside the cross passageways, provided that such equipment does not infringe the required clear space of the cross-passage.

J-4.1.6 *Level of Cross Passage*

The level of cross-passage inside the tunnel should be designed in accordance to the following requirements:

a) In trainways where passengers have to walk on the track bed during evacuation, the floor of the cross-passages in such trainways should be kept close to the level of the track bed. The maximum permitted level difference between the level of track bed and the floor of the cross-passage should be 250 mm. Further, a smooth surface for transition of level difference should be provided at such cross-passages.

b) In trainways where passengers have to walk on a walkway mounted at the level of the train floor during evacuation, the floor of the cross-passages in such trainways should be kept in level with the walkway. Further, such walkways should always be provided on the cross-passageway side of the trainway for unobstructed access to the cross-passageway.

J-4.1.7 For open-cut trainways, an engineering analysis should be conducted to evaluate the impact of the trainway configuration on safe egress from a train fire to a point of safety.

J-4.1.8 Where the engineering analysis indicates that the configuration will impact tenability beyond the immediate vicinity of the fire, egress routes should be provided such that the maximum distance from any point within the open-cut section to a point of egress from the trainway should not be more than 380 m.

J-4.1.9 All the distances mentioned in **J-4.1.3**, **J-4.1.5** and **J-4.1.8** should be permitted with a maximum variation of $^{+10}_{-0}$percent.

J-4.2 Size of Egress Routes

J-4.2.1 Cross-passageways should be a minimum of 1 200 mm in clear width and 2 100 mm in height.

J-4.2.2 The width of exit stairs should not be required to exceed 1 200 mm for enclosed trainways.

J-4.2.3 If double leaf doors wider than 1 200 mm are provided in egress routes serving trainways, then size of active leaf should not be less than 810 mm.

J-4.3 Egress Components

J-4.3.1 Walking surfaces serving as egress routes within guide ways should have a uniform, slip-resistant design except as permitted herein:

a) Where the trainway track bed serves as the emergency egress pathway, it should be nominally level and free of obstructions.

b) Walkways that are more than 750 mm above the floor or grade below should be provided witha continuous handrail along the side opposite the trainway.

c) Raised walkways that are greater than 1 200 mm wide and located between two trainways should not be required to have a handrail.

d) Doors in the means of egress, except cross-passageway doors, should open in the direction of exit travel.

e) Doors in the means of egress should,

   1) open fully when a force not exceeding 220 N is applied to the latch side of the door, and

   2) be adequate to withstand positive and negative pressures caused by passing trains and the emergency ventilation system.

J-4.3.2 Horizontal sliding doors should be permitted in cross-passageways.

J-4.4 Signage, Illumination and Emergency Lighting

J-4.4.1 Warning signs posted on entrances to the trainway and on fences or barriers adjacent to the trainway should clearly state the hazard (for example, DANGER: HIGH VOLTAGE, 25 000 V) with letter sizes and colours in conformance with requirements of *Metro Railway Rules*.

J-4.4.2 System egress points should be illuminated.

J-4.4.3 Points of exit from elevated and enclosed trainways should be marked with internally or externally illuminated signs.

J-4.4.4 Tunnel lighting should be 100 percent on emergency power source, that is, UPS. Minimum illumination of 10 lux should be maintained on tunnel egress routes. Emergency lighting should be powered from a source independent of that supplying the normal lighting.

J-4.4.4 *Identification*

Emergency exit facilities should be identified and maintained to allow for their intended use.

J-4.4.5 Enclosed trainways greater in length than the minimum length of one train should be provided with directional signs as appropriate for the emergency procedures developed for the metro system.

J-4.4.6 Directional signs indicating station or portal directions should be installed at maximum 25 m intervals on either side of the enclosed trainways.

J-4.4.7 Directional signs should be readily visible by passengers for emergency evacuation.

J-5 FIRE PROTECTION AND LIFE SAFETY SYSTEMS

J-5.1 Emergency Access

J-5.1 Except as described herein, points of egress and exits from the guide way should serve as emergency access routes.

J-5.2 If security fences are used along the trainway, access gates should be provided in security fences.

J-5.3 Access gates should be a minimum 1 200 mm wide and should be of the hinged or sliding type.

J-5.4 Access gates should be placed as close as practicable to the portals to permit easy access to tunnels.

J-5.5 Information that clearly identifies the route and location of each gate should be provided on the gates or adjacent thereto.

J-5.6 Access to the elevated trainway should be from stations or by mobile ladder equipment from roadways adjacent to the track way.

J-5.7 If no adjacent or crossing roadways exist for the elevated trainway, access roads at a maximum of 750 m intervals should be required.

J-5.8 Where the configuration of an open-cut trainway prevents or impedes access for firefighting, provisions should be made to permit fire fighter access to that section of trainway at intervals not exceeding 750 m.

J-5.9 All the distances mentioned in J-5.7 and J-5.8 above should be permitted with a maximum variation of $^{+10}_{0}$ percent.

J-5.10 Distance between Tunnel Hydrants

Double headed type hydrants should be provided inside tunnels.

a) The travel distance to tunnel hydrant should not be more than 30 m.

b) Tunnel hydrant should be installed on a pipe having diameter of not less than 100 mm.

J-6 EMERGENCY VENTILATION SYSTEM FOR TRAINWAY

J-6.1 General

J-6.1.1 The following defines the requirements for the mechanical ventilation systems used in passenger trainway area.

J-6.1.2 Mechanical emergency ventilation should be provided in underground or enclosed trainways exceeding 300 m.

J-6.1.3 *Exemption*

a) A mechanical emergency ventilation system is not required for underground or enclosed trainways at most 60 m in length.

b) An engineering analysis is required for underground or enclosed trainways more than 60 m in length but less than 300 m to determine if a mechanical emergency ventilation is required; and

c) Emergency ventilation meeting the tenability criteria for occupied areas should not be required in storage track area like stabling line, depot line, Y-siding, etc where the storage track has no openings along its length to passenger trainway areas and where a fire hazard analysis indicates that a fire on a train in the storage track area will not impact passengers or passenger areas.

J-6.1.4 *Engineering Analysis*

The analysis should take into consideration all the factors that affect fire safety. A report of the analysis should be submitted. If the engineering analysis is not carried out, then a mechanical ventilation system should be provided.

J-6.2 The engineering analysis of the emergency ventilation system should include the following:

a) A validated trainway analytical simulation program that provides a quantitative analysis of airflow dynamics produced in the fire scenario, a validated computational fluid dynamic (CFD) technique, or both, as approved; and

b) The no-fire (or cold) air velocities that can be measured during commissioning to confirm that a mechanical ventilation system as built meets the requirements determined by the analysis.

J-6.2.1 Where required by **J-6.1.2**, the mechanical ventilation system should make provision for the protection of passengers, employees, and emergency personnel from fire and smoke during a fire emergency.

J-6.3 Design

J-6.3.1 The emergency ventilation system should be designed to cater the following:

a) Provide a tenable environment along the path of egress from a fire incident in enclosed station and enclosed trainways;

b) Produce sufficient airflow rates within enclosed trainways to meet critical velocity;

c) Be capable of reaching full operational mode within 180 s;

d) Address the maximum number of trains that could be between ventilation shafts during an emergency; and

e) Maintain the required airflow rates for a minimum of 2 h.

J-6.3.1.1 Where the airflow rates required to accomplish **J-6.3.1** (a), **J-6.3.1** (b), or approved alternative performance criteria are dependent upon the unimpaired function of the air distribution system, that system should be designed to continue operation when exposed to the conditions generated during the design incident for the duration of 2 h.

J-6.3.1.2 Where the airflow rates required to accomplish **J-6.3.1**(a), **J-6.3.1**(b), or approved alternative performance criteria are dependent upon the continued integrity of structural and architectural features, those features should be designed to remain intact when exposed to the conditions generated during the design incident for the duration determined as per **J-6.3.1**(e).

J-6.3.2 *Additional Design Requirements*

The design should encompass the following:

a) The heat release rate from a vehicle and any other combustible materials (if permitted) in the trainways that could contribute to the fire load at the incident site, subject to the approval of the Metro Rail Administration;

b) The rate of fire growth

c) Fire scenarios and fire profiles.

d) Station and trainway geometries.

e) The effects of elevation, elevation differences, ambient temperature differences and ambient wind.

f) A system of fans, shaft and devices for directing airflow in stations and trainways.

g) Predetermined procedures for initiating quick response from the OCC/SCR during fire.

h) A ventilation system reliability engineering analysis that, as a minimum considers the following subsystems:

    1) Electrical;

    2) Mechanical; and

    3) Supervisory control.

j) Criteria for the system reliability analysis in **6.3.2** (h) should be established and approved.

k) The analysis should consider as a minimum of the following events:

    1) Fire in the trainway or station;

    2) Local incident within the electrical utility that interrupts power to the emergency ventilation system;

    3) Derailment; and

    4) The loss of a fan that results in the most adverse effect on the ventilation system performance.

J-6.3.3 The design and operation of the signalling system, and ventilation system should be coordinated to match the total number of trains that could be between ventilation shafts during an emergency.

J-6.3.4 Emergency ventilation air distribution system should be permitted to serve more than one trainway.

J-6.4 Emergency Ventilation Fans

a) The emergency ventilation system fans that are designated for use in fire and similar emergency should be capable of satisfying the emergency ventilation requirements to move train-way air in directions to provide the needed ventilation response as per engineering analysis.

b) Individual emergency ventilation fan motors should be designed to achieve their full operating speed in no more than 30 s from a stopped position when started across the line and in no more than 60 s for variable speed motors.

c) Emergency ventilation fans, their motors, and all related components exposed to the exhaust airflow should be designed to operate at 250 °C for a minimum of 2 h.

d) Local fan motor starter and related operating control device should be located away from the direct airstream of the fans to the greatest extent practical.

e) Thermal overload protective devices in fan motors, damper motors, or on motor controls used for emergency ventilation should not be permitted.

f) Non-emergency ventilation airflows that do not impact the emergency ventilation airflows should be permitted to be left operational where identified in the engineering analysis.

g) The ventilation system designated for use in emergencies should be capable of operating at full capacity in either the supply mode or exhaust mode to provide to provide the needed ventilation response where dilution of noxious products is to be maximized.

h) The ventilation system designated for use in emergencies should be capable of being turned off and dampers closed to provide the needed ventilation response where dispersion of noxious products is to be minimized.

j) Fan should be rated in accordance with the ANSI/AMCA 300, AMCA 250/ISO 13350, ASHRAE Handbook-Fundamentals, ISO 5801, and ASHRAE 149.

k) Fans that are associated only with the passengers or employee comfort and that are not designed to function as a part of emergency ventilation system should shut down automatically on identification and initiation of a fire emergency ventilation program so as not to jeopardize or conflict with emergency airflows.

J-6.5 Airflow Control Devices

a) Devices that are interrelated with the emergency ventilation system and that are required to meet the emergency ventilation system airflow should be structurally capable of withstanding both maximum repetitive and additive piston pressure of moving trains and emergency airflow velocities.

b) Devices in the emergency ventilation system that are exposed to the exhaust airflow and are critical to the system's effective functioning in the event of an emergency should be constructed of materials suitable for operation in an ambient atmosphere at the design condition of 250 °C for 2 h.

c) Finishes applied to non-combustible devices should not be required to meet the provisions of **J-6.5(b)**.

d) Other devices should be designed to operate throughout the anticipated temperature range. Over current elements in devices or on device controls required to support the emergency ventilation should not be permitted where such over current elements are subject to false operation due to exposure to elevated temperatures during a fire emergency.

K-6.6 Testing

a) Equipment used for emergency ventilation (including fans, dampers and airflow control devices and associated electrical equipment) should be approved in accordance with the requirements of a recognized standard for the type of equipment to be installed and should be factory acceptance tested.

b) The non-fire (or cold) airflows provided by the installed mechanical ventilation system should be measured during commissioning to confirm that the airflow meets the requirement determined by the engineering analysis.

L-6.7 Emergency Ventilation Openings

a) Emergency ventilation openings should be positioned or designed to minimize recirculation of smoke into the station or enclosed trainway through any openings, such that a tenable environment is maintained along the path of egress for the time of tenability and as required for designated points of safety.

b) Adjacent structures and property uses should also be considered.

M-6.8 Emergency Ventilation System

a) Operation of the emergency ventilation system should be initiated from the operations control centre.

b) The operations control centre should receive verification of proper response by emergency ventilation fan(s) and an interrelated device(s).

c) Local controls should be permitted to override the operations control centre becomes inoperative or where the operation of the emergency ventilation system is specifically redirected to another site.

N-6.9 Power Supply for Emergency Ventilation System

a) The design of the power for the emergency ventilation system should comply with the requirements of **H-8** of this Part.

b) Overcurrent elements that are designed to protect conductors serving motors for both emergency fans and related emergency devices should not be permitted where such overcurrent elements are subject to false operation due to exposure to elevated temperatures during a fire emergency. All other motor and fan protection device should be bypassed during a fire emergency, except for motor overcurrent and excessive vibration.

c) The emergency ventilation circuits routed through the station public areas and trainway should be protected from physical damage by fixed guideway transit or passenger rail vehicles or other normal operations and from fire.

J-6.10 Critical Velocity

a) The minimum steady-state velocity of the ventilation airflow moving toward the fire within an enclosed trainway or enclosed passageway that is required to control back layering at the fire site, such that a tenable environment is maintained along the path of egress upstream of the fire, and as required for designated points of safety.

b) The equation for critical velocity is as follows:

$$V_c = K_1\, K_g \left(\frac{gHQ}{\rho C_\rho\, AT_I}\right)^{\frac{1}{3}}$$

$$T_{\mathrm{f}} = \left(\frac{Q}{\rho C_\rho\, AV_c}\right) + T$$

$$K_{\mathrm{g}} = \{1 + 0.0374\,(G)^{0.8},\ 1,\ \begin{matrix} G < 0 \\ G \geq 0 \end{matrix}$$

where

V_c = critical velocity $(\mathrm{m/s}$ or fpm)

A = the annulus area (not including the area of blockages, such as vehicles) perpendicular to the flow (m^2 or ft^2)

C_{p} = the specific heat of the air ($\mathrm{kJ/kg/K}$ or $\mathrm{Btu/lb/R}$)

g = acceleration due to gravity ($\mathrm{m/s}^2$ or $\mathrm{ft/s}^2$)

G = absolute value of tunnel grade, as a percent

K_{g} = grade factor

H = height from the base of the fire to the tunnel ceiling at the fire site (not tunnel height) (m or ft)

K_1 = Critical Froude number factor with a constant value of 0.606 (critical Froude number of the negative one-third power)

ρ = average density of the approach (upstream) air ($\mathrm{kg/m}^3$ or $\mathrm{lb/ft}^3$)

Q = convective heat the fire adds directly to the air at the fire site (kW or Btu/s)

T = temperature of the approach air (K or R)

T_{f} = Average temperature of the fire site gases (K or R)

ANNEX K

(*Clause* 6.7.3)

FIRE PROTECTION CONSIDERATIONS FOR VENTING IN INDUSTRIAL BUILDINGS

K-1 APPLICATION

K-1.1 The provisions given below are applicable only to single storey industrial buildings (factories and storage buildings) covering large floor areas without sub-dividing/separating walls which are usually designed to meet modern production methods.

K-1.2 The requirements of fire and explosion venting of industrial buildings, as dealt with in this section, fall under two categories:

a) Smoke and fire venting; and

b) Explosion relief vents.

K-2 SMOKE AND FIRE VENTING

K-2.1 The basic considerations for formulating the design and other requirements for smoke and fire vents are as given in **K-2.1.1** to **K-2.1.20**.

K-2.1.1 The smoke and hot combustion products from a fire, being lighter than the surrounding air, tend to rise, and on reaching the roof or ceiling spread out (mushroom) on all sides and form a layer which floats on top of the cold air beneath. In the absence of vents, this layer becomes progressively deeper until the whole building is filled with hot smoky gases. The time consumed for this to happen may be only a few minutes, depending on variables like, type of materials on fire, process/storage conditions involved, etc.

K-2.1.2 The hot gases at the roof level moved by convection currents contribute to rapid lateral spread of fire.

K-2.1.3 The provision of properly designed and suitably located vents in adequate number helps the speedy removal of smoke and hot gases, thereby preventing spread of fire, besides reducing risks of explosion of unburnt gases, and reducing damage to the contents and structure of the building by heat and smoke. In addition, they facilitate firefighting operations, and minimize personal hazards to the firemen.

K-2.1.4 The time taken for accumulation of smoke and hot gases within a building on fire being very short, the venting devices installed should be designed to operate in the early stage of the fire and must be automatic so as to ensure speed and efficiency in their operation.

K-2.1.5 The smoke and fire venting system should be designed in such a manner as to keep the temperature of the combustion products from the fire as low as possible, preferably below approximately 150 °C.

K-2.1.6 Automatic venting systems are complementary to the fire extinguishing systems, and automatic sprinklers, where provided, should operate before the operation of the vents; otherwise, venting may delay sprinkler operation.

K-2.1.7 It is easier to vent a building of smoke than clear it of smoke once it has been filled.

K-2.1.8 Venting is particularly desirable in large area industrial buildings or warehouses, windowless buildings, underground structures or in areas housing hazardous operations. Automatic fire vents should be provided for all industrial occupancies (including storage buildings) classified as medium hazard or above having floor areas exceeding 750 m^2, irrespective of whether they are compartmentalized or not.

K-2.1.9 These provisions do not cover other aspects, of ventilation (or lighting) designed for regulation of temperature within a building for personal comfort or meeting process needs.

K-2.1.10 Similarly, fire and smoke venting requirements as given here under are also not applicable to multi-storeyed buildings, as their requirements are different and more complex.

K-2.1.11 It is difficult to determine precise venting requirements on account of the many variables involved. For instance, the rate of combustion varies appreciably according to the nature, shape, size, and packaging of the combustible materials as well as the size, height, and disposition of the stacks of materials.

K-2.1.12 In industrial buildings of floor area less than 750 m^2 and used as low fire hazard occupancies, conventional ventilators fitted high up near the eaves of the external walls may serve as vents for smoke and hot gases, provided care is taken to ensure that they are kept open at all times or are designed to open automatically in case of fire.

K-2.1.13 Extinction of fires by closing the doors and windows is not likely in the case of industrial buildings because of their large size, where sufficient air to sustain the fire at least in the initial stages can be expected to be present.

K-2.1.14 Of the two types of building ventilation, namely, vertical, and horizontal, vertical ventilation is the one commonly adopted in the case of single storey industrial buildings.

K-2.1.15 Since 70 percent to 80 percent of heat produced in a fire is convective heat, the ventilation system has to be suitably designed to ensure early outflow of the heat and thereby minimize fire spread.

K-2.1.16 Combustible roof linings should be avoided, as they themselves will contribute to the spread of fire, thereby multiplying the venting problems.

K-2.1.17 A wind blowing across a flat roof or a roof with a pitch under 40° produces a negative pressure, that is, it tends to draw gases out of the building and so aids venting of hot gases. Wind blowing across a roof of pitch greater than 40° will draw gases out on the leeward side, but oppose outward flow on the windward side of the roof.

K-2.1.18 For vents to work at full efficiency, the area of the inlets for cold air entering the compartment must equal at least the total area of the vents. Ideally, the inlets should be as close to the ground as possible.

K-2.1.19 Where roof vents are installed in a single-storey building any neighbouring buildings, particularly those of more than one storey, will be subject to some degree of exposure hazard either from flying birds or radiation, or both, as a result.

K-2.1.20 If vents are to be installed, the size, design, number and disposition of the vents and the associated roof screens/curtain boards have to be assessed after careful analysis of the various factors stated under **K-2.1.11**, as well as other related factors like type of building construction, nature and height of roof, process hazards, exposure hazard, etc.

K-2.2 Venting Area

K-2.2.1 The estimated requirements for ventilation are largely based on the assumed build-up of the fire from the time of initial outbreak to the time of effective firefighting action by fire brigade.

K-2.2.2 The vent area required to be provided should be approximately proportional to the perimeter of the fire area, because the entrained air forms the bulk of the vented gases.

K-2.2.3 The effective area should be the minimum cross-sectional area through which the hot gases must flow out to the atmosphere.

K-2.2.4 No consideration should be given to the increased air movement obtained by power operated fans, since it must be assumed that in the event of fire, power will be interrupted, or fans damaged by heat.

K-2.2.5 The total vent areas to be provided should be as per the following ratios of effective area of vent openings to floor area for various occupancy classifications indicated:

a) Low heat release content (Sub-division G-1) — 1 : 150

b) Moderate heat release content (Sub-division G-2) — 1 : 100

c) High heat release content (Sub-division G-3) — 1 : 30 to 1 : 50

K-2.3 Types of Vents

K-2.3.1 Venting should be accomplished by any of the types such as monitors, continuous gravity vents, until type vents or sawtooth roof skylights.

K-2.3.2 Where monitor type vents are installed, wire glass or metal panels should be used only if the sash is arranged to open automatically.

K-2.3.3 The use of plain thin glass for venting should be avoided on account of its unpredictable behaviour during fire. However, if glass or other suitable plastic sheet materials with early disintegration characteristics are used, they should be designed for automatic operation.

K-2.3.4 Where monitors or unit type vents are used, the panels should be hinged at the bottom and designed to open automatically. Both sides of the vents should be designed to vent simultaneously to ensure that their effectiveness at the time of fire is not in any way impeded by wind direction.

K-2.3.5 Where movable shutters are provided for continuous gravity vents, these should open automatically in the event of fire.

K-2.3.6 Unit type vents should be of relatively small area, ranging between 1 m^2 and 9 m^2, having light weight metal frames and housing with hinged dampers which should be designed for both manual and automatic operation.

K-2.3.7 Sawtooth roof skylight should be considered as satisfactory for venting purposes only when designed for automatic operation.

K-2.3.8 Likewise, exterior wall windows should not be reckoned as satisfactory means for venting of fire gases and smoke in industrial buildings. However, they may be reckoned as additional means of venting when, they are located close to the eaves and are provided with ordinary glass or movable sash arranged for both manual and automatic operation.

K-2.3.9 Baffles should not be installed inside vents, as they greatly reduce the effective area for venting.

K-2.4 Vent Operation

K-2.4.1 The vents should be automatic in operation, unless where specified in these provisions that they should be designed for both manual and automatic operation.

K-2.4.2 The release mechanism should be simple for operation and independent of electrical power since electrical services may be interrupted by fire.

K-2.4.3 The automatic operation of vents should be achieved by actuation of fusible links or other types of heat and smoke detectors, or by interlocking with operation of sprinkler system or any other automatic fire extinguishing system covering the area. Following their release, the vents should be designed to open by a system of counterweights and associated equipment utilizing the force of gravity or spring loaded levers.

K-2.4.4 Automatic fire alarm system, where installed, should be coupled to the automatic vents to ensure simultaneous operation.

K-2.4.5 Automatic sprinklers, where installed, should operate before the vents open in order to avoid any likely delay in sprinkler operation. However, heat actuated devices used for vent release should be suitably shielded from sprinkler discharge so that water does not delay their action. Further, provision of operating the vents manually may also be provided.

K-2.4.6 Premises where height of roof apex is 10 m or more or where the materials handled or stored have high smoke producing characteristics, in addition to fusible links, the vent release mechanism should be interlinked to smoke actuated automatic fire detectors to ensure early operation of vents.

K-2.4.7 Non-corrosive materials should be used for hinges, hatches and other related parts to ensure long fail-safe operation of the vents.

K-2.4.8 In case of any doubts regarding the types of vents required to be installed for any particular occupancy, authorities having jurisdiction should be consulted.

K-2.5 Size, Spacing and Disposition of Vents

K-2.5.1 Vents should be correctly sited to ensure their functional efficiency. Ideally, they should be sited at the highest point in each area to be covered.

K-2.5.2 They should, as far as possible, be located immediately above the risk to be protected so as to allow free and speedy removal of smoke and other combustion products in the event of fire.

K-2.5.3 The minimum dimension for an effective vent opening should be not less than 1.25 m in any direction.

K-2.5.4 The spacing of the individual vent should be based on the principle that more number of well distributed smaller vents are more effective than fewer number of badly located larger vents.

K-2.5.5 The maximum spacing between vents for the three occupancy classifications should be as follows:

a) Low heat release content : 45 m between content centres

b) Moderate heat release content : 36 m to 37 m between release content centres

c) High heat release content : 22.5 m to 30 m between content centres, depending on the severity of fire potential.

K-2.5.6 Vents should be placed in a sheltered situation where advantage can be taken of the prevailing wind. The design of the vent should be such as to produce a suction effect. A wind blowing across a flat roof or one with a pitch of 40° produces a negative pressure, that is, it tends to draw gases out of the building and so aids venting of hot gases. Wind blowing across a roof of pitch greater than 40° will draw gases out of the leeward side, but oppose outward flow on the windward side of the roof.

K-2.5.7 Low level inlets, with total area not less than the total area of vents, should be provided to permit outside air to be drawn in to aid automatic venting. These inlets, which may be in the form of doors, windows, or such other openings, should be designed for manual operation when desired.

K-2.6 Roof Screens or Curtain Boards

K-2.6.1 Industrial buildings with large areas and having no subdivision/separating walls limiting the area of individual compartments to 750 m^2 or less, should be provided with roof screens or curtain boards.

These screens which extend from the roof downwards at specific intervals not only prevent lateral spread of heat and smoke in the event of fire below, but substantially assist in early operation of automatic sprinklers and vents.

K-2.6.2 They should be of sheet metal or any other substantially non-combustible material strong enough to withstand damage by heat or impact.

K-2.6.3 They should be reasonably gas-tight, although small openings for passage of pipes, conduits, etc, should be permitted.

K-2.6.4 They should extend down from the roof/ceiling for a minimum depth of 2.2 m. Around specific hazards, the depth should be 4 m. Where roof/ceiling height exceeds 15 m they should extend down to within 3 m of the floor. For pitched sawtoothed roofs, they should extend down to truss level dividing the roof into compartments.

K-2.6.5 In moderate hazard occupancies, the distance between the screens/curtain boards should not exceed 75 m and the curtained areas should be limited to a maximum of 4 500 m^2.

K-2.6.6 In high hazard occupancies, the distance between screens should not exceed 30 m and the curtained area should be limited to 750 m^2.

K-2.6.7 The curtained roof area should be so arranged that they effectively aid in the venting of smoke and hot gases through the automatic vents provided in each area.

K-2.6.8 In sprinklered buildings, the screens should preferably be so located as to coincide with the individual sprinkler system areas.

K-3 EXPLOSION RELIEF VENTS

K-3.1 Industrial premises where combustible dusts can accumulate or where flammable gases, vapours or mists in explosive concentrations may be present are constantly exposed to explosion hazards. Pressures developed by such explosions may be of the order of 7×10^5 Pa and ordinary buildings will not be able to withstand the shock of such pressures. Hence, such buildings require explosion relief vents for preventing structural damage.

K-3.2 Basic Principle/Considerations

K-3.2.1 Most ordinary building walls will not withstand a sustained internal pressure as great as 6.9×10^3 Pa. Hence, explosion relief vents for buildings must be designed to operate at pressures well below those at which the building walls will fail.

K-3.2.2 There is a rise in pressure during an explosion within an enclosure even with open, unobstructed vents, and any delay in opening the venting devices increases that pressure.

K-3.2.3 Structural damage can be minimized by locating hazardous operations or equipment outside buildings and cut-off from other operations by a pressure resisting wall. Such isolated processes or equipment should be housed in single-storey buildings properly vented and a device provided at the inlet of the collector which will prevent an explosion from blowing back through the duct work and into the building.

K-3.2.4 Where highly hazardous operations cannot be located outside of main buildings, they should be segregated by pressure resisting walls and each such unit should be ventilated outdoors. External walls may be of heavy construction, if equipped with suitable vents or high weight panels which blow out easily.

K-3.2.5 Operations or equipment involving explosion hazards should not be permitted in basements or areas partially below grade.

K-3.2.6 Fire can be expected to follow an explosion in most occupancies, so that any fixed fire extinguishing equipment, like sprinklers, if installed, should be such that only the minimum damage is caused to it.

K-3.2.7 For a given material, the finer the particle size of the dust, the more violent is the explosion. Some materials, such as aluminium powder, hydrogen, and acetylene, are difficult to vent effectively due to the rapid rate of pressure rise. Some slow burning materials, such as coal dust in a confined space, may do much damage because of the longer duration of their presence. Some dusts, such as magnesium, titanium and zirconium and several metal hydrides may react with and ignite in some common inert gases, such as nitrogen and carbon dioxide.

K-3.2.8 The maximum explosion pressure in a vented structure decreases as the size of the vent increases but is independent of the rupturing pressure of a diaphragm.

K-3.2.9 The most effective vent for the release of explosion pressures is an unobstructed vent opening.

K-3.2.10 Pressure required to rupture diaphragms of the same area and material directly varies with the thickness of the material.

K-3.2.11 The slower the rate of pressure rise, the more easily can the explosion be vented.

K-3.2.12 The degree of venting required is directly proportional to the degree of explosion hazard.

K-3.2.13 Experience has shown that most explosions of dusts, vapours and gases do not involve a large part of the total volume of the enclosure, and frequently occur near the upper or lower limits of the explosive range. Consequently, such explosions are relatively weak compared with the optimum.

K-3.2.14 Rectangular unrestricted vents are as effective as square vents of equal area.

K-3.3 Types of Explosion Relief Vents

K-3.3.1 The explosion relief vents should be any one or more of the following types, depending on individual requirements as assessed by the Authority. Open or unobstructed vents, louvres, open roof vents, hanger type doors, building doors, windows, roof or wall panels or movable fixed sash.

K-3.3.2 The effect or external wind pressure or suction on these devices should be taken into consideration while designing and selecting the type of vents, since wind pressures may reach over 2×10^5 Pa in severe windstorms.

K-3.3.3 The type of vent for explosion relief for any occupancy should be selected with life safety as the primary aim followed by minimum damage to property.

K-3.3.4 Where large hanger type doors of metal curtain doors inside walls are used as vents, care should be taken to ensure that they are kept wide open during operations.

K-3.3.5 Where weather hoods are used to cover roof vents, they should be as light as possible and lightly attached so as to enable them to be blown off quickly when an explosion occurs.

K-3.3.6 Doors and windows when used as explosion vents should be installed to swing outwards. Doors should have friction, spring or magnetic latches that will function automatically to permit the door to open under slight internal pressure.

K-3.3.7 Movable sash should be of the top or bottom hinged or protected type. These should be equipped with a latch or friction device to prevent accidental opening due to wind action or intrusion. Such latches or locks should be well maintained.

K-3.3.8 Fixed sash should be set in place with very light wall anchorages, or, if tight, should be securely fitted and glazed with plastic panes in plastic putty.

K-3.3.9 Where the process is such that the whole of a building or a room may be desirable to arrange for a lightly constructed wall or roof to collapse and thus avert the worst effects of an explosion.

K-3.4 Design, Size and Disposition of Vents

K-3.4.1 The required area of explosion vents should ordinarily depend on the expected maximum intensity of an explosion in the occupancy, the strength of the structure, the type of vent closure and other factors.

K-3.4.2 Venting should be planned in such a manner as to prevent injury to personnel and damage to exposure. In congested locations, substantial ducts or diverters should be provided to direct the blast.

K-3.4.3 When ductwork is used, the ducts should be of sufficient strength to withstand the maximum expected explosion pressure.

K-3.4.4 Where explosions are likely within duct and piping systems, they should be vented by the use of suitable diaphragms designed to blow out at a predetermined pressure. There should be no physical connection between ductwork system for more than one collector.

K-3.4.5 In large structures, the position of vents should be relative to the point of origin of explosion, when it can be determined.

K-3.4.6 Where relatively slow explosions involving coal dust, chlorinated solvents, etc are involved, light, hinged swinging panels may be preferred to diaphragm type of vents.

K-3.4.7 Obstructions of any kind blocking the vents from the risk covered should be avoided, particularly where risks of rapid violent explosions are present.

K-3.4.8 Counterweights add to the inertia of the vents and so should be avoided.

K-3.4.9 Various relieving devices, including devices actuated by detonators, should start to open at as low a pressure as possible. They should be of light construction, so that full opening can be quickly attained.

K-3.4.10 Vents should be of such size and design as to prevent rupture of the protected device or apparatus.

K-3.4.11 Skylights or monitors with movable sash that will open outwards, or fixed sash containing panes of glass or plastic that will blow out readily under pressure from within, can be used to supplement wall vents or windows, provided resistance to their displacement or opening is kept as low as consistent with the requirements for structural strength.

K-3.4.12 Flexible plastic sheets when used for vent closures should be installed in slotted frames in such a way that pressure from within bulges the sheets and releases them from the holding frame.

K-3.4.13 Fragile sheets made of plastic, when used for vent closures, should be thin sheets that will crack or rupture under less pressure, than single strength glass. For this reason, use of transparent or translucent plastic sheets is more advantageous than use of glass in window sash.

K-3.4.14 If closed vents are used, they should be larger in area than unenclosed vents to provide equivalent explosion pressure relief.

K-3.4.15 Small enclosures, such as machines, should be vented more generously than buildings, because if an explosion occurs in a machine, its entire volume may be involved.

K-3.4.16 Vents for the protection of buildings and equipment should be installed on the following basis:

a) Small enclosures of less than 30 m^3, machines and ovens of light construction: 1 000 cm^2 for each 0.3 m^3 to 0.9 m^3.

b) For small enclosures of more substantial construction having reasonably high bursting strength: 1 000 cm^2 for each 0.9 m^3.

c) Fairly large enclosures of 30 m^3 to 700 m^3, such as bins, silos, rooms, storage tanks, etc: 1 000 cm^2 for each 0.9 m^3 to 1.5 m^3. In these cases, attempt should be made to the extent possible to predict the likely point of origin of the explosion in relation to the vent.

d) Large rooms and buildings over 700 m^3 containing hazardous equipment comprising a small fraction of the entire volume:

   1) For heavy reinforced concrete, walls: 100 cm^2 for each 2.25 m^3.

   2) For light reinforced concrete, brick, or wood construction: 1 000 cm^2 for each 1.65 m^3 to 2.25 m^3.

   3) For lightweight construction such as prefabricated panels: 1 000 cm^2 for each 1.5 m^3 to 1.65 m^3.

e) Large rooms or building over 700 m^3 containing hazardous equipment comprising a large part of the entire volume of a room or building should be vented as generously as possible: 1 000 cm^2 for each 0.3 m^3 to 1.05 m^3.

f) In order to obtain these ratios, the size of the building or room must be limited. For some hazardous materials, such as hydrogen, acetylene, carbon disulphide, etc, these limits are extremely low.

g) Emphasis should always be placed on segregating hazardous areas by means of firewalls or separating walls to prevent spread of fire.

h) Interior walls of light construction, such as tile, should be avoided in hazardous locations since they can cause injuries to personnel in the event of an explosion.

ANNEX M

(*Clause* 1.4)

PERFORMANCE BASED DESIGN

M-1 GENERAL

M-1.1 Performance based design may be applicable under following conditions to any occupancy, subject to:

a) Approval from state/local authority, where they have resource (local/shared/outsourced) to evaluate a performance-based design for any building;

b) The performance-based design should meet the goals and objectives of this Annex and should be carried out by a registered professional;

c) The local authority having jurisdiction should make the final determination whether the performance objectives have been met; and

d) All necessary documentation as per this annex pre- and post-construction should be part of the submission and should be retained during the entire life of the building.

M-1.2 The provisions of this Annex provides performance based design (PBD) which is applicable only to validate the fire safety aspects for heritage buildings (constructed well before the first version of NBC) that are either made available to public or are converted to other building occupancy (and constrained to add additional staircase/refuge that damages it heritage nature).

The Authority may exempt compliance (of such heritage buildings as above constructed before the publication of the first NBC) with the relevant requirements in this NBCS, if the alternate design(s) proposed based on performance-based solutions duly validated by engineering calculations/computational fluid dynamics (CFD) modelling, achieve the objectives.

PBD is an engineering approach to fire protection design based on (1) agreed upon fire safety goals and objectives, (2) deterministic and/or probabilistic analysis of fire scenarios, and (3) quantitative assessment of design alternatives against the fire safety goals and objectives using accepted engineering tools, methodologies, and performance criteria.

M-1.3 The application of performance-based fire engineering is highly individualized, excluding its universal adoption across different structures. Due to its reliance on custom-built environmental and occupancy variables, any implementation should undergo a unique validation process by the relevant jurisdiction.

Implementing a performance-based approach necessitates a rigorous assessment of site-specific data to ensure all fire dynamics calculations reflect the unique hazards of the structure. The proponent is responsible for establishing safety parity with prescriptive standards through quantitative evidence. Due to the sophisticated nature of computational fluid dynamics (CFD) modelling, an independent technical audit is recommended to validate the integrity of the design's assumptions and outcomes.

The implementation of PBD requires a multilateral agreement on risk thresholds involving all key stakeholders, including the authority having jurisdiction (AHJ). Due to the sophisticated nature of these designs, specialized fire science expertise is mandatory to ensure that the transition from a theoretical model to a specific environment is technically sound.

NOTE — Computational models, particularly CFD simulations, should be recalculated to reflect the unique spatial geometry and airflow dynamics of the site. Also, the analysis must incorporate local emergency response variables, ensuring the design aligns with the actual equipment and arrival times of the area's fire services.

M-2 MINIMUM CRITERIA

M-2.1 The minimum criteria to accept the PBD solutions should be the compliance to the following:

a) Safe egress (ASET > RSET) through validated evacuation modelling.

b) Controlled fire and smoke spread, maintaining tenable conditions; and

c) Reliable fire suppression and detection exceeding the minimum requirements of this Part.

NOTE — ASET = Available Safe Egress Time; and RSET = Required Safe Egress Time

M-2.2 Tenability refers to the conditions within a space that allow occupants to survive and potentially evacuate safely during a fire. Various factors contribute to tenability, and recommendations suggested is limiting the exposure to the most life-threatening hazards. Thus, to ensure occupant safety in fire scenarios, maintaining tenability criteria at a height of 1.8 m from the floor level is a crucial consideration.

Where possible, the toxicity effects (life threatening hazard) is arrived by obtaining the amount of fractional effective dose (FED) of asphyxiant gases (like, carbon monoxide, hydrogen cyanide); and fractional effective concentration (FEC) of the irritant gases (like, HCl, NO, SO_2). The requirements are:

a) Maintaining FED < 0.3 (recommended to prevent incapacitation of sensitive individuals); and

b) Maintaining FEC < 0.3 (recommended).

FEC is used to assess the combined effect of multiple irritant gases (present in the fire effluent) expressed as:

$$FEC = \sum(Ci/Fi)$$

where

Ci = the concentration of each individual irritant gas (i).

Fi = the concentration of that specific irritant gas (i) that is expected to cause a significant reduction in the possibility of escape and survivability. These Fi values are typically based on experimental data and toxicological studies.

NOTE — Specialist literature be referred to obtain the values of Fi.

M-2.3 In addition, the following thermal exposure limits are recommended:

a) *Convective Heat Exposure* — Air temperature should not exceed 60 °C to prevent heat stress; and

b) *Radiant Heat Exposure* — Maintain below 2.5 kW/m² to avoid skin burns and incapacitation.

M-2.4 Also, the visibility through smoke criteria is essential and the same is suggested as minimum visibility of 5 m to 10 m should be maintained for safe evacuation and wayfinding.

M-2.5 The PBD involves iterative process in arriving at the desired outcome. *See* Fig. 23 for the typically accepted flowchart.

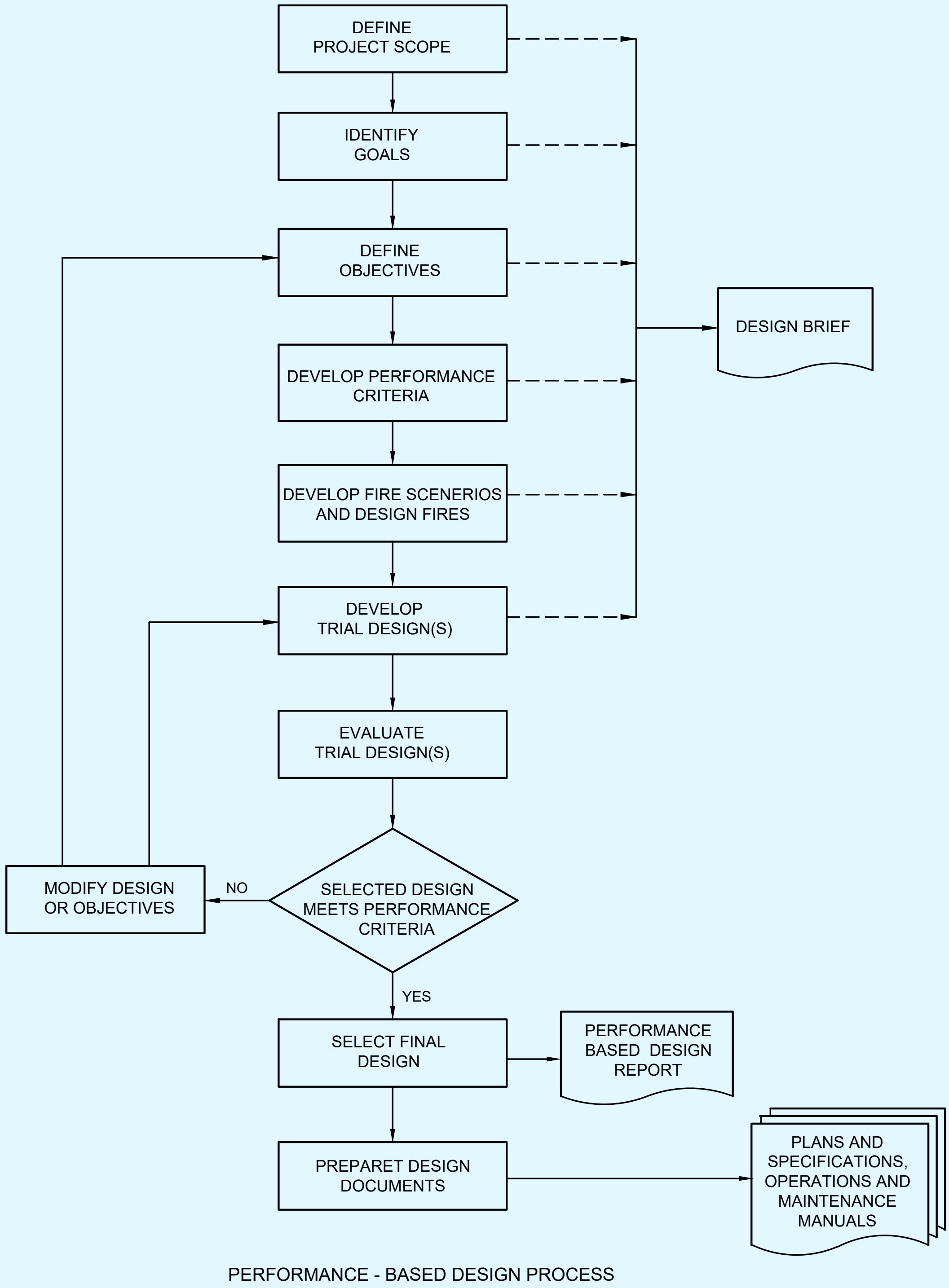

DEFINE PROJECT SCOPE
IDENTIFY GOALS
DEFINE OBJECTIVES
DESIGN BRIEF
DEVELOP PERFORMANCE CRITERIA
DEVELOP FIRE SCENERIOS AND DESIGN FIRES
DEVELOP TRIAL DESIGN(S)
EVALUATE TRIAL DESIGN(S)
MODIFY DESIGN OR OBJECTIVES
NO
SELECTED DESIGN MEETS PERFORMANCE CRITERIA
YES
SELECT FINAL DESIGN
PERFORMANCE BASED DESIGN REPORT
PREPARET DESIGN DOCUMENTS
PLANS AND SPECIFICATIONS, OPERATIONS AND MAINTENANCE MANUALS
PERFORMANCE - BASED DESIGN PROCESS

FIG. 23 FLOWCHART DEPICTING THE PROCESS IN PERFORMANCE BASED DESIGN

ANNEX N

(*Table 7G*)

(*Informative*)

SUGGESTED REQUIREMENTS OF FIRE PROTECTION FOR SPECIFIC INDUSTRIES

(Supplementary to Table 7G)

Sl No.	**Type of Factory**	**Type of Installation**								**Recommended Water Supply** litre		**Recommended Pump Capacity** litre per minute
		Extinguisher	Small Bore Hose Reels	Wet Riser	Down Comer	Yard Hydrant	Automatic Sprinkler System	Manual Fire Alarm System	Automatic Fire Detection & Alarm System	Static Tank at Ground Level	Overhead / Terrace Tank	Fire Pump Ground Level
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Minimum Firefighting Requirements for Factories/Industries – LOW HAZARD (Notes 1, 2a, 3, 4, 5 and 13)												
i)	Artisans workshops, village and cottage industries, tiny sector industries (duly licensed by the Govt. of India)	R	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
ii)	Aggregate built-up area less than 500 m^2	R	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
iii)	Aggregate built-up area from 500 m^2 to less than 1 500 m^2	R	R	NR	NR	NR	NR	NR	NR	15 000	5 000 (Note 12)	R (Note 7a)
iv)	Aggregate built-up area from 1 500 m^2 to less than 2 500 m^2	R	R	NR	NR	NR	NR	NR	NR	25 000	5 000 (Note 12)	R (Note 7a)

Sl No.	Type of Factory	Type of Installation								Recommended Water Supply litre		Recommended Pump Capacity litre per minute
		Extinguisher	Small Bore Hose Reels	Wet Riser	Down Comer	Yard Hydrant	Automatic Sprinkler System	Manual Fire Alarm System	Automatic Fire Detection & Alarm System	Static Tank at Ground Level	Overhead / Terrace Tank	Fire Pump Ground Level
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
v)	Aggregate built-up area more than 2 500 m^2	Pl. see Appendix "1" and also Notes 8, 9, 10 and 11										
Minimum Firefighting requirements for Factories/Industries – ORDINARY HAZARD (Notes 1, 2b, 3, 5 and 13)												
vi)	Aggregate Built-up area less than 500 m^2	R	R	NR	NR	NR	NR	NR	NR	20 000	5 000 (Note 12)	R (Note 7a)
vii)	Aggregate Built-up area from 500 m^2 to less than 1 500 m^2	R	R	NR	NR	R	NR	NR	NR	40000	10 000 (Note 12)	R (Note 7b)
viii)	Aggregate Built-up area from 1 500 m^2 to less than 2 500 m^2	R	R	R	R	R	NR	R	R	60 000	15000 (Note 12)	R (Note 7c)
ix)	Aggregate Built-up area more than 2 500 m^2	Pl. see Appendix "2" and also Notes 8, 9, 10 and 11										
Minimum Firefighting requirements for Factories/Industries – High Hazard 'A' (Notes 2c, 5 and 13)												
x)	Aggregate built-up area less than 1 000 m^2	R	R	R	R	R	R	R	R	75 000	10 000 (Note 12)	R (Note 7d)

Sl No.	**Type of Factory**	**Type of Installation**								**Recommended Water Supply** litre		**Recommended Pump Capacity** litre per minute
		Extinguisher	Small Bore Hose Reels	Wet Riser	Down Comer	Yard Hydrant	Automatic Sprinkler System	Manual Fire Alarm System	Automatic Fire Detection & Alarm System	Static Tank at Ground Level	Overhead / Terrace Tank	Fire Pump Ground Level
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
xi)	Aggregate built-up area from 1 000 m^2 to less than 2 500 m^2	R	R	R	R	R	R	R	R	1 00 000	15 000 (Note 12)	R (Note 7d)
xii)	Aggregate built-up area more than 2 500 m^2	Pl. *see* Appendix ‘3’ and also Notes 8, 9, 10 and 11										
Minimum Firefighting requirements for Factories/Industries – High Hazard "B" (Notes 2c and 6)												
Please *see* Appendix ‘4’ and also Notes 8, 9, 10 and 11												
Firefighting provisions should comply with various provisions contained in Note 8. In addition, all factories/industries should be protected as per the applicable standards like oil industry safety directorate (OISD) or others as specified in Note 6.												
R - Required. NR - Not Required.												

NOTES

1 The aggregate built up area of all floors of the facility could be a process building or a storage, a utility building or open storage and any other facilities as the case may be.

2a Buildings above 9 m are not permitted for factories/industries mentioned in Sl No. 1, 2 and 3 of low hazard of Annex 'A' Table.

2b Buildings/Plants above 18 m in height are not permitted for factories/industries mentioned in Sl No. 1 to 4 of ordinary hazard of Annex 'A' Table. However, where nature of process within the Plants demand heights beyond 18 m (for example, where there are tall machinery, vessels, columns, reactors, etc are involved) and occupant load is less (for example, power plants, boiler installations, etc), increase in heights can be allowed. Non-industrial occupancies within the complex but beyond operational area such as offices, residential and the like should comply with respective provisions in this NBCS according to the occupancy.

2c Buildings/plants above 15 m in height are not permitted for high hazard factories/industries. However, where there are vessels, columns, reactors, etc, are involved and specifically related to the process requirements, the heights can be more than 15 m. However, where nature of process within the building/plants demand heights beyond 15 m (for example, where there are tall machinery, vessels, columns, reactors, etc are involved) and occupant load is less (for example, power plants, boiler installations, etc), increase in heights can be allowed. Non-industrial occupancies within the complex but beyond operational area such as offices, residential and the like should comply with respective provisions in this NBCS according to the occupancy.

3 In case, the factories/industries complex consists of building(s) with occupancies having mixed hazards, fire protection systems should be governed by the highest hazard.

4 Those factories/industries which were defined or licensed as "Artisans workshops, Village and Cottage Industries, Tiny sector industries" by the Government of India should need to provide only extinguishers and buckets, their quantity and distribution should comply with IS 2190.

5 Multiple occupancy industrial estates (all in one building) should be protected according to the requirements for 'Ordinary' hazard industries. No high hazard occupancies should be allowed in such buildings.

6 In case of high hazard industries-A (where applicable) and high hazard industries-B like Petrochemical industries, Refineries and the like, compliance with the requirements of other agencies like Oil Industry Safety Directorate (OISD), Petroleum and Explosives Safety Organisation (PESO), Petroleum and Natural Gas Regulatory Board (PNGRB), Oil Mines Regulations (OMR), Central Electricity Authority (CEA) should be necessary in addition to those from Annex 'A' Table.

7a Entire occupancy should be protected by one electric driven main pump of at least 450 lpm discharge capacity at 50 m head, one standby pump of similar capacity (with reliable back-up power supply like DG Set).

7b Entire occupancy should be protected by one electric driven main pump of at least 900 lpm discharge capacity at 50 m head, one standby pump of similar capacity (with reliable back-up power supply like DG Set).

7c Entire occupancy should be protected by one electric driven main pump of at least 1 620 lpm discharge capacity at 70 m head, one standby diesel engine driven pump of similar capacity and one jockey pump of capacity of at least 180 lpm.

7d Entire occupancy should be protected by one electric driven main pump of at least 2 280 lpm discharge capacity at 70 m head, one standby diesel engine driven pump of similar capacity and one jockey pump of capacity of at least 180 lpm.

8 Entire occupancy should be protected by hydrant, sprinkler, water spray, water mist, clean agent, foam, fire alarm systems, etc as applicable in accordance with the current versions of IS 13039, IS 15105, IS 15325, IS 15519, IS 12385, IS 15693, IS 2189, IS 15908, etc in all respects that include design and installation of pumps, pipelines, etc.

9 Certain occupancies may also be protected by automatic water mist systems with appropriate (pressure) applications. Installation and design of such systems should comply to IS 15519.

10 For all occupancies, pumping capacities and water requirements should need to be provided wherever indicated in respective columns in Annex 'N' Table. However, where pumping capacities and water requirements are not indicated in the respective columns, reference should be made to the concerned Indian Standard codes of practices for hydrant/sprinkler/water spray, etc, for details. In either case, design and installation of systems like hydrant, sprinkler, spray systems, etc, should strictly be carried out as per provisions in respective Indian Standards stated in Note 8 above.

11 Where application of water as extinguishing medium is not appropriate due to the presence of water-reactive materials or other valid acceptable reasons, a suitable alternative extinguishing system and method should be provided in accordance with relevant Indian Standards.

12 Overhead fire water tank should be connected to hose reels and also sprinkler system (where applicable).

13 Classifications of various occupancies shown in Annex 'B' is only indicative for ready reference and understanding. While designing hydrant and sprinkler systems, classifications for the purpose of design and installation should strictly adhere to those available in IS 13039 and IS 15105 respectively.

Appendix '1' to Annex N

Low Hazard Factories/Industries with Aggregate Built-up area more than 2 500 m^2

Sl No.	Description	Extinguisher	Hose Reel	Hydrant System	Sprinkler System		Fire Alarm System	Special Protection
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
i)	Abrasive manufacturing premises	R	R	R	NR	Required for packing material/other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
ii)	Aerated water factories, mineral water factories	R	R	R	NR	Required for packing material/ bottles and other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
iii)	Agarbatti manufacturing	R	R	R	NR	Required for packing material/Finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
iv)	Analytical and/or quality control laboratories (without pilot plant)	R	R	R	Required if the combined floor area of the building is more than 5 000 m^2	NR	Suitable detection system backed up by manual call stations should be provided for the entire factory where combined area of the process/Storage blocks	

Appendix ‘1’ to Annex N

Low Hazard Factories/Industries with Aggregate Built-up area more than 2 500 m^2

Sl No.	Description	Extinguisher	Hose Reel	Hydrant System	Sprinkler System		Fire Alarm System	Special Protection
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
							exceeds 5 000 m^2	
v)	Areca nut slicing and/or betel nut factories	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
vi)	Asbestos steam packing and lagging manufacturers	R	R	R	NR	NR	Suitable detection system backed up by manual call stations should be provided for the entire factory where combined area of the process/storage blocks exceeds 5 000 m^2	
vii)	Battery charging/battery service station	R	R	R	R	R	Suitable detection system backed up by manual call stations should be provided for the entire factory where combined area of the process/storage blocks exceeds 5 000 m^2	Water mist systems as per IS 15519

Appendix '1' to Annex N

Low Hazard Factories/Industries with Aggregate Built-up area more than 2 500 m^2

Sl No.	**Description**	**Extinguisher**	**Hose Reel**	**Hydrant System**	**Sprinkler System**		**Fire Alarm System**	**Special Protection**
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
viii)	Battery manufacturing	R	R	R	R	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Suitable detection system backed up by manual call stations should be provided for the entire factory where combined area of the process/storage blocks exceeds 5 000 m^2	Water mist systems in battery charging stations as per IS 15519
ix)	Breweries	R	R	R	NR	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
x)	Brick works	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xi)	Canning factories	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	

Appendix ‘1’ to Annex N

Low Hazard Factories/Industries with Aggregate Built-up area more than 2 500 m^2

Sl No.	Description	Extinguisher	Hose Reel	Hydrant System	Sprinkler System		Fire Alarm System	Special Protection
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
xii)	Cardamom factories	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xiii)	Cement factories and/or asbestos or concrete products manufacturing	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	Clean agent-inert gas systems (CO2, Nitrogen) for bag filters, mill house, coal bins
xiv)	Ceramic factories and crockery and stoneware pipe manufacturing	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xv)	Clay works	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xvi)	Clock and watch manufacturing	R	R	R	NR	Raw Material godowns should be sprinklered if the value of plastic/rubber and other similar commodities in the storage area exceeds 20 percent of the total	Manual fire alarm system should be provided throughout, operations like spray painting, wood working, solvent cleaning etc, should need to be spot-protected if combined area	

Appendix ‘1’ to Annex N

Low Hazard Factories/Industries with Aggregate Built-up area more than 2 500 m^2

Sl No.	**Description**	**Extinguisher**	**Hose Reel**	**Hydrant System**	**Sprinkler System**		**Fire Alarm System**	**Special Protection**
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
						value of the storage building	occupied by such operations exceed 10 percent of the total manufacturing area	
xvii)	Coffee curing, roasting and grinding premises	R	R	R	Required if the area occupied by process building exceeds 2 000 m^2	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	If combined area of the entire factory is more than 2 000 m^2, manual fire alarm system should be required, Suitable detection system backed up by Manual call stations should be provided for the entire factory where combined area of the process/storage blocks exceeds 5 000 m^2	If combined area of process and storage blocks in the same building exceeds 2 000 m^2, sprinkler installation will be required in the entire area
xviii)	Condensed milk factories, milk pasteurising plant and dairies	R	R	R	NR	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xix)	Confectionery manufacturing	R	R	R	NR	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	

Appendix '1' to Annex N

Low Hazard Factories/Industries with Aggregate Built-up area more than 2 500 m^2

Sl No.	Description	Extinguisher	Hose Reel	Hydrant System	Sprinkler System		Fire Alarm System	Special Protection
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
xx)	Crockery and stoneware pipe manufacturing	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xxi)	Electric generating houses (Hydro electric)	R	R	R	NR	Sprinkler protection for storage areas not forming part of main occupancy if area exceeds 2 000 m^2	Auto fire alarm system for all areas except detached storage buildings and utility blocks where manual alarm systems should be provided	Water spray system for transformers, FDS/NIFPS system, cable galleries, conveyors including transfer towers, etc as per IS 3034 and IS 15325
xxii)	Electric Lamps (Incandescent and Fluorescent) and TV Picture Tube Manufacturing	R	R	R	NR	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xxiii)	Electric Sub-Station/ Distribution Station	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	Water spray system for transformers if capacity thereof is more than 10 MVA or oil capacity exceeds 2 000 litre.

Appendix '1' to Annex N

Low Hazard Factories/Industries with Aggregate Built-up area more than 2 500 m^2

Sl No.	**Description**	**Extinguisher**	**Hose Reel**	**Hydrant System**	**Sprinkler System**		**Fire Alarm System**	**Special Protection**
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
								(As per CEA Regulations and IS 3034, IS 15325)
xxiv)	Electro Plating Works	R	R	R	NR	NR	NR	
xxv)	Electronic and/or Computer equipments Assemble and Manufactures	R	R	R	NR	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xxvi)	Engineering workshops heavy (Structural Steel Fabricators, Sheet Metal Fabricators (Tin Printing excluded), Hot or Cold Rolling, Pipe Extruding, Stamping, Pressing, Drawing (other than wire Drawing) or Forging Mills, Ore Crushing Mills, Ferrous and non Ferrous Metal Smelting or Extraction Works and Foundries (allowing storage of Wooden	R	R	R	NR	Raw material godowns should be sprinklered if the value of plastic/rubber and other similar commodities in the storage area exceeds 20 percent of the total value of the storage building.	Manual fire alarm system should be provided throughout, operations like manufacture of plastic/rubber components, powder coating/spray painting, drying of painted goods, use or storage of flammable liquids having flash point of 23 °C and below, wood working, upholstering, engine testing and flammable gas plant should need to be spot-protected by appropriate means if combined area	

Appendix '1' to Annex N

Low Hazard Factories/Industries with Aggregate Built-up area more than 2 500 m^2

Sl No.	Description	Extinguisher	Hose Reel	Hydrant System	Sprinkler System		Fire Alarm System	Special Protection
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Patterns only) and galvanizing works and the like)						occupied by such operations exceed 10 percent of the total manufacturing area. Else such areas should be fire separated from the main operations	
xxvii)	Engineering workshops Light (Blacksmiths, Electroplating, Anodizing or Lead, Zinc or other Metal Coating Works, Machine Shops, Heat Treatment shops, Electro Magnets manufacturing, Electrical and Mechnical Machinery Assemblers/Manufacturers, General Engineering Goods and Merchandise Manufacturers, Maintenance and Repair Workshops, Mfrs. of Welding Electrodes and Wire drawing, Automobile factories and the like)							

Appendix ‘1’ to Annex N

Low Hazard Factories/Industries with Aggregate Built-up area more than 2 500 m^2

Sl No.	Description	Extinguisher	Hose Reel	Hydrant System	Sprinkler System		Fire Alarm System	Special Protection
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
xxviii)	Fruits and vegetables dehydrating/drying factories	R	R	R	NR	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xxix)	Fruit products and condiment factories	R	R	R	NR	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xxx)	Glass and glass Fibre manufacturing	R	R	R	NR	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xxxi)	Gold thread factories/ gilding factories	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xxxii)	Granite manufacturing	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	If inflammable liquids having a flash point of less than 65° are used, manual foam spray

Appendix '1' to Annex N

Low Hazard Factories/Industries with Aggregate Built-up area more than 2 500 m^2

Sl No.	**Description**	**Extinguisher**	**Hose Reel**	**Hydrant System**	**Sprinkler System**		**Fire Alarm System**	**Special Protection**
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
								system should be used in the areas concerned
xxxiii)	Gum and/or Glue and Gelatine Manufacturing	R	R	R	NR	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xxxiv)	Ice Candy and Ice-cream Manufacturing	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xxxv)	Ice Factories	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xxxvi)	Ink (excluding Printing Ink) Factories	R	R	R	NR	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	

Appendix '1' to Annex N

Low Hazard Factories/Industries with Aggregate Built-up area more than 2 500 m^2

Sl No.	**Description**	**Extinguisher**	**Hose Reel**	**Hydrant System**	**Sprinkler System**		**Fire Alarm System**	**Special Protection**
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
xxxvii)	Laundries	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xxxviii)	Mica products manufacturing	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xxxix)	Pottery works	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xl)	Poultry farms	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xli)	Salt Crushing Factories and Refineries	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	

Appendix ‘1’ to Annex N

Low Hazard Factories/Industries with Aggregate Built-up area more than 2 500 m^2

Sl No.	**Description**	**Extinguisher**	**Hose Reel**	**Hydrant System**	**Sprinkler System**		**Fire Alarm System**	**Special Protection**
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
xlii)	Sugar Candy Manufacturing	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xliii)	Sugar Factories and Refineries	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xliv)	Tanneries/Leather Goods Manufacturers	R	R	R	NR	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xlv)	Tea Blending and Tea Packing Factories	R	R	R	Required if the area occupied by process building exceeds 2 000 m^2	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	If combined area of the entire factory is more than 2 000 m^2, manual fire alarm system should be required, suitable detection system backed up by manual call stations should be provided for the entire factory where combined area of the process/ storage blocks exceeds 5 000 m^2	If combined area of process and storage blocks in the same building exceeds 2 000 m^2, sprinkler installation will be required in the entire area

Appendix ‘1’ to Annex N

Low Hazard Factories/Industries with Aggregate Built-up area more than 2 500 m^2

Sl No.	**Description**	**Extinguisher**	**Hose Reel**	**Hydrant System**	**Sprinkler System**		**Fire Alarm System**	**Special Protection**
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
xlvi)	Umbrella Assembling Factories	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xlvii)	Vermicelli Factories	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xlviii)	Water Treatment/Water Filtration Plants and Water Pump House	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xlix)	Zinc/Copper/Aluminium Factories	R	R	R	NR	NR	Suitable detection system backed up by manual call stations should be provided for the entire factory where combined area of the process/storage blocks exceeds 5 000 m^2	
	R – Required. NR – Not Required.							

Appendix '2' to Annex N

Ordinary Hazard Factories/Industries with Aggregate Built-up Area more than 2 500 m^2

Sl No.	**Description**	**Extinguisher**	**Hose Reel**	**Hydrant System**	**Sprinkler System**		**Fire Alarm System**	**Special Protection**
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
i)	Airport and other transportation terminal building	R	R	R	To be fully sprinklered	To be fully sprinklered (cargo)	To be fully protected by automatic intelligent fire alarm system	Kitchen hoods and ducts should be protected with wet chemical systems as per this NBCS. Also, systems as per ICAO standards.
ii)	Aluminium factories	R	R	R	NR	NR	NR	
iii)	Bakeries	R	R	R	NR	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
iv)	Beedi factories	R	R	R	NR	NR	NR	
v)	Biscuit factories	R	R	R	NR	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
vi)	Bobbin factories	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	

Appendix ‘2’ to Annex N

Ordinary Hazard Factories/Industries with Aggregate Built-up Area more than 2 500 m^2

Sl No.	**Description**	**Extinguisher**	**Hose Reel**	**Hydrant System**	**Sprinkler System**		**Fire Alarm System**	**Special Protection**
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
vii)	Bookbinders, envelopes and paper bag manufacturers	R	R	R	Required when a single un-compartmented area is more than 2 000 m^2	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
viii)	Cable manufacturing	R	R	R	Required when a single un-compartmented area is more than 2 000 m^2	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
ix)	Carbon paper/typewriter ribbon manufacturers	R	R	R	Required when a single un-compartmented area is more than 2 000 m^2	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
x)	Cardboard box manufacturing	R	R	R	NR	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xi)	Carpenters, wood wool and furniture manufacturers. Basket weavers, cane furniture manufactuirng	R	R	R	Required when a single un-compartmented area is more than 2 000 m^2	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	

Appendix '2' to Annex N

Ordinary Hazard Factories/Industries with Aggregate Built-up Area more than 2 500 m^2

Sl No.	Description	Extinguisher	Hose Reel	Hydrant System	Sprinkler System		Fire Alarm System	Special Protection
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
xii)	Carpet and drugget factories	R	R	R	NR	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xiii)	Chemical manufacturing involving chemicals, dyes, intermediates, pigments, acids, medicinal/ pharmaceuticals formulation and toilet preparation including soap manufacturing, chemical mixing and blending factories using no chemicals/ solvents having flash point below 23 °C	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	If the quantity of chemicals/ solvents having flash point below 23 °C is less than 200 litre in process and there is no storage of such solvents/chemicals more than 200 litre then such industries can be considered under this table. Else, *see* High hazard
xiv)	Cigar and cigarette factories	R	R	R	Required in full	Required in full	Automatic fire alarm system should be provided for godown buildings, manual system for process blocks	

Appendix ‘2’ to Annex N

Ordinary Hazard Factories/Industries with Aggregate Built-up Area more than 2 500 m^2

Sl No.	**Description**	**Extinguisher**	**Hose Reel**	**Hydrant System**	**Sprinkler System**		**Fire Alarm System**	**Special Protection**
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
xv)	Coffee grinding premises	R	R	R	NR	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xvi)	Coir, carpets, rugs and tobacco, hides and skin presses	R	R	R	NR	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xvii)	Cork products manufacturing	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xviii)	Dry cleaning, dyeing, laundries	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xix)	Electric generating stations (other than hydel)	R	R	R	NR	Sprinkler protection for storage areas not forming part of main occupancy if area exceeds 2 000 m^2	Automatic fire alarm system for all areas except detached storage buildings and utility blocks where manual alarm systems should be provided	Water spray system for transformers, FDS/NIFPS system, cable galleries, conveyors including transfer towers, etc as per IS 3034 and IS 15325

Appendix '2' to Annex N

Ordinary Hazard Factories/Industries with Aggregate Built-up Area more than 2 500 m^2

Sl No.	**Description**	**Extinguisher**	**Hose Reel**	**Hydrant System**	**Sprinkler System**		**Fire Alarm System**	**Special Protection**
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
xx)	Enamelware factories	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xxi)	Filter and wax paper manufacturing	R	R	R	Required when a single un-compartmented area is more than 2 000 m^2	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xxii)	Flour mills	R	R	R	Required if combined floor plate area exceeds 2 000 m^2	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xxiii)	Garment makers	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xxiv)	Ghee factories (other than vegetable)	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	

Appendix '2' to Annex N

Ordinary Hazard Factories/Industries with Aggregate Built-up Area more than 2 500 m^2

Sl No.	Description	Extinguisher	Hose Reel	Hydrant System	Sprinkler System		Fire Alarm System	Special Protection
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
xxv)	Grain and/or seeds disintegrating and/or crushing factories	R	R	R	Required if combined floor plate area exceeds 2 000 m^2	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xxvi)	Grease manufacturing	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xxvii)	Hat and topee factories	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xxviii	Hosiery, lace, embroidery and thread factories	R	R	R	Required if combined floor plate area exceeds 2 000 m^2	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xxix)	Incandescent gas mantle manufacturers	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	

Appendix ‘2’ to Annex N

Ordinary Hazard Factories/Industries with Aggregate Built-up Area more than 2 500 m^2

Sl No.	**Description**	**Extinguisher**	**Hose Reel**	**Hydrant System**	**Sprinkler System**		**Fire Alarm System**	**Special Protection**
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
xxx)	Industrial gas manufacturing Including halogenated hydrocarbon gases	R	R	R	NR	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system for entire unit if area of single largest building exceeds 2000 m^2	
xxxi)	Linoleum factories	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xxxii)	Man-made yarn/fibre manufacturing (except acrylic)	R	R	R	Required if combined floor plate area exceeds 2 000 m^2	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Automatic fire alarm system should be provided when combined floor plate exceeds 5 000 m^2, else manual systems should be provided	
xxxiii)	Manure and fertiliser works. (blending, mixing and granulating only)	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xxxiv)	Mineral oil blending and processing	R	R	R	Required when a single un-compartmented area is more than 2 000 m^2	Required for packing material/finished goods and other raw materials godowns if exceeding	Manual fire alarm system for entire unit if area of single largest building	

Appendix ‘2’ to Annex N

Ordinary Hazard Factories/Industries with Aggregate Built-up Area more than 2 500 m^2

Sl No.	Description	Extinguisher	Hose Reel	Hydrant System	Sprinkler System		Fire Alarm System	Special Protection
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
						2 000 m^2 in area	exceeds 2 000 m^2	
xxxv)	Oil and leather cloth factories	R	R	R	Required when a single un-compartmented area is more than 2 000 m^2	Required for Packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xxxvi)	Oxygen plants	R	R	R	Required for manufacturing blocks	Required for storage blocks	Automatic fire alarm system should be provided throughout	
xxxvii)	Plywood manufacturing/wood veneering factories	R	R	R	Required when a single un-compartmented area is more than 2 000 m^2	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xxxviii)	Paper and cardboard mills	R	R	R	NR	Raw material and Finished goods storage should be provided with sprinklers	Automatic fire alarm system should be provided throughout	
xxxix)	Plastic goods manufacturing polytetra fluoroethylene, flourinated ethylene-	R	R	R	Required if combined floor plate area exceeds 2 000 m^2	Raw material and finished goods storage should be provided with sprinklers if area exceeds	Manual fire alarm system for entire unit if area of single largest building	

Appendix '2' to Annex N

Ordinary Hazard Factories/Industries with Aggregate Built-up Area more than 2 500 m^2

Sl No.	Description	Extinguisher	Hose Reel	Hydrant System	Sprinkler System		Fire Alarm System	Special Protection
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	propylene, poly-chlorotrifluroethylene, polyvinyl chloride, polyvinyl acetate, polyvinylidene chloride, vinyl chloride-vinylidene, chloride copolymer, polyvinylidene flouride, polycarbonate, phenylene oxide polymer, polysulfone, chlorinated polyether, phenolics, melamine formaldehyde, urea formaldehyde, silicones, phenol furfural, phenol formaldehyde, tetraflouro ehtylene, polyvinyl fluoride, cresol formaldehyde, ployamide (nylon). rope works, assembling of plastic goods such as toys and the like					2 000 m^2	exceeds 2 000 m^2	
xl)	Plastic goods manufacturing polyethylene,	R	R	R	Required if combined floor plate area exceeds	Raw material and finished goods storage should be provided with	Manual fire alarm system for entire unit if area of bulding(s) exceeds	Many chemicals are water reactive with water and alternative systems

Appendix '2' to Annex N

Ordinary Hazard Factories/Industries with Aggregate Built-up Area more than 2 500 m^2

Sl No.	Description	Extinguisher	Hose Reel	Hydrant System	Sprinkler System		Fire Alarm System	Special Protection
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	polypropylene, polybutylene, ethylenemethacrylic acid ionomer, polyvinyl alcohol, polyvinyl butyrate, polyvinyl formaldehyde, polystyrene, styrene-acrylonitrile copolymer, acrylonitrile- butadiene-styrene, polymethyl methacrylate, cellulose acetate, cellulose acetate butyrate, cellulose propionate, Cellulose triacetate, ethyl cellulose, acetal, epoxy, polyesters, polyurethanes, acid monomer, acrylate, allyl, methyl methacrylate, polythene				2 000 m^2	sprinklers	2 000 m^2	(not involving water) should be used
xli)	Plastic goods manufacturing foamed plastics	R	R	R	R	Raw material and finished goods storage should be provided with sprinklers	Manual fire alarm system for entire unit	

Appendix ‘2’ to Annex N

Ordinary Hazard Factories/Industries with Aggregate Built-up Area more than 2 500 m^2

Sl No.	**Description**	**Extinguisher**	**Hose Reel**	**Hydrant System**	**Sprinkler System**		**Fire Alarm System**	**Special Protection**
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
xlii)	Printing press premises	R	R	R	Required if area of building(s) exceeds 2 000 m^2	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system required if area of building(s) exceeds 2 000 m^2	
xliii)	Pulverising and crushing mills of metal and metallic ores (excluding aluminium and magnesium metals)	R	R	R	NR	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system is required if the floor area exceeds 2 000 m^2	
xliv)	Pulverising and crushing mills of metallic ores of aluminum and magnesium and coal	R	R	R	Required if area of building(s) exceeds 2 000 m^2	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Automatic fire alarm systems if the floor area exceeds 2 000 m^2	Depending on the circumstances like water reacting chemicals, open-sided structure, etc, sprinklers may be replaced with water mist systems
xlv)	Rice mills	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
xlvi)	Rope works (other than plastic)	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	

Appendix ‘2’ to Annex N

Ordinary Hazard Factories/Industries with Aggregate Built-up Area more than 2 500 m^2

Sl No.	**Description**	**Extinguisher**	**Hose Reel**	**Hydrant System**	**Sprinkler System**		**Fire Alarm System**	**Special Protection**
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
xlvii)	Rubber tyres and tubes manufacturing	R	R	R	Required if area of building(s) exceeds 2 000 m^2	Required for packing material/finished goods godowns	Automatic fire alarm systems if the floor area exceeds 2 000 m^2	
xlviii)	Shellac factories	R	R	R	NR	NR	Manual fire alarm system required	Only local protection, that is, where chemicals used, have a flash point below 23 °C, with medium velocity water spray for manufacturing blocks, similar protection for the area where materials are stored (raw material as well as finished goods)
xlix)	Silk filatures and cocoon stores	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
l)	Spray painting	R	R	R	R	NR	NR	If area of the building exceeds 500 m^2, protection systems like sprrinklers, inert gas agents should be installed

Appendix ‘2’ to Annex N

Ordinary Hazard Factories/Industries with Aggregate Built-up Area more than 2 500 m^2

Sl No.	**Description**	**Extinguisher**	**Hose Reel**	**Hydrant System**	**Sprinkler System**		**Fire Alarm System**	**Special Protection**
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
li)	Soaps and glycerine factories	R	R	R	NR	Raw material and finished goods godowns should be sprinklered if the storage area is more than 2 000 m^2	Automatic fire alarm systems if the floor area exceeds 2 000 m^2	
lii)	Starch factories	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
liii)	Steel plants	R	R	R	NR	NR	Automatic fire alarm systems if the floor area exceeds 2 000 m^2	
liv)	Tanneries/leather goods manufac- turers	R	R	R	Required if area of building(s) exceeds 2 000 m^2	Required for packing material/finished goods and other raw materials godowns if exceeding 2 000 m^2 in area	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
lv)	Tank farms other than those categorised under high hazard ‘A’	R	R	R	Water spray/foam system as applicable should be provided for all tanks			

Appendix ‘2’ to Annex N

Ordinary Hazard Factories/Industries with Aggregate Built-up Area more than 2 500 m^2

Sl No.	**Description**	**Extinguisher**	**Hose Reel**	**Hydrant System**	**Sprinkler System**		**Fire Alarm System**	**Special Protection**
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
lvi)	Textile mills	R	R	R	Required for all process blocks from mixing operations till weaving shed	Required for raw material and finished goods godowns	Automatic fire alarm systems should be provided for raw materials and finished goods godowns	Hazardous areas like singeing, raising, polymerizing, etc should be fire separated (2 h) from adjoining blocks. Concealed spaces/return air ducts/plenum in all process blocks upto weaving should be provided with quick response sprinklers. Diversion systems should be provided where the chute feed machines are installed between blow and carding sections
lvii)	Tea factories	R	R	R	Required if area of building(s) exceeds 2 000 m^2	Required if area exceeds 2 000 m^2	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
lviii)	Tobacco (chewing) and pan-masala making	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	

Appendix '2' to Annex N

Ordinary Hazard Factories/Industries with Aggregate Built-up Area more than 2 500 m^2

Sl No.	Description	Extinguisher	Hose Reel	Hydrant System	Sprinkler System		Fire Alarm System	Special Protection
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
lix)	Tobacco grinding and crushing	R	R	R	NR	Required if the area of building exceeds 2 000 m^2	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
lx)	Tobacco redrying factories	R	R	R	Required if the area of building exceeds 2 000 m^2	Required if the area of building exceeds 2 000 m^2	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	
lxi)	Woollen mills	R	R	R	Required for all processing areas	Required for raw material/finished goods godowns	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	

R – Required. NR – Not Required.

Appendix ‘3’ to Annex N

High Hazard "A" Factories/Industries with Aggregate Built-up Area more than 2 500 m^2

Sl No.	**Description**	**Extinguisher**	**Hose Reel**	**Hydrant System**	**Sprinkler System**		**Fire Alarm System**	**Special Protection**
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
i)	Aircraft hangers	R	R	R	Required in full	Required in full	Automatic intelligent fire alarm system with flame detectors	High expansion foam systems should need to be installed. Also, systems as per ICAO standards
ii)	Aluminium/magnesium powder plants	R	R	R	NR	NR	Manual fire alarm system for entire unit if area of single largest building exceeds 2 000 m^2	Special dry powder systems
iii)	Bituminized paper and/or hessian cloth manufacturing including tar felt manufacturing	R	R	R	Required if area of the building exceeds 2 000 m^2	Raw material and finished goods godowns should be sprinklered	Manual fire alarm system for entire unit	
iv)	Chemical manufacturing involving chemicals, dyes, intermediates, pigments, acids, medicinal/ pharma-ceuticals formulation and toilet preparation including soap manufacturing, chemical mixing and blending factories using chemicals/ solvents having flash point below 23 °C and metallic	R	R	R	MV spray systems and/or foam system should be provided locally as applicable for vessels, pumps, compressors, reactors, columns, etc where chemicals having flash point below 23 °C are in process. (Suitable care should taken to check whether chemicals are water reacting)	MV spray systems and gaseous protection systems as applicable for godowns storing materials with flash points below 23 °C. (Suitable care should taken to check whether chemicals are water reacting)	Manual fire alarm systems should be provided for entire unit	All tanks having a diameter of 9 m or more, storing Class A or B chemicals should be provided with medium velocity spray systems and foam systems as applicable backed up with suitable detection systems

Appendix ‘3’ to Annex N

High Hazard "A" Factories/Industries with Aggregate Built-up Area more than 2 500 m^2

Sl No.	Description	Extinguisher	Hose Reel	Hydrant System	Sprinkler System		Fire Alarm System	Special Protection
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	nitrates, coal tar and wood distillation plant							
v)	Cotton waste factories	R	R	R	Entire area should be sprinklered if the combined area of all buildings exceed 2 000 m^2		Manual fire alarm systems should be provided for entire unit	
vi)	Coal and/or coke and/or charcoal ball briquettes manufacturing	R	R	R	NR	Raw materials and finished goods godown should be sprinklered when area is more than 2 000 m^2	Manual fire alarm systems should be provided for entire unit	
vii)	Celluloid goods manufacturing	R	R	R	NR	NR	Manual fire alarm systems should be provided for entire unit	Alcohol resistant foam, carbon dioxide (CO_2), dry chemicals where applicable for all process areas and godowns
viii)	Cigarette filter manufacturing	R	R	R	Required for all process areas	Raw materials and Finished goods godown should be sprinklered when area is more than 2 000 m^2	Manual fire alarm systems should be provided for entire unit	
ix)	Cinema films and t.v. production studios	R	R	R	Required for all process areas	Godowns should be sprinklered if area is more than 2 000 m^2	Automatic fire alarm system should be provided	
x)	Cotton seed cleaning or de-linting factories, cotton ginning and pressing units	R	R	R	Required for all process areas	Godowns should be sprinklered if area is more than 2000 m^2	Manual fire alarm systems should be provided for entire unit	

Appendix ‘3’ to Annex N

High Hazard "A" Factories/Industries with Aggregate Built-up Area more than 2 500 m^2

Sl No.	**Description**	**Extinguisher**	**Hose Reel**	**Hydrant System**	**Sprinkler System**		**Fire Alarm System**	**Special Protection**
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
xi)	Distilleries	R	R	R	Local protection with medium velocity spray/foam systems as applicable should be provided for process areas	NR	Automatic fire alarm system should be provided	
xii)	Duplicating and stencil paper manufacturing	R	R	R	Required for all process areas	Godowns should be sprinklered if area is more than 2 000 m^2	Manual fire alarm systems should be provided for entire unit	
xiii)	Fire-works manufacturing	R	R	R	Required for all process areas	Required for all raw material and finished goods godowns	Manual fire alarm systems should be provided for entire unit	
xiv)	Foamed plastics manufacturing and/or converting plants	R	R	R	Required for all process areas	Required for all raw material and finished goods godowns	Manual fire alarm systems should be provided for entire unit	
xv)	Jute mills and jute presses	R	R	R	Required for all process areas	Required for all raw material and finished goods godowns	Manual fire alarm systems should be provided for entire unit	
xvi)	LPG bottling plants	R	R	R	Required for all process areas	Required for all storage and decantation, truck loading areas	Manual fire alarm systems should be provided for entire unit	LPG storage tankage like bullets and spheres should be protected with medium velocity water spray systems backed up with suitable detection systems as per IS 15325.

Appendix '3' to Annex N

High Hazard "A" Factories/Industries with Aggregate Built-up Area more than 2 500 m^2

Sl No.	Description	Extinguisher	Hose Reel	Hydrant System	Sprinkler System		Fire Alarm System	Special Protection
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
								Also, systems as per OISD- STD-144 and other applicable OISD standards
xvii)	Match factories	R	R	R	Required for all process areas	Required for all raw material and finished goods godowns	Manual fire alarm systems should be provided for entire unit	
xviii)	Man made fibres (acrylic fibres/yarn making)	R	R	R	Required for all process areas	Required for all raw material and finished goods godowns	Automatic fire alarm systems should be provided for entire unit	
xix)	Mattress and pillow making	R	R	R	Required for all process areas if area of the building is more than 2 000 m^2	Required for all raw material and finished goods godowns having area more than 2 000 m^2	Manual fire alarm systems should be provided for entire unit	
xx)	Metal or tin printers	R	R	R	Required for all process areas if area of the building is more than 2 000 m^2	Required for all raw material and finished goods godowns having area more than 2 000 m^2	Manual fire alarm systems should be provided for entire unit	
xxi)	Oil mills	R	R	R	Required for all process areas if area of the building is more than 2 000 m^2	Required for all raw material and finished goods godowns having area more than 2 000 m^2	Automatic fire alarm systems should be provided for entire unit	Local protections such as medium velocity spray or foam systems as applicable should be provided in process and storage areas

Appendix ‘3’ to Annex N

High Hazard "A" Factories/Industries with Aggregate Built-up Area more than 2 500 m^2

Sl No.	Description	Extinguisher	Hose Reel	Hydrant System	Sprinkler System		Fire Alarm System	Special Protection
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
xxii)	Oil extraction plants (other than those forming part of ghee factories and oil refining factories)	R	R	R	Required for all process areas if area of the building is more than 2 000 m^2	Required for all raw material and finished goods godowns having area more than 2 000 m^2	Automatic fire alarm systems should be provided for entire unit	Local protections such as medium velocity spray or foam systems as applicable should be provided in process and storage areas
xxiii)	Oil terminals/depots handling flammable liquids having flash point of 23 °C and below	R	R	R	Automatic medium velocity water spray and /or foam systems should be provided as applicable for all tanks backed up with suitable automatic detection systems. Also, systems as per OISD-STD-117 and other applicable OISD standards			
xxiv)	Paints and varnish factories	R	R	R	Required for all process areas if area of the building is more than 2 000 m^2	Required for all raw material and finished goods godowns having area more than 2 000 m^2	Automatic fire alarm systems should be provided for entire unit	Local protections such as medium velocity spray or foam systems as applicable should be provided in process and storage areas
xxv)	Printing ink manufacturing	R	R	R	Required for all process areas if area of the building is more than 2 000 m^2	Required for all raw material and finished goods godowns having area more than 2 000 m^2	Automatic fire alarm systems should be provided for entire unit	Local protections such as medium velocity medium velocity spray or foam systems as applicable should be provided in process and storage areas
xxvi)	Saw mills	R	R	R	NR	NR	Manual fire alarm system should be provided for entire unit	

Appendix ‘3’ to Annex N

High Hazard "A" Factories/Industries with Aggregate Built-up Area more than 2 500 m^2

Sl No.	Description	Extinguisher	Hose Reel	Hydrant System	Sprinkler System		Fire Alarm System	Special Protection
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
xxvii)	Solvent extraction plants	R	R	R	NR	NR	Automatic fire alarm systems should be provided for entire unit	Entire factory and storage tanks to be protected by medium velocity water spray system and/or foam system
xxviii)	Surgical cotton manufacturers	R	R	R	Required for all process areas	Required for all raw material and finished goods godowns	Automatic fire alarm systems should be provided for entire unit	
xxix)	Tank farms storing flammable liquids having flash point of 23 °C and below	R	R	R	Automatic medium velocity water spray and /or Foam systems should be provided as applicable for all tanks backed up with suitable automatic detection systems. Also, systems as per OISD-STD-116 and other applicable OISD standards			
xxx)	Tarpaulin and canvas proofing factories	R	R	R	Required for all process areas where building area is more than 2 000 m^2	Required for all raw material and finished goods godowns where the building area is more than 2 000 m^2	Automatic fire alarm systems should be provided for entire unit	
xxxi)	Turpentine and rosin distilleries	R	R	R	NR	NR	Automatic fire alarm systems should be provided for entire unit	Local protections such as medium velocity water spray or foam systems as applicable should be provided in process and storage areas

Appendix '3' to Annex N

High Hazard "A" Factories/Industries with Aggregate Built-up Area more than 2 500 m^2

Sl No.	Description	Extinguisher	Hose Reel	Hydrant System	Sprinkler System		Fire Alarm System	Special Protection
					Process Blocks	Storage Blocks		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
xxxii)	Tyre retreading and resoling factories	S	R	R	Required for all process areas where building area is more than 2 000 m^2	Required for all Raw material and finished goods godowns where the building area is more than 2 000 m^2	Automatic fire alarm systems should be provided for entire unit	
	R – Required. NR – Not Required. S – Suitable							

Appendix '4' to Annex N

High Hazard 'B' Factories/Industries (All Chemicals, Petroleum, Gas Processing, Petrochemicals, Fertilizer Plants, Thermal Power Plants, etc)

Sl No.	Description	Fire Extinguishers, Firefighting Equipment	Hydrant System, Fire Monitors, Hose Reels	Fire Alarm System	Sprinkler System	High Volume Long Range (HVLR) Monitors	Gas/HC/Fire/Heat Detection System	Automatic Heat/Fire Detection and Suppression System	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
i)	Process units (columns, boilers, furnaces, reactors, vessels, drums, etc)	R	R (Note 1)	R	R (Note 2)	Refer Note 3	R (Note 4)	NR	
ii)	Tank farm areas (storage of liquid/gas flammable	R	R	R	R	R	R	R	High volume long range monitors of capacity 500 to

Appendix ‘4’ to Annex N

High Hazard ‘B’ Factories/Industries (All Chemicals, Petroleum, Gas Processing, Petrochemicals, Fertilizer Plants, Thermal Power Plants, etc)

Sl No.	Description	Fire Extinguishers, Firefighting Equipment	Hydrant System, Fire Monitors, Hose Reels	Fire Alarm System	Sprinkler System	High Volume Long Range (HVLR) Monitors	Gas/HC/Fire/Heat Detection System	Automatic Heat/Fire Detection and Suppression System	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	products Class A and cluster of Class A and B products)				(Note 5, 6)	(Note 7, 8)		(Note 9)	4 000 gpm (variable flow) as required as per Standards; HVLR monitors of 10 500 gpm should be considered to fight fire in large dia tanks. Fire water monitors around the tank farm area as per IS/OISD standards
iii)	Pump house area (Pumps and Compressors - rotary equipment)	R	R	R	R	NR	R (Note 4)	NR	
iv)	Loading/unloading gantry (tank wagon and tank truck loading/unloading)	R	R	R	R	R	R (Note 4)	NR	Water sprinkler throughout the length of Gantry. Hydrocarbon (HC) detectors at drains
v)	LPG filling stations	R	R	R	R	NR	R	NR	LPG storage – Mounded storage, Horton spheres, Bullets should have water sprinklers with medium velocity spray

Appendix ‘4’ to Annex N

High Hazard ‘B’ Factories/Industries (All Chemicals, Petroleum, Gas Processing, Petrochemicals, Fertilizer Plants, Thermal Power Plants, etc)

Sl No.	Description	Fire Extinguishers, Firefighting Equipment	Hydrant System, Fire Monitors, Hose Reels	Fire Alarm System	Sprinkler System	High Volume Long Range (HVLR) Monitors	Gas/HC/Fire/Heat Detection System	Automatic Heat/Fire Detection and Suppression System	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
vi)	Conveyor belt areas	R	R	R	R	NR	NR	R (Note 10)	Handling flammable dusts like coal / lignite dust, etc
vii)	Sub-station and electrical panels	R	NR	R	NR	NR	NR	R (Note 11, 12)	Substation to be air pressurized
viii)	Chlorination plant	R	NR	NR	R	NR	R (Note 13)	NR	
ix)	Transformers	R	R	R	R	NR	NR	R (Note 14)	
x)	Cable trenches, racks and cable galleries	R	NR	R	NR	NR	R	R (Note 11 and 12)	Adequate ventilation and sealing in cable gallery housing
xi)	Quality control lab	R	R	R (Note 15)	R	NR	R	NR	

Appendix ‘4’ to Annex N

High Hazard ‘B’ Factories/Industries (All Chemicals, Petroleum, Gas Processing, Petrochemicals, Fertilizer Plants, Thermal Power Plants, etc)

Sl No.	Description	Fire Extinguishers, Firefighting Equipment	Hydrant System, Fire Monitors, Hose Reels	Fire Alarm System	Sprinkler System	High Volume Long Range (HVLR) Monitors	Gas/HC/Fire/Heat Detection System	Automatic Heat/Fire Detection and Suppression System	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
xii)	Admin. building	R	R	R (Note 15)	R	NR	NR	NR	
xiii)	Control room	R	NR	R	R	NR	NR	R (Note 16)	
xiv)	Firefighting pumps and fire water system	Electric and diesel/HSD driven pumps of similar capacity and same head. Jockey pump with 3 percent to 5 percent capacity of main pumps. Overhead fire water tanks and reservoir with adequate capacity to fight two simultaneous fires.							
xv)	Fire tenders	Independent fire station equipped with water, foam, dry chemical power tenders and rescue vehicles - response time on fire call must be within 05 min.							

R – Required. NR – Not Required.

NOTES

1 Fire water network with fire hydrants, monitors all around the process unit and tank farm areas should be provided in accordance with relevant Indian Standards, OISD. Fire hydrants should be at different platforms/levels in TPH/boilers/furnaces/columns/reactors.

2 Water sprinklers in technological platforms for all static equipment normally reflux drums, air-fin fan coolers, etc should be provided in accordance with relevant Indian Standards, OISD.

3 Elevated fire water monitors (variable flow) to fight fires at tall columns / boiler house / reactors / technological platforms, etc should be provided in accordance with relevant Indian Standards, OISD.

4 Hydrocarbon detectors, gas detectors, heat sensors at strategic / critical locations normally drain points of vessels, columns, pump drain, tank drain points, etc should be provided in accordance with relevant Indian Standards, OISD.

5 Fixed foam pourer system for Class-A products storage tanks should be provided in accordance with relevant Indian Standards, OISD.

6 Water Sprinklers ring at top and middle of tanks for water cooling in all storage tanks should be provided in accordance with relevant Indian Standards, OISD.

7 HVLR - Remote/manual operated variable flow monitors having discharge of 500 gpm to 4 000 gpm capacity should be provided as per requirement. HVLR Monitor of 10 500 gpm should be considered for large dia tanks (for > 60 M and above). Fire robot may be considered for fighting multiple tank/area fires as per the relevant Indian Standards.

8 Medium expansion foam generators (MEFG) may be provided to fight fire due to accidental spillage of flammable materials in tank dykes/spill fires.

9 Automatic site configurable linear heat detection and foam suppression system should be provided for EFR tanks (rim seal areas) Class A products.

10 Linear heat detection system, site configurable type with water mist/spray system should be provided in all conveyor belts for early detection of rise in temperature.

11 Linear heat detection system, site configurable type should be provided in all cable cellars, trenches, for early detection.

12 All electrical panels should be provided with linear heat detection and inert gas suppression system (environment friendly halon free).

13 Chlorine leakage kit, chlorine protective suit, sensors, neutraliser, etc should be provided.

14 Water mist /deluge system and nitrogen injection fire prevention system (NIFPS) with site configurable linear heat sensing detector should be provided for oil filled transformers.

15 Wireless heat and smoke detection with alarm and notification to concerned should be provided.

16 Clean agent inert gas fire suppression system (environment friendly halon free) should be provided in all control rooms.

LIST OF STANDARDS

The following list records those standards which are acceptable as 'good practice' and 'accepted standards' in the fulfilment of the requirements of this Part. The latest version of a standard should be adopted at the time of enforcement of this Part. The standards listed may be used by the Authority for conformance with the requirements of the referred clauses in this Part.

In the following list, the number appearing in the first column within parentheses indicates the number of the reference in this Part.

	IS No.	*Title*
(1)	IS 3808 : 1979	Method of test for non-combustibility of building materials (*first revision*)
(2)	IS/ISO 834-1 : 1999	Fire resistance tests — Elements of building construction: Part 1 General requirements
	IS/ISO 834-4 : 2000	Fire Resistance tests — Elements of building construction: Part 4 Specific requirements for load bearing vertical separating elements
	IS/ISO 834-5 : 2000	Fire resistance tests — Elements of building construction: Part 5 Specific requirements for load bearing horizontal separating elements
	IS/ISO 834-7 : 2000	Fire-resistance tests — Elements of building construction: Part 7 Specific requirements for columns
	IS/ISO 834-8 : 2003	Fire-Resistance tests — Elements of building construction: Part 8 Specific requirements for non-load bearing vertical separating elements
	IS/ISO 834-9 : 2003	Fire-resistance tests — Elements of building construction: Part 9 Specific requirements for non-load bearing ceiling elements
(3)	IS 8757 : 2021	Glossary of terms associated with fire safety (*second revision*)
	IS 7673 : 2004	Glossary of terms for fire fighting equipment (*first revision*)
(4)	IS 8758 : 2013	Recommendations for fire precautionary measures in the construction of temporary structures and pandals (*second revision*)
(5)	IS 9668 : 1990	Code of practice for provision and maintenance of water supplies and fire fighting
	IS 3844 : 1989	Code of practice for installation and maintenance of internal fire hydrants and hose reels on premises (*first revision*)
(6)	IS 1646 : 2015	Fire safety of buildings (General): Electrical installations — Code of practice(*third revision*)
(7)	IS 9457 : 2025	Safety colours, safety signs and accident prevention tags — Code of practice (*second revision*)
	IS 12349 : 1988	Fire protection — Safety sign
	IS 12407 : 1988	Graphic symbols for fire protection plan
(8)	IS/ISO 7240-7 : 2023	Fire detection and alarm systems Part 7: Point-type smoke detectors using scattered light, transmitted light, or Ionization (*first revision*)

IS No.	*Title*
IS/ISO 7240-12 : 2022	Fire detection and alarm systems: Part 12 Line type smoke detectors using a transmitted optical beam (*first revision*)
(9) IS 655 : 2006	Specification for air ducts (*third revision*)
(10) IS 1649 : 1962	Code of practice for design and construction of flues and chimneys for domestic heating appliances (*first revision*)
IS 1642 : 2013	Code of practice for safety of buildings (general): Details of construction (*second revision*)
(11) IS 12777 : 1989	Fire safety — Flame spread of products — Method for classification
(12) IS 1642 : 2013	Code of practice for safety of buildings (general): Details of construction (*second revision*)
(13) IS 16246 : 2015	Elastomer insulated cables with limited circuit integrity when affected by fire — Specification
(14) IS 6044 (Part 1) : 2018	Liquefied petroleum gas storage installations — Code of practice: Part 1 Residential commercial and industrial cylinder installations (*third revision*)
IS 6044 (Part 2) : 2021	Code of practice for liquefied petroleum gas storage installations: Part 2 Commercial, industrial and domestic bulk storage installations (*second revision*)
(15) IS 2175 : 1988	Specification for heat sensitive fire detectors for use in automatic fire alarm system (*second revision*)
IS/ISO 7240-5 : 2018	Fire detection and alarm systems: Part 5 Point-type heat detectors (*second revision*)
IS/ISO 7240-7 : 2023	Fire detection and alarm systems: Part 7 Point-type smoke detectors using scattered light, transmitted light, or Ionization (*first revision*)
IS/ISO 7240-11 : 2011	Fire detection and alarm systems: Part 11 Manual call points
IS/ISO 7240-15 : 2014	Fire detection and alarm systems: Part 15 Point-type fire detectors using scattered light, transmitted light, or ionization sensor in combination with a heat sensor (*first revision*)
IS/ISO 7240-12 : 2022	Fire detection and alarm systems: Part 12 Line type smoke detectors using a transmitted optical beam (*first revision*)
(16) IS 2189 : 2026	Selection, installation and maintenance of automatic fire detection and alarm system — Code of practice (*third revision*)
(17) IS 636 : 2018	Non-percolating flexible fire fighting delivery hose *(fourth revision)*
IS 884 : 2025	First-aid hose-reel for fire fighting — Specification (*second revision*)

IS No.	*Title*
IS 901 : 1988	Specification for couplings, double male, and double female instantaneous pattern for fire fighting (*third revision*)
IS 902 : 1992	Specification for suction hose couplings for fire fighting purposes (*third revision*)
IS 903 : 2025	Fire hose delivery couplings, branch pipe, nozzles and nozzle spanner — Specification (*fifth revision*)
IS 904 : 1983	Specification for two-way and three-way suction collecting heads for fire fighting purposes (*second revision*)
IS 905 : 1980	Specification for delivery breechings, dividing and collecting, instantaneous pattern for fire fighting purposes (*second revision*)
IS 906 : 2024	Specification for revolving branch pipe for fire fighting (*fourth revision*)
IS 907 : 1984	Specification for suction strainers, cylindrical type for fire fighting purpose (*second revision*)
IS 908 : 1975	Specification for fire hydrant, stand post type (*second revision*)
IS 909 : 1992	Specification for underground fire hydrant: Sluice valve type (*third revision*)
IS 910 : 1980	Specification for combined key for hydrant, hydrant cover and lower valve (*second revision*)
IS 926 : 1985	Specification for fireman's axe (*second revision*)
IS 927 : 1981	Specification for fire hooks (*second revision*)
IS 928 : 1984	Specification for fire bells (*second revision*)
IS 937 : 1981	Specification for washers for water fittings for fire fighting purposes (*second revision*)
IS 939 : 1977	Specification for snatch block for use with fibre rope for fire brigade use (*first revision*)
IS 941 : 1985	Specification for blowers and exhauster for fire fighting (*second revision*)
IS 942 : 1982	Functional requirements for 275-l/min portable pump set for fire fighting (*second revision*)
IS 943 : 1979	Functional requirement for 680-l/min trailer pump for fire brigade use (*second revision*)
IS 944 : 1979	Functional requirement for 1800-l/min trailer pump for fire brigade use (*second revision*)
IS 947 : 1985	Functional requirement for towing tender for trailer fire pump for fire brigade use (*first revision*)

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IS 948 : 1983	Functional requirement for water tender, Type A, for fire brigade use (*second revision*)
IS 949 : 2012	Functional requirement for emergency (rescue) tender for fire brigade use (*second revision*)
IS 950 : 2012	Functional requirements for water tender, Type B for fire brigade use (*third revision*)
IS 952 : 1986	Specification for fog nozzle for fire brigade use (*second revision*)
IS 955 : 1980	Functional requirements for dry power tender for fire-brigade use (150 kg capacity) (*first revision*)
IS 957 : 1967	Specification for control van for fire brigade
IS 1941 (Part 1) : 1976	Functional requirements for electric motor sirens: Part 1 AC, 3-phase 50 Hz, 415 Volts type (*second revision*)
IS 2097 : 2024	Specification for foam making branch pipe (*third revision*)
IS 2175 : 1988	Specification for heat sensitive fire detectors for use in automatic detectors for use in automatic fire alarm system (*second revision*)
IS 2546 : 1974	Specification for galvanized mild steel fire bucket (*first revision*)
IS 2696 : 1974	Functional requirements for 1125 l/min light fire engine (*first revision*)
IS 2745 : 1983	Specification for non-metal helmet for firemen and civil defence personnel (*second revision*)
IS 2871 : 2012	Specification for branch pipe, universal for fire fighting purposes (*second revision*)
IS 2930 : 1980	Functional requirements for hose laying tender for fire brigade use (*first revision*)
IS 3582 : 1984	Specification for basket strainers for fire fighting purposes (cylindrical type) (*first revision*)
IS 4308 : 2019	Specification for dry powder for fire fighting (*third revision*)
IS 4571 : 1977	Specification for aluminium extension ladders for fire brigade use (*first revision*)
IS 4643 : 1984	Specification for suction wrenches for fire brigade use (*first revision*)
IS 4927 : 1992	Specification for unlined flax canvas hose for fire fighting (*first revision*)
IS 4928 : 1986	Specification for delivery valve for centrifugal pump outlets (*first revision*)
IS 4947 : 2006	Specification for gas cartridges for use in fire extinguishers (*third revision*)

IS No.	*Title*
IS 4989 : 2018	Foam concentrate for producing mechanical foam for fire fighting — Specification (*fourth revision*)
IS 4989 (Part 4) : 2003	Multipurpose aqueous film forming foam liquid concentrate for extinguishing hydrocarbon and solvent fires
IS 5131 : 2002	Specification for dividing breeching with control, for fire brigade use (*second revision*)
IS 5290 : 2025	Specification for landing valve (*fourth revision*)
IS 5486 : 1985	Specification for quick release knife (*first revision*)
IS 5505 : 1985	Specification for multi-edged rescue axe (non-wedging) (*first revision*)
IS 5612	Specification for hose-clamps and hose-bandages for fire brigade use
(Part 1) : 1977	Hose clamps (*first revision*)
(Part 2) : 1977	Hose bandages (*first revision*)
IS 5714 : 1981	Specification for hydrant, stand-pipe for fire fighting (*first revision*)
IS 6026 : 1985	Specification for hand operated sirens (*first revision*)
IS 6067 : 1983	Functional requirements for water tender, Type `X' for fire brigade use (*first revision*)
IS/ISO 7240-5 : 2018	Fire detection and alarm systems: Part 5 Point-type heat detectors (*second revision*)
IS/ISO 7240-7 : 2023	Fire detection and alarm systems: Part 7 Point-type smoke detectors using scattered light, transmitted light, or ionization (*first revision*)
IS/ISO 7240-11 : 2011	Fire detection and alarm systems Part 11 Manual call points
IS 8090 : 1976	Specification for couplings, branch pipe, nozzle, used in hose reel tubing for fire fighting (*first revision*)
IS 8096 : 2005	Rubber or plastics coated fabrics for water resistant clothing — Specification (*second revision*)
IS 8423 : 1994	Specification for controlled percolating hose for fire fighting (*first revision*)
IS 8442 : 2024	Specification for stand post type water monitor for fire fighting (*second revision*)
IS 9972 : 2023	Specification for automatic sprinkler heads (*second revision*)
IS 10460 : 1983	Functional requirements for small foam tender for fire brigade use

IS No.	*Title*
IS 10993 : 1984	Functional requirements for 2 000 kg dry powder tender for fire brigade use
IS 11101 : 1984	Specification for extended branch pipe for fire brigade use
IS 11108 : 1984	Specification for portable fire extinguisher halon —1211 type
IS 11833 : 1986	Specification for dry powder fire extinguisher for metal fires
IS 12717 : 1989	Functional requirements of fire fighting equipment — High capacity portable pumpset (1 100-1 600 L/min)
IS 12796 : 1989	Specification for fire rake
IS 13039 : 2014	Code of practice for provision and maintenance of external hydrant system (*first revision*)
IS 14933 : 2001	Specification for high pressure fire fighting hose
IS 14951 : 2001	Specification for fire extinguisher, 135 l capacity mechanical foam type
IS 15051 : 2001	Specification for high pressure fire hose delivery couplings
IS 15105 : 2021	Design and installation of fixed automatic sprinkler fire extinguishing system (*first revision*)
IS 15220 : 2002/ ISO 7201-1	Specification for halon 1211 and halon 1301 — Fire extinguishing media for fire protection
IS 15683 : 2018	Portable fire extinguishers — Performance and construction — Specification (*first revision*)
IS 15493 : 2021	Gaseous fire extinguishing systems — General requirements *(first revision)*
IS 15505 : 2004/ ISO 14520-6	Gaseous fire extinguishing systems: HCFC Blend A extinguishing systems
IS 15506 : 2004/ ISO 14520-14	Gaseous fire extinguishing systems — IG 55 extinguishing systems
IS 15525 : 2004/ ISO 14520-13	Gaseous fire extinguishing systems — IG 100 extinguishing systems
IS 15501 : 2004/ ISO 14520-15	Gaseous fire extinguishing systems — IG 541 extinguishing systems
IS 15497 : 2004/ ISO 14520-12	Gaseous fire extinguishing systems — IG 01 extinguishing systems
IS 15519 : 2020	Code of practice for water mist fire protection systems — System design, installation, and commissioning (*first revision*)
IS 15528 : 2004	Gaseous fire extinguishing systems — Carbon dioxide, total flooding and

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		local application including in cabinet subfloors systems
	IS 15517 : 2004/ ISO 14520-9	Gaseous fire extinguishing systems — HFC 227ea (Hepta Fluoro Propane) extinguishing system
	IS 16018 : 2012	Wheeled fire extinguisher — Performance and construction — Specification
(18)	IS 2190 : 2024	Code of practice for selection, installation, and maintenance of portable first-aid fire (*fifth revision*)
(19)	IS 884 : 2025	Specification for first aid hose reel for fire fighting *(second revision)*
(20)	IS 15105 : 2021	Design and installation of fixed automatic sprinkler fire extinguishing system — Code of practice (*first revision*)
(21)	IS 15325 : 2020	Design and installation of fixed automatic high and medium velocity water spray system — Code of practice (*first revision*)
(22)	IS 12835 (Part 1) : 2021	Design and installation of fixed foam fire extinguishing system — Code of practice Part 1 Low expansion foam (*first revision*)
(23)	IS 15517 : 2004	Gaseous fire extinguishing systems — Carbon dioxide, total flooding and local application including in cabinet subfloors systems
(24)	IS 15519 : 2020	Water mist fire protection systems — System design, installation, and commissioning — Code of Practice (*first revision*)
(25)	IS 15493 : 2021	Gaseous fire extinguishing systems — General requirements
	IS 15505 : 2004	Gaseous fire extinguishing systems — HCFC blend A
	IS 15506 : 2004	Gaseous fire extinguishing systems — IG 55 extinguishing systems
	IS 15525 : 2004	Gaseous fire extinguishing systems — IG 100 extinguishing systems
	IS 15501 : 2004	Gaseous fire extinguishing systems — IG 541 extinguishing systems
	IS 15497 : 2004	Gaseous fire extinguishing systems — IG 01 extinguishing systems
	IS 15517 : 2004	Gaseous fire extinguishing systems — Carbon dioxide, total flooding and local application including in cabinet subfloors systems
	IS 9668 : 1990	Code of practice for provision and maintenance of water supplies and fire fighting
	IS 3844 : 1989	Code of practice for installation and maintenance of internal fire hydrants and hose reels on premises (*first revision*)
(26)	IS 2189 : 2026	Selection, installation and maintenance of automatic fire detection and alarm system — Code of practice (*second revision*)

	IS No.	*Title*
	IS 2190 : 2024	Selection, installation, and maintenance of portable first-aid fire extinguishers — Code of practice (*fifth revision*)
	IS 13039 : 2014	External hydrant systems — Provision and maintenance — Code of practice (*first revision*)
(27)	IS 4878 : 1986	Byelaws for construction of cinema buildings (*first revision*)
(28)	IS 2726 : 1988	Code of practice for fire safety of industrial buildings: Cotton ginning and pressing (including cotton seed delintering) factories (*first revision*)
	IS 3034 : 1993	Code of practice for fire safety of industrial buildings: Electrical generating and distributing stations (*second revision*)
	IS 3058 : 1990	Code of practice for fire safety of industrial buildings: Viscose rayon yarn and/or staple fibre plants (*first revision*)
	IS 3079 : 1990	Code of practice for fire safety of industrial buildings: Cotton textile mills (*first revision*)
	IS 3594 : 2024	Code of practice for fire safety of industrial buildings: General storage and warehousing including cold storage (*second revision*)
	IS 3595 : 2002	Code of practice for fire safety of industrial buildings: Coal pulverizers and associated equipment (*second revision*)
	IS 3836 : 2000	Code of practice for fire safety of industrial buildings: Jute mills (*second revision*)
	IS 4209 : 2013	Code of safety in chemical laboratories (*second revision*)
	IS 4226 : 1988	Code of practice for fire safety of industrial buildings: Aluminium/ Magnesium powder factories (*first revision*)
	IS 4886 : 1991	Code of practice for fire safety of industrial buildings: Tea factories (*first revision*)
	IS 6329 : 2000	Code of practice for fire safety of industrial buildings: Saw mills and wood works (*first revision*)
	IS 9109 : 2000	Code of practice for fire safety of industrial buildings: Paint and varnish factories
	IS 11457 (Part 1) : 1985	Code of practice for fire safety of chemical industries: Part 1 Rubber and plastic
(29)	IS 13039 : 2014	External hydrant systems — Provision and maintenance — Code of practice (*first revision*)
(30)	IS 18271 : 2023	Fire safety in commercial kitchen — Guidelines
(31)	IS 4963 : 2025	Accessibility in built environment for older adults and persons with disabilities — Requirements (*second revision*)

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(32) IS 16700 : 2023	Criteria for structural safety of tall concrete buildings (*first revision*)
(33) IS 3614 : 2021	Fire doors and doorsets — Specification (*first revision*)
(34) IS 12458 : 2019	Fire resistance of through penetration firestops — Method of test (*first revision*)
(35) IS 18190 : 2023	Fire resistance of perimeter fire barrier joint system — Method of tests

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